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PREFACE

Dear colleagues,

Welcome to the International Conference «The Caspian Region: Environmental consequences of the climate change».

The purpose of the Conference is to bring together researchers from different countries with experience in the Caspian area for exchange of data, results and ideas on environmental consequences of the climate change in the Caspian region to ensure further progress in Caspian Science. The Conference will work in a multidisciplinary way across the various fields and perspectives (climatology, hydrology, marine geology, geomorphology, palaeogeography, geochemistry, biology, etc.) through which we can address the fundamental and related questions of sustainability in the Caspian region. The Conference summarizes the results of multidisciplinary collaboration of scientists from different countries in the Caspian region during the last 20 years.

Subject matter of the conference has given rise to special scientific interest. Scientists from all the Caspian countries (Russia, Iran, Kazakhstan, Turkmenia, Azerbaijan) and also from Great Britain, Canada, United States, the Netherlands and Ukraine have wished to take part in the Conference.

Contributed papers illustrate multiplicity of the Conference subject. According to their subject matter they are combined into six sessions. The first session is devoted to the palaeoclimatic and palaeoenvironmental changes in the Caspian Sea region during the last 10 ky as the basic for the understanding the Caspian Sea and environment evolution under the non-uniformly scaled climatic changes and forecast of their development.

The second session is joined the papers on evolution of the coastal zone under the climatic and sea level changes. Complete cycle of the Caspian Sea level oscillations in the XX^{th} century has reached up to 3 m and is believed by researchers as the natural laboratory for investigations of the short-term sea level fluctuations and their consequences in the coastal zone: development of the coastal relief, changes of the coastal landscapes, their geochemical evolution and evolution of the coastal biodiversity.

Evolution of the Caspian Sea deltas under the climate and sea level changes is discussed in the third session. The state and development of the mouths of rivers are the main problem of that region. The Volga delta is of the greatest important for the Russian coastal zone of the Caspian Sea. It is the unique natural system of vital ecological and economic importance.

Papers, devoted to current condition of the Caspian Sea, combined into the forth session. Hydrometeorological changes in this region influence on the functioning of the marine ecosystem. Reconstruction of the thermohaline water structure, geochemical evolution and evolution of marine biodiversity take place.

Environmental problems of the Caspian Sea region and ecological management are discussed in the fifth session. Last years ecological and geochemical condition of environment in oil and gas-producing regions owing to borehole exploring, extraction and transportation of hydrocarbon raw material in the Caspian coastal and shelf zone puts in the forefront.

And the last, sixth, session covers the forecasts of climate change and the response of the Caspian Sea environment on them.

The Conference is sponsored by Faculty of Geography of Moscow State University and Russian Foundation for Basic Research (project N 10-05-06070).

The Organizing Committee thanks all the participants and wishes the Conference going on well.

Organizing Committee

PLENARY SESSION

CONNECTION OF THE CASPIAN SEA LEVEL LARGE FLUCTUATIONS WITH FLUCTUATIONS OF GLOBAL CLIMATE DURING LATE PLEISTOCENE AND HOLOCENE

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Keywords: climate, Caspian Sea, climate change, climate modeling, paleoclimate

INTRODUCTION

During the last late-Pleistocene and post-glacial epochs, the Caspian Sea fluctuated between regressive and transgressive stages. Sometimes, the Caspian Sea overflowed to the Black Sea through the Manych Strait (Chepalyga, 2006). The origin of sea level changes can be considered from the point of response of regional-scale water budget to planetary climate changes. All of its inflow and outflow components are functions of climate regime. It allows estimate them based on data of climate modeling.

GLOBAL CLIMATE CHANGES DURING THE QUATERNARY

Typical spectral density of different core records (both ice and deep-sea) demonstrates that much of the energy at low frequencies corresponds to periods around 100 kyr. At high frequencies the spectral density shape displays a red-noise continuum. It is superimposed some weak spectral peaks belonging to the Milankovitch periodicities (Berger, 1978). On the average, the obliquity band (41-kyr period) accounts for less than 11%, and the precessional band (~ 20-kyr period) accounts for less than 1% of total variance (Wunsch, 2003).

However, not very often, the climatic response to variations in insolation can be distinguished from noise. It occurs when large obliquity corresponds to a period when the date of perihelion takes place during the Northern hemisphere summer. Transition from the cold late Pleistocene to the warm Holocene was provided by such effect. This transition was not gradual; the process was complicated by short-term events (e.g., the Allerød (AL)-Younger Dryas (YD) cycle).

DESCRIPTION OF MODELING RESULTS

History of sea level variations influenced by climate conditions was studied based on climate modeling results. A modeling initiative, the Palaeoclimate Modeling Intercomparison Project – PMIP1 (Joussaume, 1999) has focused on two slices of the past: the mid-Holocene (6 kyr calendar years Before Present or ~5.3 kyr radiocarbon years BP) and the last cold period of the Late Quaternary (21 kyr calendar years BP or ~18 kyr radiocarbon years BP) because climatic conditions were remarkably different at those times and there is much of data describing their environmental properties. Apart from both the AL (~14,5 kyr calendar years BP) and the YD (~12 kyr calendar years BP) were studied as examples of short-scale variability. Designations of the PMIP models are presented in Kislov and Toropov (2006). Table 1 specifies all model boundary conditions and parameters. Orbital parameters determine insolation anomalies. In the mid-Holocene, at 6 kyr BP, they were +5% in summer and -5% in winter, but at 21 kyr BP they are practically near the zero (Berger, 1978).

CLOSED-BASIN SEA WATER-BUDGET MODEL

The Caspian Sea is fed by rivers. The greatest contribution (more than 80% of the mean total volume of the runoff) is produced by the Volga River. Other principal component of the annual water budget is the evaporation over the sea surface. Precipitation over the sea area is less than 20% of evaporation.

Table 1

PMIP boundary conditions and parameters

Boundary conditions and parameters	Control experiment (current climate)	6 kyr BP	21 kyr BP
SST and sea ice	modern	Modern	Calculated or prescribed by CLIMAP
Continental ice sheets	modern	Modern	Prescribed (Peltier, 1994)
Vegetation and land-surface characteristics	modern	Modern	Modern (besides areas covered by ice)
Aerosol optical depth	modern	Modern	modern
Solar constant	1365 Wm-2	1365 Wm-2	1365 Wm-2
Orbital parameters (Ecc is eccentricity, ε is obliquity, λ is position of the equinoxes)	Ecc=0.016724 ε=23.446 ° λ=102.04 °	Ecc=0.018682 ε=24.105 ° λ=0.87 °	Ecc=0.018994 ε=22.949 ° λ=114.42 °
CO2	280 ppm	280 ppm	200 ppm

Changes in sea surface area (f) are calculated at each climatic time-slice experiment basing on assumption that the closed sea is in hydrologic equilibrium with climate conditions. This is a reasonable assumption when considering the impact of gradual climatic change on a sea with a short hydrologic response time compared to the typical time of change of external forces. The steady-state equation of the annual budget of water for a closed-basin sea has the form Kislov and Toropov (2008):

$$ef = YF \ .$$

Where $e = E - P$, where P is on-sea precipitation (m/year) and E is the evaporation (m/year) per unit lake area, Y is the runoff m/year per unit area basin area, F the drainage basin area. Equation (1) assumes that the net groundwater flux into or out of the sea was probably minimal.

Variation of the lake area relative to the present status (denoted by index '0') may be expressed in the form

$$\frac{\Delta f}{f_0} = \frac{\Delta Y}{Y_0} + \frac{\Delta F}{F_0} - \frac{\Delta e}{e_0} \ .$$

It allows evaluating the contribution of different factors to change of the level (h) using information about lake size, bathymetry and the surrounding topography as

$$\Delta h = \left(\Delta h\right)_Y + \left(\Delta h\right)_F + \left(\Delta h\right)_e .$$

The term $(\Delta h)_F$ is responsible for changes of the sea basin's configurations. Level change $(\Delta h)_Y + (\Delta h)_e$ due to both runoff change and change of e is calculated based on data of numerical simulations of climate models. Note that the value $(\Delta h)_e$ over the Caspian Sea was estimated (based on simplified regional climate modeling (Kislov and Sourkova, 1998)) as a small value compare to the first term in equation (3). Modern observation data demonstrate that contribution of the Y and e changes to the dispersion of the sea level fluctuations is 0.026 and 0.007 (m/year)2, consequently (Golitsin et al, 1998). Hence, significant changes of the sea are influenced by the river runoff changes $(\Delta h)_Y$.

SIMULATION OF RIVER RUNOFF AND SEA LEVEL CHANGES DURING THE MID-HOLOCENE, LAST GLACIAL MAXIMUM, COLD YD AND WARM AL EVENTS

In the simulations for 6 kyr BP the change of runoff of rivers (characterizing as $(Y - Y_0)/Y_0$) belonging to the Caspian Sea were 5%. It less than their observational interannual variability. Therefore there was no large change of the sea surface and sea level. At 21 kyr BP the total river runoff to the Caspian Sea is substantially decreased (-50%) compared to today. It means a substantial dropping of level (~50 m).

At 12–14 kyr BP, insolation anomalies were +10% in summer and -10% in winter (compare to modern level). The sea surface temperature was lower over the North Atlantic Ocean than today during the YD but during the AL there were no large differences. This information was taken into account under the climate simulations. During the AL annual river runoff volume belonging to the Caspian Sea is slightly increased (6%) and during the YD it is decreased (12%) compared to today.

DISCUSSION

The important question is whether the result belonging to the one snapshot (21 kyr BP) can be extrapolated to others similar periods? This idea probably proves to be true when observed sea-level curves denoting time-behavior of the Black Sea and the Caspian Sea are compared to the curve depicting the global climate changes (Fig.1). Taking into account uncertainties of the reconstructed data, it is possible to conclude that at least several regression stages occurred simultaneously with Late Quaternary glacial planetary periods.

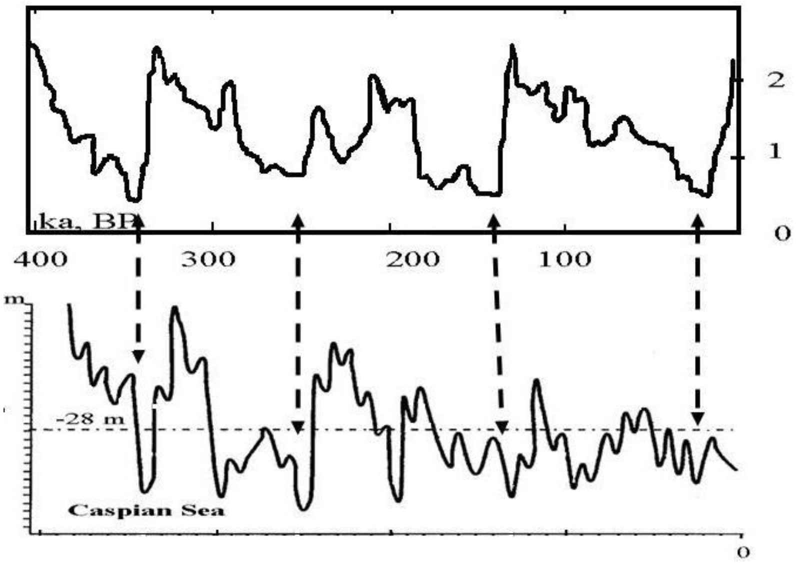

Fig.1. Global climate change (marine isotope data, Shackleton et al, 1990) and the Caspian Sea level variations after Svitoch (2003). Arrows mark synchronous extremes of global cold events and regression stages.

As far as the transgression stages are concerned, the simulation of their onset and duration remains as more difficult problem because there is no clear understanding about a source of “additional” volume of water capable to increase a Caspian Sea level on a mark permitting an overflowing from the Caspian Sea to the Black Sea. There are several speculations lying beyond the paradigm of the climate modeling, but there are no reliable facts or evidence to back these hypotheses (Kislov and Toropov, 2006).

CONCLUSIONS

Based on results of climate simulation it was demonstrated that in response to glacial conditions of the last glacial maximum, lowering levels of the Caspian Sea (Atelskya regression stage) are simulated simultaneously. Hence, these level change reflect planetary scale climate forces.

Analysis of observational data makes possible the conclusion that several last regression stages occurred simultaneously with glacial planetary periods. This lends credit to the idea of the connection between deep regression states of the Caspian Sea and mature stages of Late Quaternary glacial/cooling/drying planetary periods. The origin of the strong Caspian transgression stages is not clear because there is no understanding about a source of "additional" volume of water capable to increase a Caspian Sea level on a mark permitting an overflowing from the Caspian Sea to the Black Sea.

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PALAEOENVIRONMENTAL AND PALAEOCLIMATIC CHANGES IN THE CASPIAN SEA REGION SINCE THE LATEGLACIAL FROM PALYNOLOGICAL ANALYSES OF MARINE SEDIMENT CORES

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INTRODUCTION

The Caspian Sea has known many small and large scale changes of its water level which have in the recent times had a dramatic impact on socio-economical activities around it (Kazancı et al., 2004; Leroy et al., 2010). To reconstruct past sea level changes in the Caspian Sea (CS) and the past climate of the region, the traditional approach so far has been to look at outcrops, to analyse their sediment and micro/macrofossil contents and to obtain radiocarbon dates on bivalve shells. Low stands are not recorded with this method otherwise than by a hiatus. The CS level variability is dominated by the variability of precipitation over the Volga River basin. The precipitation during summer plays a dominant role and can explain the two major events that happened in the 1930s (drop) and after 1977 (rise) (Arpe and Leroy, 2007). At a longer timescale it is not impossible that other drivers of the water level played a role such as anthropogenic and tectonic ones.

Recently marine cores have been obtained in the shallow and more rarely in the deeper central and southern basins of the Caspian Sea. Their multidisciplinary analyses covering both low and high stands holds the key to understanding when sea level changes occurred, which is a step before understanding why they occur.

PROXIES

Besides pollen and non-pollen palynomorphs (Mudie et al., in press), a new proxy is being developed in the Caspian region, which is dinocysts. These small prokaryote organisms are often endemic to the Caspian region and it is only recently that their taxonomy has been firmly established (Marret et al., 2004) allowing now different scientists to use the same names and compare their data. Various forms, species and genera are related to different environments such as water salinity, water temperature, nutrient content (Mertens et al., 2009).

SURFACE SAMPLES

Surface samples are essential to interpret past changes, as they are a stepping stone to link microfossil assemblages to known environmental and climatic conditions (analogues). A collection of surface samples form useful training sets and allow using pollen/dinocyst-based palaeoclimatic reconstructions such as transfer functions. So far for pollen, some spectra have been published in Kazancı et al. (2004) for the lagoon of Anzali in N. Iran and in Djamali et al. (2009) in the Golestan National Park in NE Iran. These, along side unpublished data, show the very open character of the landscape around the CS: steppe (dominant *Artemisia* pollen) and desert (dominant Chenopodiaceae pollen) and the forested area on the south and southwest. These forests still contain some elements that have survived from the Tertiary and which have disappeared from Europe, such as *Parrotia persica* and *Gleditsia caspica*. For the dinoflagellate cysts, some modern assemblages have been published from core tops (Marret et al., 2004) across the south and central basins and from grab samples in the lagoon of Anzali (Kazancı et al., 2004). Typical modern samples are dominated by *Impagidinium caspienense* and correspond to a brackish salinity of 12-13.

DATING

Radiocarbon dating is the best tool to date the sea-level changes of the Caspian Sea over the last 40,000 years. However no detailed studies have been made so far of its marine reservoir effect. This is well known to skew radiocarbon dating due to old carbon present in the water and being incorporated in living organisms as they grow (Ascough et al., 2005). The magnitude of this effect is not the same in all locations (and at all times). For the world ocean a reservoir correction of 400 years is generally accepted. Some experiments made in Israel have however shown that a reservoir effect of up to 2000 years may happen. In the case of volcanic fumaroles, a reservoir effect of up to 1500 years has been noted due to the release of old $C0_2$ (www.c14dating.com/corr.html).

Preliminary work on radiocarbon in the Caspian Sea has shown that many different sources of old carbon exist, as well as other negative influences on the quality of radiocarbon ages: old carbon in the water, effect of various types of methane seepages, activity of surface waters (108-117 pMC) and detrital carbonates and/or detrital organic matter (Escudié et al., 1998; Leroy et al., 2007). Various reservoir effects have been used to correct radiocarbon dates in the literature. They range from 290 to 440 yr (383 yr in Leroy et al., 2007; 290 yr in Kroonenberg et al., 2007; and 390-440 yr in Kuzmin et al., 2007). This poor precision needs to be resolved. The best material to date would be remains of terrestrial plants, which are however quite rare in marine cores.

For the more recent times, i.e. the last 150 years, the radionucleide method is the best, either ^{210}Pb alone or in combination with ^{137}Cs.

THE LAST FEW CENTURIES

Palynological analyses (pollen and dinocysts) of a sediment core taken in the Kara-Bogaz Gol (KBG) in the frame of an INCO-COPERNICUS project have been used to reconstruct rapid environmental changes over the last two centuries (chronology based on 210Pb) (Leroy et al., 2006). A natural cyclicity (65 years) of water level changes in the CS (Kroonenberg et al., 2000) and in the KBG (Giralt et al., 2003) and anthropogenic factors (building of a dam separating the CS and the KBG waters) combine to induce rapid changes in water levels of the KBG, in the salinity of its waters and in vegetation cover of its surroundings. The impact of low water levels on the dinocysts is marked by a lower diversity and the survival of two species that are typical of the KBG, the CS species present in the KBG having disappeared. During periods of higher water levels (AD 1871–1878), the lake is surrounded by a steppe-like vegetation dominated by *Artemisia*; whereas during periods of low water levels (AD 1878–1913 and AD 1955–1998), the emerged shore are colonised by Chenopodiaceae. The period of AD 1913–1955 corresponding to decreasing water levels has an extremely low pollen concentration and a maximum of reworking of arboreal taxa.

Two short marine cores (c. 150 cm) have been taken off shore the coast of Iran (off Anzali in the west and off Babolsar in the centre) at water depths of 250 m (H. Lahijani, pers. comm.). The sequences cover the last 200 years according to radionucleide profiles. Unpublished data indicate that the dinocyst assemblages are dominated by *Impagidinium caspienense* with increasing *Lingulodinium machaerophorum* towards the top. The pollen spectra are dominated by *Artemisia* and Chenopodiaceae off shore Anzali, whereas *Alnus* is very abundant off shore Babolsar.

THE LATE HOLOCENE

Pilot cores (140–182 cm long) have been taken in the south basin, the middle basin and the northern part of the middle basin during a French–Russian oceanographic cruise (August 1994), on board a Russian military ship, rented for the sea cruise in the frame of the same INCO-COPERNICUS project. Core locations were in deep water, and were chosen to avoid direct river influence (SR01GS9414CP or in short CP14 in the south basin, 330 m; SR01GS9418CP or CP18, 480 m in the central basin; and SR01GS9421CP or CP21, 460 m depth in the north of the central basin). A chronology available for one of the cores is based on calibrated radiocarbon dates (ca 5.5–0.8 cal. ka BP) on bulk sediment corrected for their detrital content.

Pollen, spores and dinoflagellate cysts have been analysed on these sediment cores (Leroy et al., 2007). The pollen and spores assemblages indicate fluctuations between steppe and desert. In addition some outstanding zones display a bias introduced by strong river inflow. The dinocyst assemblages change between slightly brackish (abundance of *Pyxidinopsis psilata* and *Spiniferites cruciformis*) and more brackish (dominance of *Impagidinium caspienense*) conditions.

During the second part of the Holocene, important flow modifications of the Uzboy River and the Volga River as well as salinity changes of the Caspian Sea, causing sea-level fluctuations, have been reconstructed. A major change is suggested at ca 4 cal. ka BP with the end of a high level phase in the south basin (core CP14). Amongst other hypotheses, this could be caused by the end of a late and abundant flow of the Uzboy River (now defunct), carrying to the Caspian Sea either meltwater from higher latitudes or water from the Amu-Daria. A similar, later clear phase of water inflow has also been observed from 2.1 to 1.7 cal. ka BP in the south basin and probably also in the north of the middle basin.

THE EARLY HOLOCENE AND LATEGLACIAL

A further two cores from the same cruise of 1994 are being analysed for the pollen and dinocyst content. These Kullenberg cores are each 10 m long (Chalié et al, 1997). Core GS05 (south basin, museum number SR01GS9405) was taken in a different coring station than core CP 14, i.e. in a more southerly location, and core GS18 (middle basin, museum number SR01GS9418) comes from the same station than core CP 18 (Leroy et al., 2007). However preliminary dating on ostracod shells suggests that no overlap occur between the pilot and the Kullenberg cores due to severe losses at the top of the Kullenberg cores during core penetration.

The pre-Holocene sediment of the two cores is silicate rich. Preliminary results for the south basin suggest a very open landscape during the Lateglacial with intensive mechanical weathering in a cold climate and high water levels (Leroy et al., 2000, in prep.; Pierret et al., in prep.). At the beginning of the Holocene, the sedimentation switches to carbonates and the water level drops. A progressive colonisation by shrubs takes place and the erosion becomes chemical. The development of trees is delayed and they become more abundant only after 4000 cal. yr BP in line with a further increase of chemical erosion.

The dinocyst assemblages of the middle basin core show a late change from slightly brackish water to more brackish water (as in the present) only at 4 cal. ka and not at the transition to the Holocene. The dinocyst assemblages of the southern core change at 10 cal. ka, but from the present day values of salinity (brackish) to a lower salinity. This period of lower salinity correspond to that seen at the base of core CP14, which terminates at c. 4 cal. ka. Therefore the two basins did not have the same water level history leaving a possible role to the Apsheron sill.

CONCLUSIONS

In the absence of a complete palynological record for the Holocene, much remains to be done in the Caspian Sea. In the near future a transfer function for pollen and dinocysts should be developed at the scale of the whole sea. Palaeoclimatic records from marine cores covering a whole climatic cycle with robust age-depth model should be obtained (Cordova et al., 2009).

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PLEISTOCENE CONNECTION AND HOLOCENE SEPARATION OF THE CASPIAN AND BLACK SEAS: DATA FROM THE MODERN KURA DELTA, AZERBAIJAN

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Keywords: Caspian Sea, Black Sea, Pleistocene, paleogeography, Kura delta

INTRODUCTION

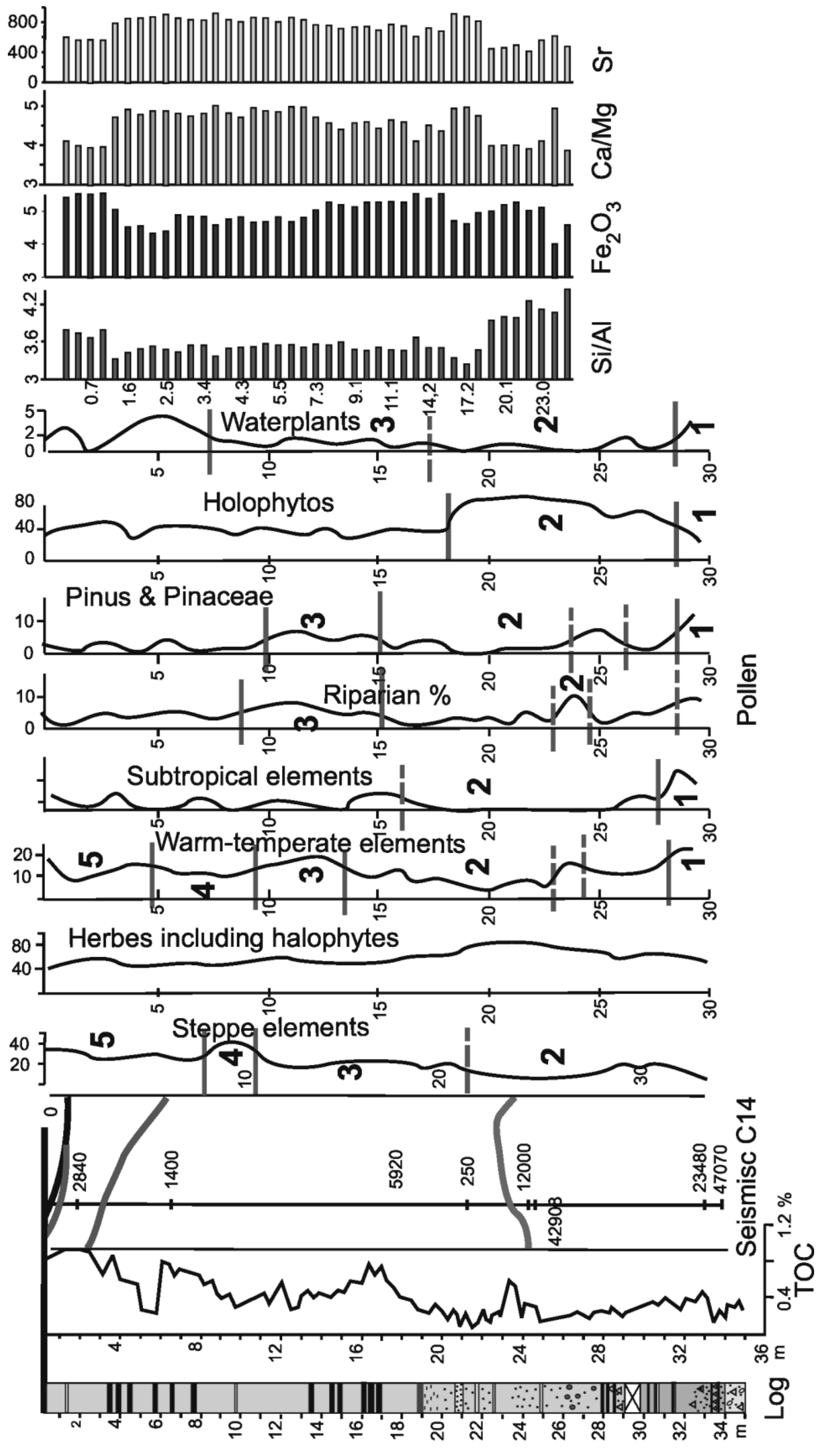
Past breaks in Caspian sea-level trends caught everyone by surprise. Nobody predicted the sharp fall in the thirties, the sharp rise in 1977 and the sudden fall in 1995, even though in the last case numerous Global Circulation Models and hydrological balances have been run to predict future sea-level behaviour. The problem is that the period for which instrumental observations exist, since 1834, is too short to validate any model of long-term trends, and the historical record before that is too fragmentary and too contradictory to derive any reliable trend from them. Therefore we studied paleodata on past sea-level changes in the Caspian area in the Holocene.

One of the most promising sites that can give information both on the absolute elevation and chronology of highstands and lowstands, as well as a semi-continuous record of paleo-ecological conditions, is the modern delta of the Kura river in the southern Caspian Sea in Azerbaijan, a conspicuous fluvial- and wave-dominated delta body protruding offshore until at least 50 m water depth. In an earlier project we recognised the traces of two major lowstands, and two major highstands in the last 1500 years of the Kura Delta history, based on shallow sparker surveys and shallow drilling, sampling and paleoenvironmental analysis.

We now extended the record further back into the Holocene and upper Pleistocene by an extensive seismic survey, drilling and coring of two deep wells, detailed sedimentological, geochemical, paleoecological and chronological analyses. The data have been integrated in a Petrel geological model, visualised using 3-D Inside reality software, and will be matched with the output of 3-D process-based numerical simulation models to be developed for the Kura delta. In this way we obtained a much more detailed and much more reliable Holocene sea-level curve for the Caspian, and especially for the depth and the timing of the lowstands, which are difficult to study on land.

RESULTS

A seismic survey was carried by the subcontractor KMGRU (now KGKTI) in June-July 2007 using an Edgetech subbottom profiler with a maximum penetration of 6 m in sand and 80 m in fine deepwater sediment. In practice only 20-50 m penetration was obtained during the survey. However the quality of the data is considerably better than that of the 2001 survey. Two cores down to 35 m were collected in January, 2009 (Fig. 1).


Sr
Ca/Mg
Fe_2O_3
Si/Al
Waterplants
Holophytos
Pinus & Pinaceae
Riparian %
Pollen
Subtropical elements
Warm-temperate elements
Herbes including halophytes
Steppe elements
Seismisc C14
TOC
1.2 %
Log
m

The first analytical results in the integration of seismic data with grainsize, pollen, geochemistry and 14C dating of core A show a subdivision into four or five sequences, which however do not strictly coincide.

1. Seismic data show three major reflectors, the deepest one of which at ~ 24 m depth (orange reflector in figure above) seems to correspond with the Pleistocene-Holocene boundary according to 14C dating. This might coincide with the occurrence of reddish clays in the log, though they start at a deeper level. Ages range between 23480 and 47070 cal yr BP. Geochemical data show higher values for Si/Al, Ti, Fe_2O_3, Ni, Cr and lower values for Ca/Mg, Sr and TOC than later horizons. Pollen biozone 1, which might coincide with this unit, shows high amount of *Pinus* and water plants and low halophytes, suggesting a large influence of fresh water and pollen influx from the Volga through coast-hugging marine currents. These sediments resemble in many aspects the brownish Late Pleistocene sediments recovered from the deepest part of the South Caspian Basin (Chalié et al., 1997; Jelinowska et al., 1998) and also to some extent the so-called 'chocolate clays' recovered from the bottom of the Black Sea (Bahr et al., 2005, Hiscott et al., 2007) and cropping out in the North Caspian Plain (Badyukova, 2005).

2. Close to this (orange) reflector, at 24,55m depth, peaty sediments were found dated at 12000 cal BP, also characterised by a peak in TOC. This sequence is characterised by a high content of halophytes (Biozone 2), suggesting deposition under salt marsh conditions close to sea level. This is not a distinctive sequence in the seismics. Geochemical data indicate the lowest contents in Fe_2O_3 of the whole core, low Ni, Co, V and comparatively high Ca and Sr contents. In view of the water depth of the top of the core at 40.13 m, sea-level must have been almost 65 m lower than the present one of -27m below oceanic level, i.e. -92m (24,55+40,13+27m) below oceanic level. This is within the range of estimates for the Early Holocene Mangyshlak regression (Varushchenko et al, 1987).

3. The third horizon from ~24 m up to the next reflector (green in the figure) at about 4-8 m depth, consists of greyish marine muds with minor sand intercalations, and in which several cycles can be discerned on the basis of TOC contents. Ca and Sr contents are much higher than in horizon 1, whereas Ti, Fe_2O_3, Ni and V are substantially lower. This series shows increasing contribution of warm temperate pollen, increasing (Volga-derived) *Pinus* and Kura-riparian pollen, and decreasing halophytes, suggesting a rising sea level. Two 14C ages have been obtained for this interval, 5920 cal BP at 17.20m, and 1400 cal y BP on a large mollusc at 6 m depth, close to the strong reflector at the top of this unit. This horizon therefore spans a major part of the Holocene. The upper age is very similar to earlier ages obtained from the Kura delta close to the same reflector, interpreted as indicating the 6^{th} century AD Derbent lowstand known from historical data, which may have been as deep as -48 m (Hoogendoorn et al., 2005). The depth of the upper boundary of this unit varies to some extent in the different analyses. The lowstands may correspond with the Warm Mediaeval Period (Kroonenberg et al., 2007, 2008).

4. The unit on top of the 'green' reflector, generally between 1,5 and 6 metres depth, and possibly limited at the top by the yellow reflector, is not well individualised in the lithology:greyish and green muds predominate. The contents of Si, Fe_2O_3, Cr, Ni, and V seem slightly lower than in adjacent units, while Ca, Mg, Sr and TOC are higher. There is a definite peak in steppe pollen (*Artemisia*, *Ephedra*) and a dip in the warm temperate pollen, indicating warm semi-arid conditions. The only 14C date from this horizon is 2840 y cal BP, the *Didacna* specimen used for dating was apparently reworked. On the basis of the analogy with earlier data from the Kura delta (Hoogendoorn et al; 2005), this unit may well represent the Warm Mediaeval Period between the lowstands of the 6th and 12th entury AD.

5. The uppermost ~ 1,5 m between the yellow reflector and the surface shows a tendency to cooler climatic conditions according to the pollen profiles, and thus may correspond to a period of sea-level rise heralding the start of the Little Ice Age highstand (cf. Kroonenberg et al., 2007). The shales in this interval are slightly richer in Fe_2O_3, Ni, Cr, V, Zn and lower in Ca, Mg and Sr than the underlying horizon. Well B shows similar characteristics in seismics, lithology and geochemistry, but no palynological data are available yet. The geochemical contrasts between the lowermost Fe-rich and Ca-poor units and the upper Fe-poor and Ca-rich units are particularly striking. Three ages have been obtained, one >45000 in what is presumably Unit 1, one 17500 BP in Unit 2, and one 9240 cal. BP in an equivalent of unit 3.

SiO_2/Al_2O_3, Fe_2O_3, Ca and Sr in Well B One of the most important conclusions that can be drawn from the project is the similarity in Late Pleistocene sedimentation in the Caspian and in the Black Sea, suggesting that this unit was deposited when both seas were united during the last major Glacial highstand (Khvalyn) of the Caspian (so-called chocolate clays). Those in the Black Sea might therefore either originate directly from an overflow of the Caspian, or proceeding from drainage basins that have similar characteristics as the rivers discharging in the Caspian Sea. The striking difference in geochemical characteristics between the Pleistocene (high Fe, low Ca) and Holocene (low Fe, high Ca) sediments corroborate earlier findings from deep sea cores in the Caspian, and point to major changes in the drainage basins feeding the Caspian Sea during the Late Glacial-Holocene transition.

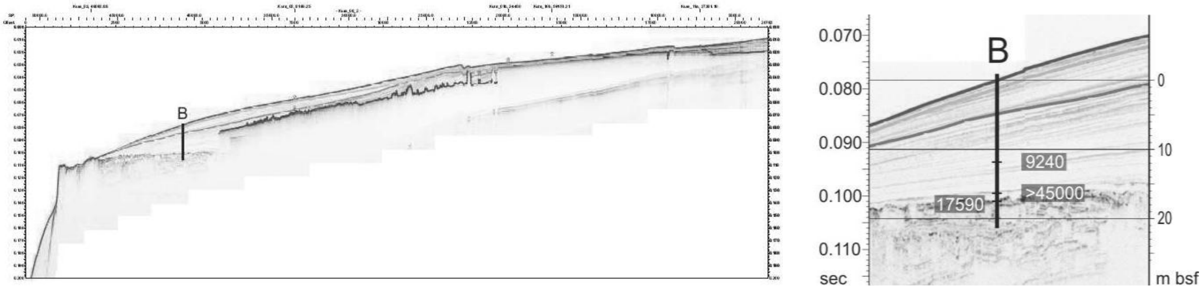


Fig. 2. Interpretation – Core B

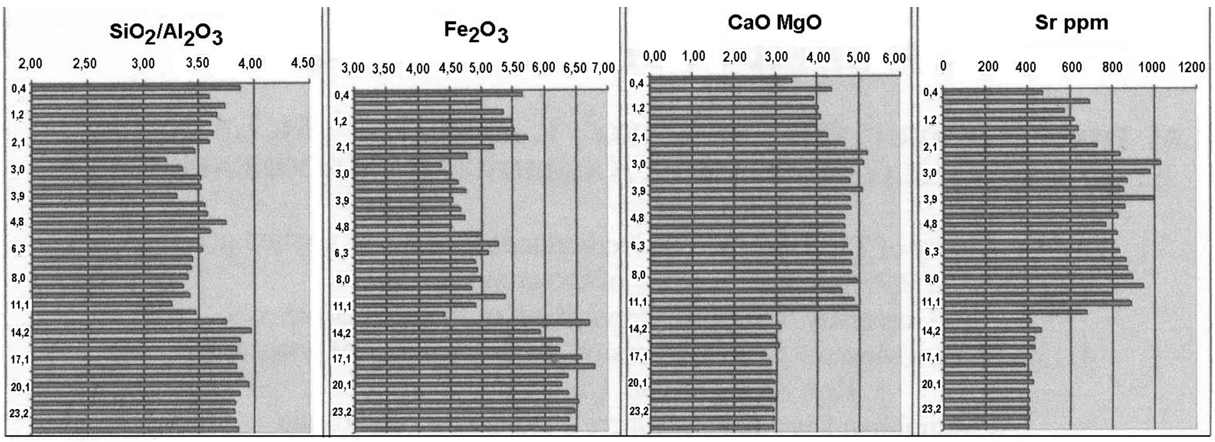


Fig. 3. SiO_2/Al_2O_3, Fe_2O_3, Ca and Sr in Well B

Holocene sea-level cycles, the main subject of this project, are clearly discernible in the palynological and TOC data, and seem to conform to earlier less precise data, but we are awaiting more 14C data to see the finer details of sea-level change. After all, the best sealevel curve from the Caspian will combine results from an integration of data from all sites studied so far by us in this and other projects in the Caspian Sea, in which the Kura data provide the best data for dating the lowstands. The data collected in this project make the necessary data base complete enough to give a comprehensive picture of Holocene Caspian Sea level change in our forthcoming publications.

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ENVIRONMENTAL GEOCHEMISTRY OF THE CASPIAN COASTAL ZONE

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INTRODUCTION

Presently the Caspian region draws a great attention of researchers due to the rapid fluctuations of the sea-level and increase of the anthropogenic load. In 20^{th} century the Caspian Sea showed a full sea-level cycle with amplitude of about 3 m, which included stages of regression (1929-1977) and transgression (1978-1995). Rapid sea-level fall had a number of negative consequences: shallowing of the near-shore waters, deterioration of shipping conditions, decrease of feed areas for fish in the Northern Caspian, increase of soil salinization in the coastal zone, intensification of eolian processes, etc. The sea-level rise caused even more serious environmental consequences: flooding and water-logging of vast areas, destruction of the seashores, strengthening of wind-induced surges, development of hydromorphism and salinization processes in the coastal landscapes.

Another problem of the region consists in the environmental state of river mouths, which are located at the contact of riverine and marine waters and influenced by pollutants brought by rivers. Recently a problem of the environmental state in areas of oil and gas extraction is put in the forefront. This is caused by rapidly increasing offshore exploration, extraction and transportation of oil and gas in the Northern Caspian Sea. It results in strengthening of anthropogenic load on the coastal and aquatic systems, and dramatic rise of environmental risks due to possible accidents. Of a special concern is environmental state of wetlands within the Volga River mouth area which are of international importance due to Ramsar Convention.

From the beginning of 1990-ies the Caspian Sea coast was studied in frames of a number national and international projects devoted mainly to the geochemical consequences of the sea-level fluctuations for the coastal landscapes, and also environmental state of river mouths.

GEOCHEMICAL CHANGES IN COASTAL ECOSYSTEMS

Geochemical changes in coastal soils and sediments were studied in detail in Turali area (Central Dagestan). Besides, similar research was done at accumulative lagoon shores of Azerbaijan and Iran. The study showed that along accumulative shores the sea transgression gives rise to geomorphological, lythological, soil, biotic, as well as geochemical diversity of the coastal landscapes. This is caused by formation of bar-lagoon system moving landwards, inundation and water-logging processes, with a corresponding rise of the groundwater table, and also simultaneous vigorous development of vegetation in newly-formed hydromorphic and semi-hydromorphic areas. On the contrary, the sea regression leads mainly to the passive drowning of the shore zone with a following decrease of the coastal environment variability.

Geochemical conditions of the coastal landscapes are also caused by the sea-level fluctuations. Regressive stages associate with a weak variability of geochemical environment in sediments and soils. They are characterized mainly by alkaline oxic conditions, and salinization as a leading geochemical process. Geochemical diversity of the coastal zone during transgressive stages is much higher. Conditions vary from neutral to highly-alkaline, and from oxic to highly unoxic. Newly-formed geochemical processes are presented by sulfidization, gleyzation, ferrugination, organic matter accumulation, and salinization. They cause a formation of various contrast geochemical barriers in soils and sediments with a consequent redistribution of chemical elements. These processes take place on the general low background of microelements which is characteristic for the Russian part of the Caspian seashore. Content of heavy metals is essentially higher in coastal soils and sediments of Azerbaijanian and Iranian seashore, especially in the South-Western area of the Caspian.

These newly-formed geochemical processes caused by the sea-level rise were determined in all areas of the Caspian coast, however their intensity varies according to climatic conditions. Soils of humid subtropics of Lenkoran lowland and western coast of Iran are characterized by well pronounced processes of organic matter accumulation and gley formation, since in dry subtropics processes of salinization and sulfidization are more distinct.

ENVIRONMENTAL STATE OF RIVER MOUTHS

River deltas presently draw high attention due to their location in the lowermost chains of cascade landscape-geochemical systems and worsening of environmental conditions in many river basins. In the Caspian area of the most interest is a mouth area of the Volga River which is characterized by a wide variety of water subjects with different morphology, hydrodynamical regime, lythology of sediments, biota, etc. Technogenic geochemical impact on aquatic systems is different as well: from local contamination in the delta itself to the regional influence of pollutant sources scattered upstream. Multiple sources of contamination in the middle and low course of the Volga River caused an impression of a heavy pollution of aquatic systems in the Volga delta.

Long-term environmental geochemical research showed high spatial-temporal variability of geochemical conditions in aquatic systems of the Volga River mouth area, which is caused by different hydrodynamics, variations in water run-off, local peculiarities of aquatic systems. In general this mouth area presents a complicated landscape-geochemical system, which includes areas of transit and accumulation of heavy metals. Favorable circumstances can determine within the area formation of geochemical barriers and complex barrier zones with a consequent accumulation of various substances brought by the river run-off.

In frames of Russian-Dutch projects we have estimated pollutant levels and their dynamics in sediments of the Volga delta for the last 50 years on the basis of ^{137}Cs and ^{134}Cs dating (Winkels et al., 1998). It was concluded that in general Volga delta is not contaminated and is characterized mainly by background values of chemical elements in sediments of aquatic systems. Rather low pollutant levels in sediments of the Volga delta can be explained in a large extent by accumulation of technogenic substances in sediments of huge water reservoirs in the middle and low course of the river. Bottom sediments of these reservoirs are characterized by distinct geochemical anomalies of Pb, Cd, Zn and other heavy metals. Comparison of geochemical parameters for Volga delta and 2 other large European rivers (Rhine and Danube) showed that it is a Rhine delta which is the mostly polluted. Despite of a sharp decrease of pollutant levels in Rhine sediments since 1960-s this delta until now has the highest levels of heavy metals and PAHs in river sediments.

Geochemical study of bottom sediments in water objects of the Volga delta revealed the lythogeochemical uniformity of the delta water objects and Cr-Pb geochemical specialization of sediments. Generally low HM contents in sediments allowed concluding on prevalence of natural factors in the formation of a geochemical background in the Volga delta. Seasonal and long-term tendencies of HM content changes in bottom sediments of water objects in the lower part of the delta are revealed. On the basis of geoinformation study of the remotely sensed data zoning of the western part of the shallow near-shore area was carried out according to the water turbidity. Spatial analysis of HM distribution in bottom sediments allowed revealing a presence of two geochemical barrier zones within the near-shore area. The first zone is located adjacent to the channel mouths, leaving to the marine border of the delta, the second zone is put forward aside the sea on 20-30 km to the beginning of area of river and sea waters mixing.

River mouths often serve as biogeochemical barriers, which determine accumulation of different substances in dissolved and suspended forms. Biogeochemical indication is one of the promising methods of the environmental geochemical research. Increase of pollutant content in the environment quite often causes its accumulation in biotic species. This species can be used as biogeochemical indicators. From a large variety of species one of the most sensitive groups of such indicators is presented by macrophytes (Lychagina, Kasimov, Lychagin, 1998).

Two biogeochemical types of macrophytes have been distinguished: non-barrier (*Phragmites australis, Trapa natans, Salvinia natans, Ceratophyllum demersum*) and barrier (*Potamogeton*). Concentrations of heavy metals in non-barrier plant species distinctly depend upon the environmental conditions and vary over a wide range. On the contrary barrier species are characterized by low variability of heavy metals determined mainly by the biogeochemical speciation of plants. Background levels of heavy metals are the highest in *Salvinia natans* and *Ceratophyllum demersum* and the lowest in *Phragmites australis*. The natural variability of heavy metals in aquatic plants is rather high. It depends on the regime of water streams and bodies.

Concentrations of heavy metals in the same plant species are higher in closed creeks with a stagnant regime than in active channels with running water. Biogeochemical research of contaminated sites revealed distinctly higher TE levels for non-barrier species. The factor of concentration is determined the highest (up to n×10) for the reed (*Phragmites australis)* which accumulates pollutants both from water and bottom sediments.

Content of dissolved and suspended forms of heavy metals in river waters as a rule widely varies. It is determined by both chemical properties of metals and external factors of migration. In general suspended form is prevailing for heavy metals transported by water streams. For some metals the share is as high as 99% of the total metal content. Volga River is characterized by very low turbidity, which determines higher share of dissolved forms of heavy metals in water of the Volga delta. In some samples contents of Cu, Pb and Cd in suspended matter exceed global background values. The fact indicates occurrence of a technogenic pollution of aquatic systems. Study of seasonal dynamics of heavy metals in water and suspended matter revealed flooding as a period of predominant input of these pollutants from the upper basin to the Volga delta.

CONCLUSION

Environmental geochemical state of the Russian part of the Caspian coastal zone until now is determined mainly by natural factors. Coastal and deltaic soils and sediments are usually characterized by background values of heavy metals and other pollutants. The most attention presently should be paid to the environmental state of areas of oil and gas extraction in the Northern Caspian Sea. Rapidly increasing offshore exploration, extraction and transportation of oil and gas in this area results in strengthening of anthropogenic load on the coastal and aquatic systems, and dramatic rise of environmental risks due to possible accidents.

ACKNOWLEDGEMENTS

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THE GREAT FLOOD HYPOTHESES IN THE BLACK SEA: CASPIAN AND MEDITERRANEAN IMPACTS IN THE PONTIC BASIN SEEN FROM ENVIRONMENTAL AND CULTURAL PERSPECTIVES

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INTRODUCTION

The history of isolation and marine re-connection of the Black Sea with the Mediterranean Sea on the west and the Caspian Sea on the east, and the impact of these events on regional environmental and cultural evolution have been the concern of the IGCP 521-INQUA 501 projects. Both projects focus on climate, sea-level change, and coastline migration in the Caspian-Black Sea-Mediterranean corridors during the past

30,000 years (for more information see Yanko-Hombach in this volume), and testing the two Great Flood Hypotheses, among other questions. The first, or Late Pleistocene "Great Flood" Hypothesis, states that the brackish Neoeuxinian Lake in the Black Sea basin filled rapidly with Caspian Sea brackish overflow via the Manych Spillway shortly after the LGM, 17–14 ka BP[1] (Chepalyga, 2003, 2007) or 15–13 ka BP (Chepalyga et al., 2008). The second, or Early Holocene Great Flood Hypothesis describes a catastrophic inundation of the Neoeuxinian Lake by inflow of Mediterranean salt water at 7.2 ka BP (Ryan et al., 1997; Ryan and Pitman, 1999) or 8.4 ka BP (Ryan, et al. 2003; Ryan, 2007). Both hypotheses propose that the massive inundations of the Black Sea basin and ensuing environmental changes profoundly impacted prehistoric humans in surrounding areas and formed the basis for Great Flood legends.

In this paper, we review the geological, paleontological, palynological, and archaeological evidence to determine whether they support these hypotheses, and we summarize the scientific evidence for alternative scenarios of Black Sea development in the Late Pleistocene and Early Holocene, paying particular attention to archaeological impacts implied by the different hypotheses.

MATERIAL AND METHODS

Our review is based on: (1) materials from a large-scale (1:200,000, and in certain areas 1:50,000) geological survey of the Northern and Caucasian Black Sea shelf in which the first author was heavily involved (Yanko, 1990), and (2) correlation of archaeological sites with geological data (Dolukhanov and Shilik, 2007; Stanko, 2007; Dolukhanov et al., 2009). The survey was, and still is, performed following a methodology developed with the joint efforts of specialists from academia, educational institutes, and industry (e.g., Shnyukov, 1982; Balabanov et al., 1993). Particular attention was given to morphological, lithological, geochemical, and paleontological markers of paleosea level stands (e.g., Shnyukov, 1982; Avrametz et al., 2007) and their geochronological control, including consideration of the possible influence of neotectonics (e.g., Glebov and Shel'ting, 2007) on paleogeographic and paleoenvironmental reconstructions.

As part of this survey, thousands of cores, tens of thousands of kilometers of seismic profiles, and hundreds of radiocarbon dates across the Black Sea shelf from the northern exit of the Bosphorus Strait on the west to the city of Batumi on the east were collected and studied in a multi-disciplinary effort. The northwestern shelf, "the cradle of the Flood Hypothesis," was studied especially well, resulting in the collection of a massive database described in numerous publications (e.g., Yanko, 1990). In none of these published studies was there ever any evidence given for abrupt flooding of the basin in the Late Pleistocene-Early Holocene, and none of the classical publications on the subject did so either (e.g., Arkhangel'sky and Strakhov, 1938; Nevessakaya, 1965; Fedorov, 1978).

Sediment cores were routinely logged for grain-size, color, texture, presence of shell, wood, and peat. Subsamples were taken for studies of mollusks, foraminifera, ostracods, and palynology studies as well as for geochemical analysis of C_{org}, and oxygen and stable carbon isotope ratios.

LATE PLEISTOCENE "GREAT FLOOD" HYPOTHESIS: EVIDENCE AND CRITICISM

According to this hypothesis (Chepalyga, 2003, 2007), the Great Flood occurred during the Early Khvalynian stage, between 17 and 14 ka BP, when water level in the Caspian basin rose 180–190 m, and a great Cascade of Eurasian Basins (the Vorukashah Sea) extended from the Aral Sea in the east to the Aegean Sea in the west, connected via the former spillways of the Uzboy and Manych-Azov-Kerch as well as the current Bosphorus and Dardanelles Straits. The Cascade encompassed about 1.5 million km^2, contained about 700,000 km^3 of semi-fresh to brackish water (1–12‰), and it left traces on coastal plains (marine transgressions), in river valleys (megafloods), on watersheds (thermokarst lakes), and on slopes.

The Early Khvalynian basin could not retain all the inflowing water, so the excess was discharged through the Manych-Azov-Kerch Spillway into the Late Neoeuxinian Lake with an estimated speed of about 1000 $km^3\ a^{-1}$—three times faster than the present river discharge. The water influx raised the Late Neoeuxinian Lake level 60–70 m and then spilled into the Sea of Marmara. This flow pattern was traced by following the distribution of 'chocolate clays', loams, and sands of 20–30 m thickness, containing endemic Caspian mollusks *Didacna*, *Monodacna*, *Adacna*, *Hypanis*, and foraminifera *Mayerella brotzkajae* and

[1] All ^{14}C are determinations discussed in this paper are uncorrected for reservoir effect and uncalibrated.

Ammonia caspica (Yanko-Hombach et al., 2007a) across all the basins from the Caspian Sea to the Dardanelles Strait. The drastic changes in sea level and coastal inundation (up to 10–20 km a^{-1}) submerged extensive floodplain areas, possibly forcing migrations of Paleolithic people into "safe areas," and stimulating cultural advances.

From a geological perspective, this hypothesis was heavily criticized by Svitoch (2008), who noted that: (1) there are no data indicative of the Aral Sea being a drainage lake, (2) there is no evidence that Siberian proglacial water was inflowing into the Caspian Sea, (3) taxonomic and spatial distribution of mollusks in Khvalynian sediments do not support the transgression as having been essentially influenced by the thawing of ice sheets on the Russian Plain, (4) there is no evidence that the Khvalynian transgression was catastrophic; in fact, sea level rose by a few centimeters per year for several thousands of years, and, therefore, encompassed the lifetimes of many generations, and (5) there are no data indicating that the quantity of Khvalynian water overflowing through the Manych Spillway into the Neoeuxinian Lake was significant. Most likely, it would have increased the level and salinity of the lake by 30 m and 5‰, respectively. Viewed from this perspective, there is no conclusive evidence that the Khvalynian transgression could serve as a prototype for the Great Flood. Moreover, natural cataclysms lasting for several thousand years and affecting tens or hundreds of human generations would never be perceived as a one-time catastrophe (such as the Biblical flood). In all probability, the flooding event as described in the Old Testament was some large-scale catastrophe that transpired most likely within a local area and was elaborated and enlarged in subsequent human memory. It was not, however, the Khvalynian transgression of the Caspian Sea, and it is incorrect to refer to it as the Great Flood. This term should be used to indicate other events of more significant scale and tragic consequences.

From an archaeological perspective, Chepalyga's (2007) argument that Paleolithic sites predating the Late Pleistocene Great Flood (e.g., Avdeevo on the Seym River) are located at lower elevations within the valley, while younger sites are situated much higher on the slopes, possibly because of superfloods engulfing the valley bottoms, is incorrect. Nearly all Upper Paleolithic sites inhabited during the various stages of the last glaciation on the East European Plain are found on elevated river terraces. This was apparently due to the fact that these rivers were major channels for meltwater discharge to the south; they were in essence 'chains of lakes'. The site of Avdeevo is a notable exception. Its lower position within the valley may be attributed to seasonal fluctuation in water level. Quoting Leonova's (1998) data on the presence/absence of specific microlithic tools in the inventory of the Kamennaya Balka site, Chepalyga suggests that the Great Flood must have disrupted contacts with the south. This argument seems to be incorrect as well. As shown by the frequencies of radiocarbon-dated sites (Dolukhanov, 2001), the density of Upper Paleolithic sites markedly increased in the periglacial zone of the East European Plain between 24 and 20 ka BP, a time when the water level of the brackish Early Neoeuxinian lake lay below 100 m. In the course of the Late Neoeuxinian transgression (18–14 ka BP), and during an environment of gradually rising temperature and humidity, groups of Paleolithic foragers moved into the Pontic Lowland from the north and settled within the valleys of small rivers. At 18 ka BP, specialized bison hunters occupied the large site of Anetovka 2, which combined the functions of a tool-making workshop, butchering site, and cult center (Stanko et al., 1989). Another site of approximately similar age, Amvrosievka, was a short-lived bison hunters' kill-site (Krotova, 1999). Dolukhanov et al. (2009) supported the suggestions of Stanko and Krotova by describing coastal landscapes for the northern Black Sea and pollen data from Ukraine indicating likely effects on Paleolithic groups due to the extermination of mammoth and woolly rhino by 18 ka BP and their replacement by bison. Similar to Amvrosievka, settlements were very likely established on the exposed Pontic shelf, which is currently submerged. During the Late Glacial period (14–10 ka BP), the local industries became enriched with microlithic elements, and this apparently developed locally without any major influx from outside (Sapozhnikov, 2005). Hence, the development of the microlithic technique was a common phenomenon for the entire Pontic steppe and was in no way related to the occurrence of a Late Pleistocene Great Flood as was proposed by the author of this hypothesis.

Thus, all Paleolithic sites occupied during Neoeuxinian time belonged to groups of foragers specialized in hunting big game. Similarities in lifestyle and lithic tools suggest that human groups circulated freely along coastal areas, including the now submerged shelf floor. No major changes in settlement or subsistence that could be related to a major ecological catastrophe are recognizable; the only exception is the disappearance of bison in Late Glacial sites, but this was apparently the result of overkill. Contacts between human groups seem not to have been severed by any calamitous events, so contrary to Chepalyga's views, population movements were not likely blocked or disrupted by a major Manych-Azov-Kerch Spillway. As such, Chepalyga's (2007) argument for a Late Paleolithic upland migration and a stimulus towards the development of water transport technology, as suggested by Mesolithic rock drawings in Gobustan of 9–8 ka BP (Dzhafarzade, 1973) seems also to be incorrect. Stanko (2007) recorded Mesolithic population increases in the lower Dniester valleys from 14–12 ka BP, but he did not find any evidence of catastrophes for the time span of 14–6 ka BP. Not until ca. 12 ka BP, however, is there evidence of a southward migration of people into the wetlands of the Danube, Dniester, and Dnieper estuaries, where waterfowl hunting may have been important. Although it is reasonable to suggest that there may have been settlements on an emergent shelf (Dolukhanov et al., 2009), no underwater sites or animal bones have yet been recovered, and the earliest evidence of regional farming dates to the Late Chernomorian stage (7–4 ka BP) as represented by numerous sites in the upper Dniester basin and scattered sites near the Azov Sea (Dolukhanov et al., 2009). Özdoğan (1999) emphasized indirect evidence that the Holocene transgression coincided with human migration from the Mediterranean area into the Pontic Lowland, not the other way, as flood avoidance would imply. However, hyperarid climate and an effective isolation of the Caspian area contributed to the prolonged survival of Mousterian technology and, possibly, Neandertal populations. The spread of Upper Paleolithic technology in that area became possible only in the aftermath of the Late Khvalynian transgression, 12.5–12 ka BP (Dolukhanov et al., 2009).

EARLY HOLOCENE GREAT FLOOD HYPOTHESIS: EVIDENCES AND CRITICISM

Based on very limited geological data obtained on the northwestern shelf and south of the Kerch Strait, the Early Holocene Flood hypothesis suggested by Ryan et al. (1997) argued that the level of the *freshwater* Neoeuxinian Lake was ca. –140 m below present sea level between 14.7 and 10 ka BP. At 7.2 ka BP, saline Mediterranean water from the rising postglacial world ocean broke through a barrier within the narrow Bosphorus channel and abruptly filled the Neoeuxinian Lake, submerging more than 100,000 km^2 of previously exposed shelf, in the process flooded coastal farms and forcing early Neolithic foragers and farmers to evacuate and move into the interior of Europe carrying with them agriculture as well as the memory that would form the historical basis for the biblical story of the Great (Noah's) Flood.

A few years later, this hypothesis was modified (Ryan et al., 2003) based on a study (Major et al., 2002) of two sediment cores recovered at water depths of –240 and –378 m. Using Sr isotope values in the core sediments as proxies, it was concluded that re-connection between the Black and Mediterranean seas (via the Marmara Gateway) began a millennium earlier than previously estimated. The timing of the flood was moved back to 8.4 ka BP, and instead of a single inundation, two lowstands (–120 m at 13.4–11 ka BP; and –95 m at 10–8.4 ka BP) and two floods (sea-level rise from –120 to –30 m at 11.0–10.0 ka BP; and from –95 to –30 m at 8.4 ka BP) were proposed. The second of these two major transgressions was labeled the Great Flood.

This hypothesis received support from IFREMER's seismic surveys, which apparently indicated well-preserved drowned beaches, sand dunes, and soils (Lericolais et al., 2007), and based on these features, they claimed that the Black Sea shoreline was at –100 m until about 8.5 ka BP. A refinement of this hypothesis was introduced by Turney and Brown (2007), who recycled Major's published mollusk ^{14}C ages into a model based on "high precision dating of the marine flooding of the freshwater Black Sea." In their model, they removed corrections for a hardwater or marine reservoir effect from the so-called "freshwater" mollusks living in the Black Sea before 7940±75 BP, and assumed a mean ΔR of 50±63 years for the oldest Black Sea marine mollusk in order to narrow the age of the early Holocene inundation. A Bayesian model was constructed for these age-adjusted data to show that the Mediterranean infilling of the Black Sea occurred between 8350 and 8230 cal bp (7505–7484 BP). Turney and Brown connected this marine incursion with the ca. 8.2 ka BP global cooling event associated with final collapse of the Laurentide ice sheet and outflow of flood water from Lake Agassiz (Clarke et al., 2004).

A freshwater character for the Neoeuxinian Lake was recently supported by Soulet et al. (2010). Based on the study of pore water from a single core located at a water depth of –350 m on the Danube traverse, the authors suggested that, during the Last Glacial Period, the Black Sea "Lake" was a fresh and ^{18}O-depleted water body. According their discoveries, they claimed that a freshwater-filled basin would have allowed Neolithic farming on the exposed ancient Black Sea shelves.

The hypothesis was closely examined in recent publications: a special June 2007 issue of *Quaternary International* (Yanko-Hombach and Yılmaz, 2007) and a major book, *The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement* (Yanko-Hombach et al., 2007). Most researchers found the Early Holocene flooding of the Black Sea to be a myth, reporting the following. The Black Sea was a semi-fresh to brackish (but never freshwater) Neoeuxinian Lake with a level about –100 m below present at the LGM. About 17 ka BP, factors related to deglaciation raised the lake level to –20 m, spilling excess semi-fresh water into the Sea of Marmara and forming a mid-shelf delta at the southern end of the Bosphorus Strait (Hiscott et al., 2007). After ca. 9.8 ka BP, the level of the Black Sea never again dropped below the –50 m isobath, nor did it exhibit fluctuations greater than about 20 m. The brackish Pontic lake ultimately became a semi-marine basin through oscillating Marmara seawater entry, with periodic immigration of Mediterranean organisms with the first wave of immigration at ca. 9.5 ka BP.

Regarding the article of Turney and Brown (2007), it is just a summary of other people's work. They operated with radiocarbon dates borrowed from an incomplete dataset (Gkiasta et al., 2003), the inadequacy of which had been already demonstrated (Dolukhanov et al., 2009), and they totally ignored the cultural and environmental context of the dated sites (not uncommon omissions by non-specialists). They overestimated the sea-level rise caused by a collapsing of the Laurentide Ice Sheet, and they based their modeling on the flawed hypothesis of Ryan et al. (1997) and Ryan and Pitman (1999) of catastrophic flooding in the Black Sea during the Early Holocene. They took it *a priori* that a paleoshoreline of the Neoeuxinian Lake was located at –155 m below present (Ballard et al., 2000) at 7460±55 BP, and that the lake was abruptly flooded at 7940±75 BP. The writers totally ignored the recent debate focused on the 'Flood' problem, including the volume edited by Yanko-Hombach et al. (2007). Based on all these flawed arguments, the writers raised an important question about the causal mechanism of the Mesolithic-Neolithic transition in Europe, which had been repeatedly discussed over the past few years (e.g., Dergachev and Dolukhanov, 2007; Ozdoğan, 2007), but it was totally ignored by Turney and Brown. All this led the writers to erroneous and misleading conclusions that an Early Holocene catastrophic flooding caused an abrupt expansion along coastal and inland routes leading to continent-wide establishment of farming, mass migration of Neolithic people into Europe due to land lost to rising sea levels, and cultural change on a regional scale.

The claim of Lericolais et al. (2007) that the Black Sea shoreline was at –100 m until about 8.5 ka BP is not based on direct dating of the dune-like features at that depth; it comes from CHIRP sonar profile correlation with a shallower core site >100 m distant, where the Holocene section is only ~0.7 m thick. CHIRP sonar profiles have an optimal vertical resolution of 10–15 cm, so, at best, this condensed core thickness means that the age of the dune top could be 9500 BP or older. In contrast, the Holocene cores of Hiscott et al. (2007) are 10–45 m thick and have permitted direct dating of the first transgressive deposits, showing that the shoreline was above –40 m at 8800 BP. This evidence fits the data of Balabanov (2007) and many others perfectly.

Cores of these thicker deposits provide details of the reconnection process, including direct palynological proxy-data for local vegetation and a relatively warm, moist climate (Mudie et al., 2007). These results contradict the data of Lericolais et al. (2007, 2010), who repeatedly claim evidence for a very dry early Holocene climate based on pollen records from their shelf cores, none of which are published as yet.

Badyukova (2010) has recently demonstrated that that there are no opportunities for dunes to persist on the sea bottom under any transgressive scenario, and stratigraphic discordance in this case is regular, and it does not indicate erosion during a catastrophic sea-level rise, as Lericolais et al. (2007, 2010) consider.

The Soulet et al. (2010) paper has serious errors. One of the main issues is that their site is located at –350 m depth, which lies below the halocline, but their model treats the situation as if they were dealing with surface water. The pore water model presented by these authors is based on incorrect assumptions about water stratification in the Black Sea, and totally ignores paleontological (e.g., Nevesskaya, 1965) and micropaleontological (Yanko-Hombach, 2007b) data that, together with palynological data (Marret et al., 2007) show the Neoeuxinian Lake to have been brackish, not freshwater.

From an archeological perspective (summarized in Yanko-Hombach et al., 2007a), no significant cultural changes characterize the archaeological record of the region during the 8.4–7.2 ka BP interval coeval with the proposed flood. During this period, the North Pontic steppe and the Caucasian coast supported Mesolithic forager groups who possessed neither domestic plants nor animals but relied increasingly on aquatic resources, harvesting of wild plant foods, and a lifestyle combining sedentism with seasonal transhumance. Sites cluster in landscapes with diverse and predictable wild resources, especially marine estuaries, lakes, and river floodplains. Even if the Black Sea rose catastrophically and flooded the North Pontic plain, few foraging bands would have been displaced from the now drowned shelf area, considering the low population density typical of steppe-dwellers. Mesolithic and early Neolithic archaeological data in Ukraine provide no support for a sudden cultural shift at the time of the proposed flood (Anthony, 2007). The earliest indications of agriculture come from the Zagros foothills in the Near East: 11.7–8.4 ka BP (Bar-Yosef and Meadow, 1995) corresponding to the cool, dry Younger Dryas climatic period, including the subsequent rapid increase in rainfall at the beginning of the Holocene. Several pollen records of Black Sea shelf cores also show absence of crop growing or animal herding before about 6,500 yr BP (Mudie et al,, 2007) and to date, the only artifact found in outer shelf sediments is one ceramic plate of disputed Neolithic age (Yanko-Hombach et al., in press).

CONCLUSIONS

Barring new and more supportive evidence, one must conclude that both “Flood” scenarios represent a contemporary legend. The intriguing geological and archaeological history of the Pontic region deserves more research and will eventually reward exploration with new discoveries.

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HOLOCENE CASPIAN SEA LEVEL CHANGE AND ORGANIC CARBON CYCLE FROM THE EXAMPLE OF THE KURA RIVER DELTA

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Keywords: Caspian Sea, Kura river delta, Holocene sea level change, organic matter

OVERVIEW OF THE MORPHOLOGY OF THE KURA DELTA

The modern Kura delta is located in southwest Caspian Sea. The delta is the fluvial dominated, and distributes its sediment load through three channels oriented North, East and South. The north flank of the delta is composed of a barrier lagoon complex. The east and south flank of the delta are delta front marsh environments, typical for a fluvial dominated delta. The southern slope has a low gradient. Morphology of the delta slopes here demonstrates classic clinoform geometry.

METHODOLOGY

Several field campaigns in 2001, 2008 and 2009m were organised to acquire the necessary data.

30 offshore shallow sesimic profiles were shot in lines parallel and perpendicular to the delta contours, 40 hand augerings up to 7 m depth were made in the onshore delta, offshore 14 piston cores down to 3 m, 8 wells down to 20 m, and 2 wells down to 35m were drilled. A number of samples have been selected for different type of analyses.

MAIN RESULTS

The offshore delta's Holocene sediments consist up to at least 20 m depth of thinly bedded silty clays and laminated dark grey clays underlain by reddened fluvial clays. Locally sand and shell-rich horizons occur.

The data have given a concise insight in the development of the delta during the last ~10000 years. They show several phases of delta retrogradation during the Caspian Sea highstands, interrupted by erosional phases during lowstands, recognisable in the sesimic profiles as prominent reflectors. The first phase is represented by reddened fluvial clays (Sequence 1) possibly affected by soil formation during a lowstand at –90 m absolute depth dated at 12000 BP. These are overlain by several metres of laminated clays and silts, 14C dated at 9240-5920 BP (Sequence 2).

This succession is truncated by a prominent reflector bounding Sequence 3 (modern delta dated at 1400 BP consisting of thin laminated clays. Sequence 3 consists of four progradational and retrogradational phases of a higher order corresponding to: 1. a lowstand at about –48m absolute depth and correlated with the 11th century Derbent Regression, 2. laminated deltaic clays and silts, passing locally to organic clays with fluvial diatom assemblages; 3. an erosional event, related to a lowstand in the 16th century; 4. last 200 years deposited succession. Onshore delta consists of progradational sequences of channel-levee sands and floodplain silts and clays deposited during gradual sea-level fall and overlain by clays and silts reflecting the last phase of rapid sea- level rise since 1977. Overall sedimentation rates in the delta determined by 210Pb methods range between 1.5–3.0 cm/year.

The amount of Corg in the upper part of the section in the Caspian Sea adjacent to river Kura delta varies from 0.2 to 1.22 % with median values 0.6-0.8 %. It demonstrates that in the sediments deposited during Caspian Sea high stand in 1929 the minimum of Corg content is localised near the mouth of the active southern channel of the Kura River and coincides with minimum of clay fraction. At the same time the maximum of organic matter content locates near the mouth of eastern channel which was inactive that time.

Further southeastwards and eastwards Corg content increases. In section corresponding to the Caspian Sea low stand in 1977 the area of minimum Corg is located at the north near the northeastern distributary. This indicates high activity of this distributary during Caspian Sea fall. The area of C_{org} minimum extends covering also the mouth of main channel and eastern part of the delta. C_{org} maximum shifts toward the basin coinciding with maximum clay fraction. During the Caspian high stand in 1995 the minimum of Corg contents is confined to the mouth of main channel.

Distribution of organic matter in the early Holocene sediments of the Kura river delta also displays the strong time dependence reflecting depositional history of the delta.

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HIGH RESOLUTION SEISMIC STRATIGRAPHY OF THE MODERN VOLGA DELTA, RUSSIA

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Keywords: Volga delta, seismic stratigraphy, Holocene, paleoecology, absolute dating

INTRODUCTION

This research project aims to resolve the small-scale stratigraphy with its great lateral and downstream heterogeneity in the modern delta using novel Very High Resolution marine geophysical techniques capable of working in very shallow water; further methods include (hand) augering, paleoecology and absolute dating techniques. During this study we have obtained a detailed image of the architecture of the Holocene Volga delta, including the location, sedimentary and paleoecological characteristics of major maximum flooding surfaces and sequence boundaries, and their relation to Volga discharge, Caspian Sea level and global climate. This should lead to a better understanding of the way ramp deltas work under conditions of rapid sea level change, as well as to a better understanding of the 3-D architecture of Paleo-Volga delta in the South Caspian Basin.

CASPIAN SEA LEVEL CHANGES

Caspian Sea levels have been less stable than world ocean levels (Rychagov, 1997). The causes and the history of the rapid Caspian Sea level changes are still debated. Currently, the consensus is that tectonic processes and associated crustal movements were the predominant factors in base level change during the Pre-Quaternary. By contrast, during the Quaternary, Caspian Sea level changes were climate-induced, and related to its continental location and isolation from the world oceans. The atmospheric processes over the sea itself and its extensive catchment area directly influence the Caspian Sea level. Sea level regime (hydrologic-water balance) depends to a great extent upon discharge from the Volga River (Overeem et al., 2003) and evaporation at the Caspian Sea surface, especially in Kara Bogaz Bay (Kosarev and Yablonskaya, 1994). Numerous transgressions and regressions have been preserved in the stratigraphic record and as coastal landscape features. The exact ages and magnitudes of these events have not yet been established with confidence. Generally, the available literature only provides data regarding transgressions that have been preserved in high stand deposits found onshore. Data on regressions is sparse.

During the Late Pleistocene-Holocene period, sea level cycles of four orders of magnitude in time and sea-level amplitude have been documented (Kroonenberg et al. 2005). When these processes are superimposed, they have produced the Caspian Sea level time history. It has been deduced that sea levels range between at least GSL + 50 m during the Last Glacial and GSL -100 m during the Early Holocene, with the current level of GSL – 27 m. The most recent cycle lasted only 65 years: sea level fell more than 3 m between 1929 and 1977 and rose 3 m again until 1998. From that year to present day, the sea level has been relatively stable (Ozyavas and Khan, 2008). Interfering processes that influence the Sea-level result in erratic large-scale transgressions and regressions. Thus, the sedimentary facies of the Caspian Basins are characterised by rapid shifts due to the massive changes in coastline position. Superimposed upon this principle pattern are seasonal changes in sea level with May-June maxima that are primarily related to variations in fluvial input.

Holocene deposits in the Volga Delta are restricted mainly to the lower delta front and do not reach more than 5–10 m in thickness, except for incised-valley fills (Fig. 1; Aybulatov, 2001).

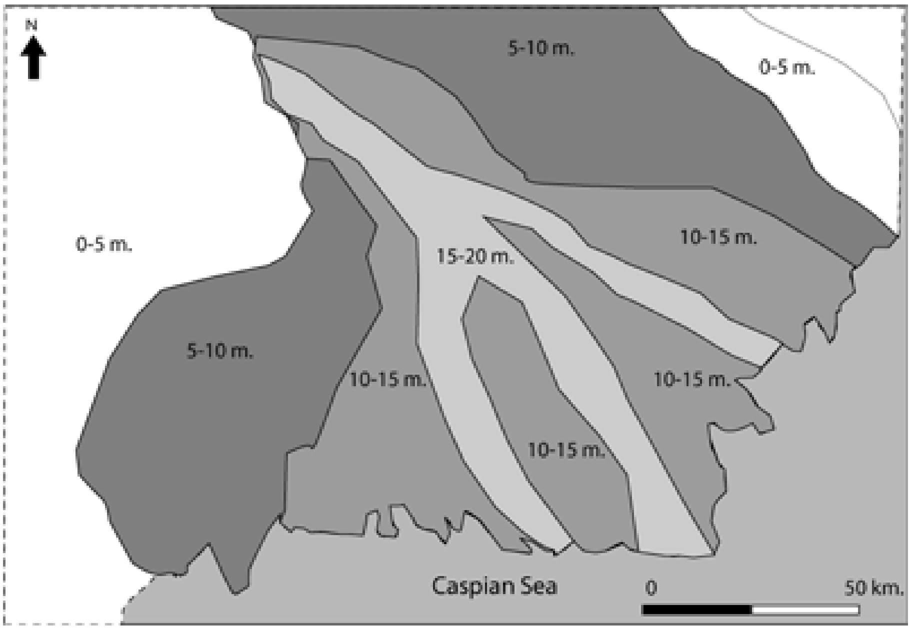

Fig. 1. Thickness of Holocene deposits according to acoustic profiling data by Zaytsev et al. (2002); note incised valleys; simplified after Aybulatov (2001)

They overlie a paleotopography of dissected Baer Hills of Late Khvalyn or Early Holocene age. Data from over 80 augerings in the Damchik part of the Astrakhan Biosphere Reserve near the delta front (Overeem et al., 2003) show a very complex system of small coarsening-upwards prograding levee or mouthbar deposits 1–3 m in thickness and fining-upwards channel fills and drowned levee complexes of the same order of magnitude, all with very little lateral continuity, even though augerings are < 100 m apart. This agrees with the small-scale nature of the distributary-channel network in the modern delta. 14C dates on organic matter, all in the range 6000–8000 yr BP, indicate sedimentation rates of 1–2 mm/y in uncompacted muds, but age data are as yet insufficient to resolve individual sea-level cycles. A sandpit near Damchik in the Astrakhan Biosphere Reserve shows a coarsening-upwards sequence of clays overlain by silty sands and fine sands. The underlying clays have more brackish-water molluscs, whereas the uppermost sandy layers have only freshwater species. A similar trend is shown by diatom assemblages. This corroborates an origin by a prograding delta system in which fluvial sands are deposited on top of brackish prodelta deposits. 14C dates suggest that progradation might have occurred during the Derbent regression, known from historical data to have taken place around 1000 yr BP. Further details are given by Overeem et al. (2003). Holocene sedimentation evidently bears much resemblance to the present lower Volga delta. The presence of several mollusc-rich layers, and ripened and mottled horizons, suggests periodic deposition and soil formation. This might be related to various transgressions and regressions of the Caspian Sea, but the rapid vertical and lateral facies changes and the lack of datable horizons so far preclude the establishment of a precise correlation and chronology.

DATA

New data were acquired during 3 field campaigns yielding ~100 km of shallow geophysical data (2 N-S transects and 2 E-W transects) and 27 cores. From the cores samples were taken for several analyses of which the palynology and 14C dating are the most important.

GEOPHYSICAL DATA

Seismostratigraphic profiling was carried out by Shirshov institute supervised by Oleg Levchenko. The total length of seismoacoustic profiles is ~80 km of which 55 km was acquired in the Damchik area. Apart from the intended reflections intensive multiples from acoustically hard boundaries were recorded in the seismoacoustic sections, mainly from the sea floor and from the first boundary of the section.

The complex and uneven character of the recording in some profiles is probably determined by background noise, vertical and lateral changes in bedding and lithofacies and gas-saturation. On the whole the seismoacoustic sections hyave a high quality covering the first 5-10 meters below the channelbed. The level of multiple reflections is rather high. It complicates the image at greater depth (more than 5-10 m dpending on the waterdepth) and suppresses useful waves. Nonetheless, the quality is sufficient to determine the major elements of the delta geometry and its shallow subsurface.

Figure 2 shows a profiles typical for the Volga delta.

From the seismic sections 6 major seismic facies, and 8 subfacies, could be distinguished.

• Channel-shapes (discontinuous) (2 subsets)
• Convex shapes (discontinuous) (2 subsets)
• (sub) Parallel sets (continuous) (2 subsets)
• Foresets (continuous) (2 subsets)
• Heterogeneous sets (continuous)
• Aggradational sets (continuous)

Furthermore maximum of 3 different surfaces could be recognized:

• The channelbed pending waterdepth,
• first discontinuity,
• Second discontinuity (Also the base of the survey).

The first and second discontinuity were not found in every section of the survey. As a reuslt we could describe 3 systems, The modern present day system which is visible on the survey. As two prior phases of Delta developement at this location

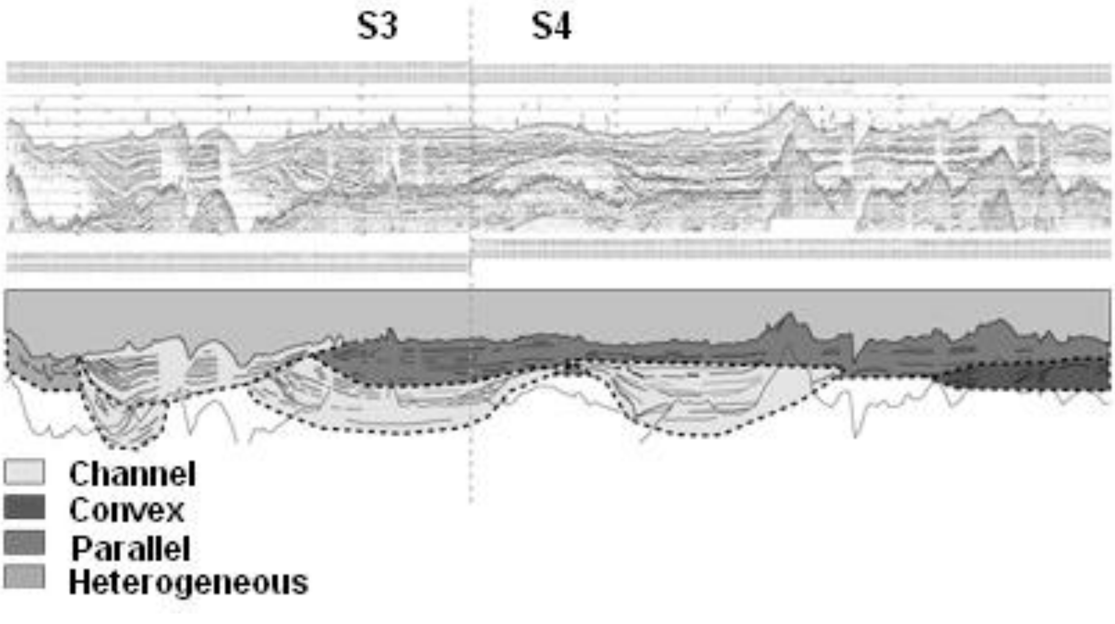

Fig. 2 Subsurface data section acquired at the Damchik Nature Reserve showing 4 types of seismic facies

LITHOLOGY

An onshore survey using a hand-auger has been carried out throughout the Damchik area of the Astrakhan Biosphere Reserve (see data map). The method included the use of casing resulting in a maximum depth of 10m below surface. Lithological data from a total of 25 cores were acquired. Data description included: depth, texture, colour, organic matter conent, prensence of shells (complete or fragments) and sedimentary structures, e.g. layering, laminations and bioturbations. Furthermore samples were taken for 14C dating and palynology.

Table 1

Overview of all lithofacies and associated depostional environment

Lithofacies	Texture	Sedimentary structures	Depositional environment
Brown Sands	Fine-medium Sand	Massive; Within individual beds fining up; Lag deposits at bottom of a bed	Fluvial channels
Dark Grey Sands	Medium sand, well sorted	Massive	Mouth bars
Grey Greenish Sands	Silty-clay to fine sand, badly sorted.	Coarsening up of a single or multiple beds; Some to substantial shell fragments at bottom and middle of sequence	Levee
Dark Brown Clays	Clay-silty clay badly sorted	Soil structure; Macro remains of organic material/vegetation	Delta plain
Dark Grey clays	Clay-silty clay, well sorted	Small beds (dm scale); slightly laminated; Few to abundant shells and shell fragments or shell layers. Regular occurrence of organic rich (black) layers (dm scale)	Distal Delta front / Avandelta
Laminated Silty Clays	Clay, silt and very fine sand	Horizontal laminations and thin layers (mm - cm scale); Few to many shells and shell fragments. Regular occurrence of organic rich (black) layers (cm scale)	Delta front / inter-distributary bay or Kultuk
Heterogeneous sets	Clay to fine sand badly sorted organic rich layers and shell layers	Sequences of sandy and clayey beds 10-50 cm thick, intercalated with clay and silty clayey layers 1-10 cm thick; composition of beds differs in colour and organic content, beds have macro remains of organic material or vegetation. Some beds contain shell fragments	Proximal delta front
Stiff Dark Brown Clays and Sands (Chocolate)	Silty-clay to fine sand	Stiff –very stiff (over-consolidated). Sequences of beds dominated by clayey deposits	Late Pleistocene basement (possibly Khvalyn)

LABORATORY DATA

Palynology: From 7 cores samples were taken for palynology.The palynological zones are based primarily on the pollen and spore components, and are therefore likely to be influenced primarily by local climate and vegetation, as well as depositional and facies changes within the delta itself. Total of 7 Palyfacies were described. Showing distinct lateral and vertical continutiy. The distance between the most northerly and most southerly cores is approximately 20km, and the influence of climate variance within the study area itself is therefore likely to be minimal.

The zones are therefore likely to give a good overall indication of the vegetation (and therefore the climate) at the time of deposition. The influence of sea level change is also important and the effects of sea level rise are shown by the presence of in-situ dinoflagellate cysts (dinocysts). These are not used as zonal indicators, but their distribution (for the most part) corresponds well with the palynological zones assigned.

14C: total of 38 samples were age date using 14C methods showin a rand betwoon 8kyr bP till modern age. Nevertheless three phases of deltaic development were recognized in these data. Including clear transgresional trends. All data from the lithofacies, palynology and 14C give a comprehensive overview of the history of the Volga delta.

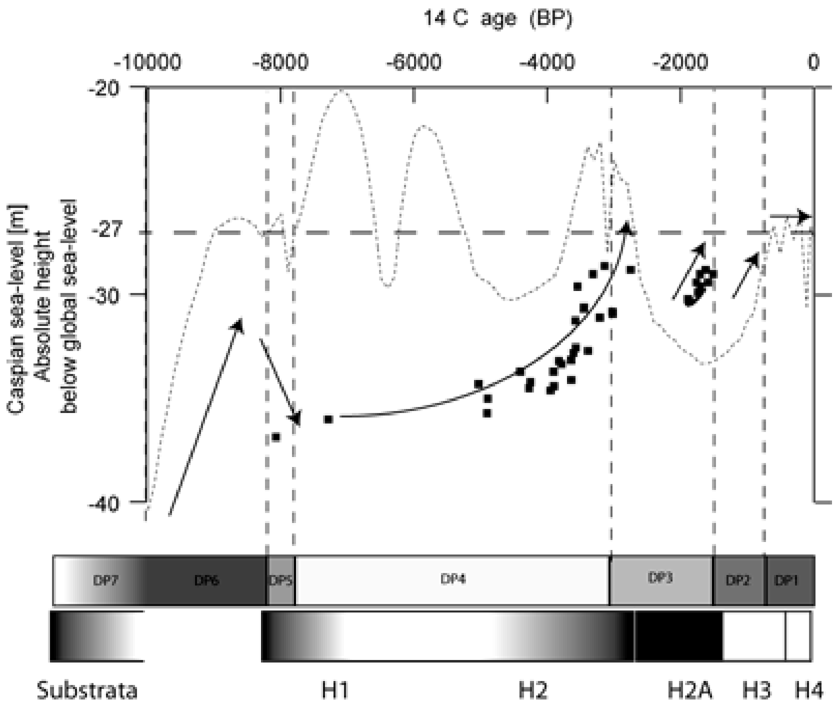

Fig. 3. 14C & palynology data

Fig. 3. Overview of 14C & palynology data plotted vs the interpreted waterdepth during deposition. The arorws show th sea levle trend as interpreted by the palynology data. The fine line is the sealevel curve as proposed by Rychakov (1997). Although similar trends are observed lowstands are more pronounced by these new data for mthe Volga Delta. The colout bar represents the palynological zones, the grey-white bar the 4 phases of delta development that have been identified at the current location of the Volga Delta.

CROSSSECTIONS

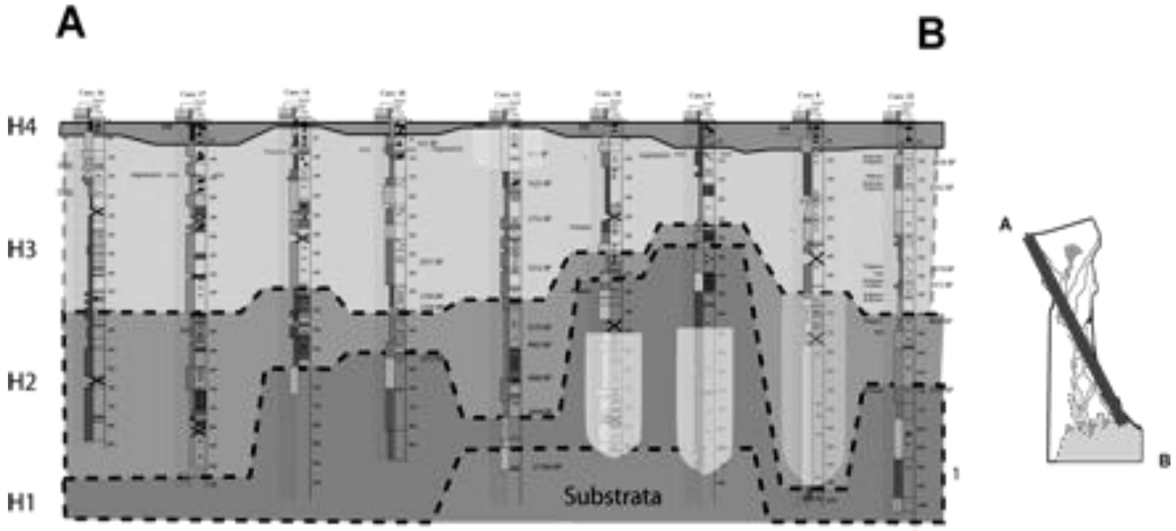

Fig. 4. Crossection in N-S direction, showing the 4 phases of delta develoment through the study area based on all available data. Crossection shows that the layering of the different phases. The influence of the substrata is probably the cause of the lateral variability while the complex sedimentary dynamics in a dwon stream direction is the cause for the verical variability through the area

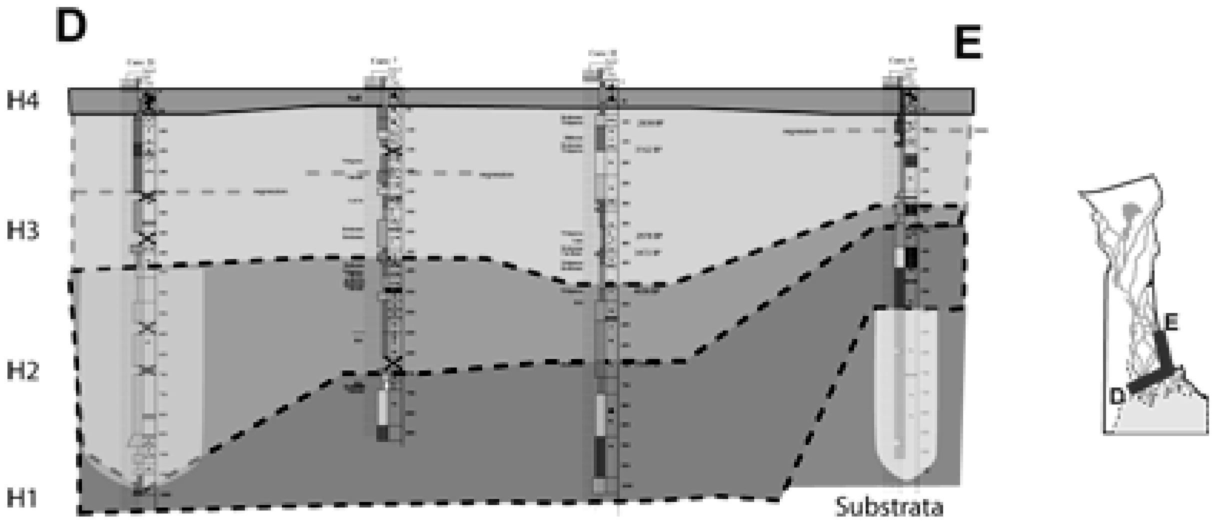

Fig. 5. Crosssection in W-E direction, also showing 4 phases of delta development. Data shows that the lateral and vertical variabilty is lower perpendicular to the flow direction of the Volga River, proof of strong anisotropy of the deposition model

CONCLUSIONS & SUMMARY

All these data have resulted in the recognition of at least 4 phases of deltaic deposition. Each of these phase is driven by rapid sea level change. The oldest phase is the substrata that are dated at 27k y B.P. Coinciding with the Khvalyn (Late Pleistocene) transgression. Next phase is a dated a ~8k yr BP although limited core- and geophysical data of this phase are available, however the palynology data shows evidence of a transgression. Next phase is the 4k yr B.P. delta, covered well by all data and also shows a transgressive setting. The geophysical data revealed that this delta is very similar to the modern day delta regarding geomorphology and active depositional environments. Next phase is the Derbent regression of ~ 1.5 k yr B.P. that reperensents an erosive surface in the stratigraphy. The top section of the delta stratigraphy is a complex that consist of Little Ice age highstand deposits with on top the subsequent regressive deposits and also includes elements in the delta front from the last 3 m sea level cycle that occurred between 1930 and present day.

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EVOLUTION OF THE VOLGA DELTA FOR THE LAST 200 YEARS

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Keywords: estuarine processes, delta evolution, variations of sea level, active and passive delta increment

INTRODUCTION

Evolution of deltas is among of the most difficult and the least studied hydrological and geomorphological processes. Studying of regional specificity of process shows that development of deltas depends on a proportion of river and marine factors, type of offshore relief, variability of level of a receiving reservoir, complexity of structure of deltas hydrographic network and anthropogenous influence. Mouth processes in the Volga delta consolidate different hydrological and morphological processes (change of spatial position of the mouth borders, dynamics of delta marine edge, flow redistribution between systems of water currents, lengthening of delta arms, development of delta bars, etc.). They reflect complex influence of Volga runoff and level of Caspian Sea change on evolution of delta.

EVOLUTION OF DELTA MARINE EDGE

Evolution of the Volga delta and its marine edge is connected with fluctuations of receiving reservoir level (Baidin, 1962; Mikhailov and others. 1978; Richagov, 1994; Kroonenberg et. al., 1997). In these conditions and in geological time scales delta position changes within a zone of the maximum displacements of the delta top in direction to a land, and its marine edge – towards the sea (fig. 1).

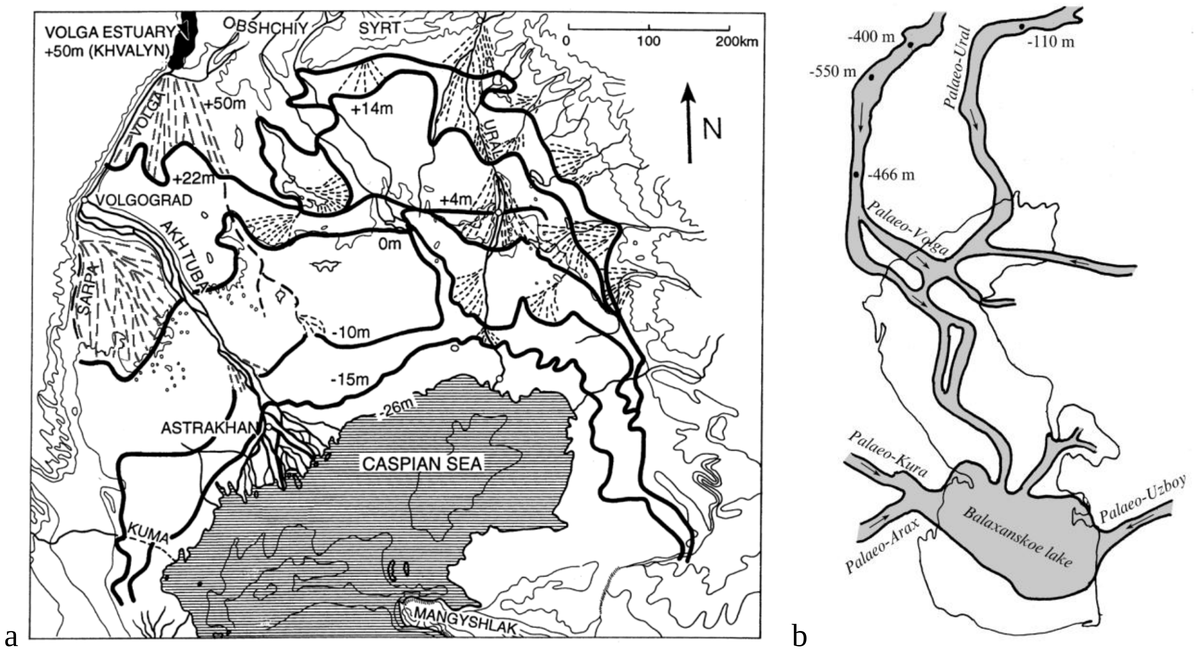

Fig. 1. Influence of Caspian sea level fluctuations on a geographical position of Volga mouth at maximum (a) and minimum (b) sea level (Kroonenberg et. al., 1997)

As a result area F_o, on which inlet processes occur, reaches its own natural maximum. For example, at extremely low level of Caspian Sea the mouth of the Volga river placed in Apsheron peninsula region (Svitoch, Badiukova, 2002). In the conditions of the maximum transgression of Khvalynskiy Sea the top of its delta was in area of a modern mouth of the Kama river.

For the last 500 years level of Caspian sea was not elevated above 25,0 m (Richagov, 1994) and did not fall less than 29,01 m. In this range of the sea level fluctuations the top of the Volga delta was stable placed in near Verkhnie Lebjazhje townAt stable position of the Volga delta top main factor of its evolution is change of its marine edge position. This process depends on fluctuations of Caspian Sea level in a complex way, and also relates with change of water and sediment flow. Generally displacement of marine edge of delta can be active and passive (Mikhailov, 1971). Accumulation of river sediments on the offshore causes active increment of marine edge of delta in the sea. Displacement of marine edge of delta under the influence of level of a receiving reservoir changes is called passive.

Stable position of delta top saves a role of marine and river factors in evolution of delta marine edge. The analysis of the combined time transgressive maps and satellite images (fig. 2) shows that process of marine edge changing of delta passes in several stages (Ruslovye processi., 1994; Alekseevskiy et. al., 2000). They differ, in particular, on intensity of changing the area of the Volga river delta *Fд* and its separate areas during 1817−2010. Dependence $F_д = f(T)$, where T − duration of delta evolution, till 1977 had increasing nonlinear character. As a result area *Fд* has increased almost in 3 times. Speed of increasing *Fд* reached 10−20 km^2/year in 1817−1935 and extremely increased in 1936−1977 (70−140 km^2/year). In separate parts of delta changing position of delta marine edge in general coincide with or differed from a main tendency of delta development. Speed of increment of delta eastern part in 1817−1920 was in 2−2,5 times more (9,0 km^2/year) than speed of increment the western and central parts where it was approximately the same (nearby 4 km^2/year). In 1920−1935 rates of changing of the delta's area (and its parts) coincided with process characteristics for the previous interval of time.

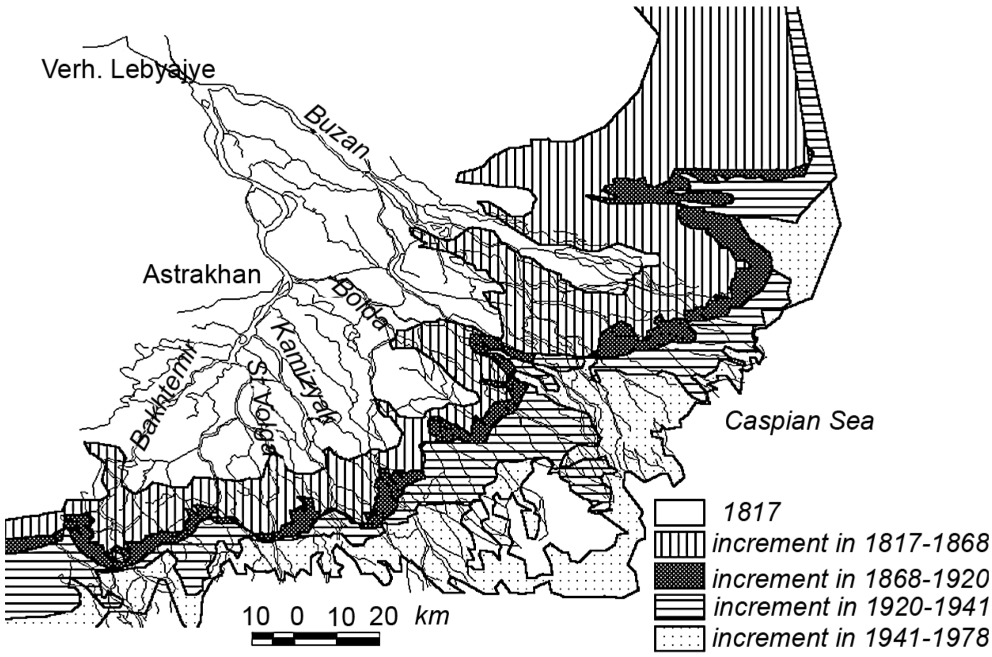

Fig. 2. Evolution of marine edge of the Volga river delta during 1817–2010

After 1935 the maximum speed of increment was observed in eastern part of delta (till 60 km^2/year). In the western and central parts of delta speeds of process were almost in 2 times less. Further speed of increment of the western and central parts has decreased a little (30−35 km^2/year). In eastern part of delta this characteristic has decreased in a greater degree (in 4 times in comparison with the period till 1935). Dependence $F_д = f(T)$ had decreasing character from 1978 till 1995. This period has corresponded to reduction of the delta's area in the conditions of the Caspian Sea level increasing. Thus in the central and east parts of delta position of delta marine edge has not changed. The areas of islands flooding more outshore than marine edge of delta appeared significant only in the western part of delta. The situation also saved after sea level stabilization on marks nearby –27,0 m BS (1995–2010).

The main factor of the delta's area changing in a mouth of the Volga river is the changing of Caspian sea level. Its enduring increasing was accompanied by linear increase of F_∂. It indicates by coincidence of tendencies of changing $F\partial$ at fast (1920−1941) and rather slow (1941−1977) sea level decrease. The maximum speed of increase the area of delta Volga corresponds with decrease in level of Caspian sea from the marks exceeding –25,5 m. In these conditions become more active processes of the delta eastern part increment. Similar consequences occur at decreasing the sea level from marks –27,8 m, when the main investment in increasing $F\partial$ introduces increment of the western and central parts of delta.

There are some periods in development of the Volga delta, when $F\partial$ has appeared like inverse function of sea level H (owing to its increase). Speed of reduction $F\partial$ differed from speed of its increase at sea level decrease owing to floodings. It has appeared considerably less. At sea level position on a mark -27,0 m in 1998 (level increase) and 1937−1938 (sea level fall) the delta area accordingly constituted 8000 and 5000 km^2. The difference in 3000 km^2 characterises process of passive and active changes of the delta area, in which course marks of islands and different parts of offshore are increased owing to accumulation of river deposits. At higher marks of a sea level in comparison with the period of their joining to delta new parts of delta are flooded.

Features of the delta area changing adjusted with change of length of its marine edge L (lengths of the coastal line considering a configuration of all gulfs and peninsulas) rather well. The tendency of increasing L from 1817 till 1998 was perturbed once. After 1977 the length of marine edge of delta has decreased for 123 km owing to rising of sea level. During the period concerning smooth decrease in a sea level dependence between L and time T (calendar years) had linear character: $L = aT + b$ where a = 1,13 and b = –1700 m. The more is sea level, the less is L. On the contrary, reducing of sea level was accompanied by increasing in length of marine edge of delta. The equation of communication between L and H looks like $L = b - a|H|$, where factor a = 54,5 m; b = 1000 m^2. Changing L in time corresponds to changing the area of the Volga's delta $F\partial$. In general case $\Delta F_\partial/\Delta T = \varphi(\Delta L/\Delta T)$. This relation is true for conditions at which change $F\partial$ and L has smooth character. Connection between variables establishes the polynomial equation:

$$\Delta F_\partial/\Delta T = 21{,}6|\Delta L|/\Delta T + 1{,}9(|\Delta L|/\Delta T)^2, \quad (1)$$

From the equation (1) follows that at intensity of increment of the Volga delta $\Delta L/\Delta T$=1, 2 and 5 km/year its area will increase accordingly for 24, 51 and 156 km^2/year.

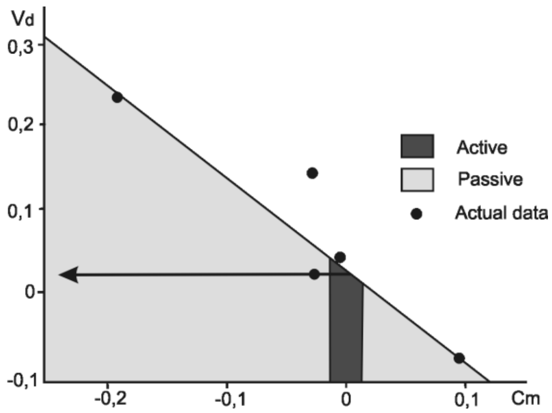

Fig. 3. Correlation of active and passive mechanisms of increment of the Volga delta in 1817–2010 ($V_д = (\Delta F/L_{av}\cdot\Delta T)$, См = $\Delta H/\Delta T$)

Speed of the area changing process of the Volga delta, carried to average length of marine edge of delta $V_\partial = \Delta F/(L_{av}\cdot\Delta t)$ in less degree depends from irregularity of marine edge of delta. This connection allows to reveal relation for mechanisms of evolution of delta at fluctuations of Caspian sea level and of the Volga river flow. Level of Caspian sea influences on speed of increment of delta (fig. 3) quite unequivocally. At small changes in sea level ($\Delta H/\Delta T \approx 0$) it corresponds to active increment of delta, which is equal, in average, 0,02−0,03 km/year. At significant changes in the level ($\Delta H/\Delta T > 0{,}035$ м/год) speed of increment increases owing to passive increment of the delta. If at $\Delta H/\Delta T = -0.05$ m/year this process stipulates for 70% of the general increment (30% of a linear gain of the area are connected with active increment of delta), at $\Delta H/\Delta T = -0{,}15$ m/year the mechanism of passive promotion ensures to 90 % of total size of increment of marine edge of delta speed. In the conditions of rising sea level ($\Delta H/\Delta T > 0$) function $\Delta F/(L_{av}\,\Delta T)$ characterises intensity of flooding of seaside region of delta.

Influence of carrying out of river deposits W_{R+G} in amounts V_∂ is less obvious. At $W_{R+G}<10^7$ t/year in top of the delta specific speed of changing the delta area V_∂ decreases to the minimum significances (0−0,6 km/year). Involving deposits almost does not influence on lengthening of deltoid arms. Increment of delta marine edge is carried out in the conditions of domination the passive mechanism of delta development. If value of W_{R+G} exceeds 10^7 t/year in the conditions of sea level increase, amount V_∂ increases according to exponential law. The maximum amount V_∂ in the Volga river delta is 0,5 km/year. In the conditions of sea transgression recession of marine edge of delta reaches a maximum at the lowered sedimentary flow.

CONCLUSION

Changing of the Volga delta area and its marine edge dynamics depends on joint influence of river and marine factors (Baidin, 1962). In the last 193 years it is basically caused by significant fluctuations of the Caspian Sea level. River factors had the subordinated significance, ensuring minor alteration of process characteristics. Position of delta marine edge, it irregularity and increment in the sea was considerably changed in time. In XIX century developed east part of delta, in XX century − central and western are more actively. Speed of increasing the delta area reached 70−140 km^2/year (at speeds of delta increment of 1,8−2,2 km/year). Rising of sea level from 1978 till 1995 has not led to significant changes in a geographical position of delta marine edge. Connection between changing of the delta area and a sea level has nonlinear character. Under little change of sea level (less than 0,015 m/year) the delta basically is exposed by active increment. If speed of increasing the sea level reduce faster, speed of delta increment increases owing to the passive mechanism of change of position of its marine edge. If level fall with a speed of 0,05 m/year this mechanism stipulates 70 %, and at speed of 0,15 m/year − 90% of total lengthening of deltoid arms. Active increment of the Volga river delta for last two centuries in average constitutes 20−30 m/year.

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SYNCHRONOUS MEASUREMENTS OF ELECTRICAL CONDUCTIVITY, TEMPERATURE AND PRESSURE IN CASPIAN SEA AND THEIR PRELIMINARY ANALYSIS

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Keywords: Caspian Sea, hydrophysical parameters, correlation analyses, spectral analyses

In the recent decades with the development of the space information and computer technologies in studies of the Earth, as a whole, and the oceans and the closed seas, in particular, began new stage. Became possible the accumulation of data from the large territories and the observation of the global processes, proceeding in the atmosphere, on dry land, in the oceans and the seas. These remote data together with contact data, obtained by more precise sensors with the small time averaging and discreteness, make it possible to more deeply analyze the hydrophysical processes, proceeding in the seas, in particular, in Caspian Sea. The number of such contact data which includes the results of the synchronous measurements of specific conductivity, temperature and the pressure, was carried out by the workers of the Institute of Geography of ANAS, together with the colleagues from France and Italy.

These measurements were conducted in the port Absheron within the period since June 12, 2008. until September 11, 2009. The time of the averaging of the measured values was 40 sec., and the time discreteness (the time interval between two sequential records) – 5 min. and were taken $N = 131285$ records on each of the measured values: on the specific conductivity, the temperature and the pressure. Station of measurement was located at a distance by 80 m of the coastline, sensors were mounted on the floor of sea at the depth 12 m. The region of measurement are characterized by the moderate flow and turbulent mixing, noticeable pollution by petroleum products (in essence, as a result the operations of oil pumping from the vessels) and by almost always existing in different degree waves.

The purpose of this work is the preliminary presentation of the results of the spectral and correlation analysis of the measured time series of specific conductivity, temperature, pressure, atmospheric pressure and sea level. Note that measured data are represented in the convenient computer formats and can be easily used by the researchers of Caspian Sea.

THE RESULTS OF MEASUREMENTS AND THEIR ANALYSIS

The dependences of electrical conductivity $C = C(t)$, temperature $T = T(t)$ and pressure $P = P(t)$ on time t are given in Fig.1. In Fig.2a, 2b and 3b the dependence on time t of electrical conductivity, temperature and pressure are given individually, correspondingly. As can be seen from these graphs, the seasonal changeability of the measured values, especially temperature, is clearly outlined. The analysis of correlations between the electrical conductivity *C* and temperature *T* showed that there is almost linear connection. The correlation coefficient R_{CT} is very high and $R_{CT} = 0.96$. However, the correlations between the electrical conductivity *C* and the pressure *P*, and so between the temperature *T* and by the pressure *P* are comparatively low and they are equal, correspondingly, $R_{CP} = 0.51$ and $R_{TP} = 0.54$.

The curve of the time series of atmospheric pressure which was plotted by using the dates from measurements on Pirallakhi island within period 17.07.2008-03.03.2009, is represented in Fig.3c.

Further, time series of electrical conductivity, temperature and pressure with a length of 455 days and the interval of discreteness 5 min underwent spectral analysis. In Fig.4 the spectra (periodograms) $S_C(\tau)$ of electrical conductivity ($\tau = \frac{2\pi}{\omega}$ – period of harmonic, which has the frequencies ω) are given. In the spectrum there is a sharp peak with $\tau = 24$ h, which corresponds to harmonic with the daily periodicity.

Let us note that the average value and the dispersion of a certain assigned time series are calculated from the formulas:

Dispersion can be calculated, also, through the spectrum this time series [1]:

$$\sigma^2_{X,Sp} = \int_0^\infty S_X(\tau)\, d\tau\pi \tag{2}$$

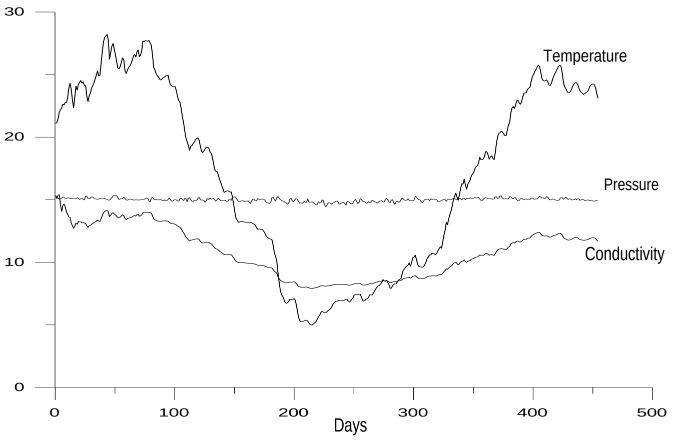


Fig.1. The dependence of the electrical conductivity $C = C(t)$ (mS/cm), the temperature $T = T(t)$ (C^0) and the pressure $P = P(t)$ (dBar) on time t

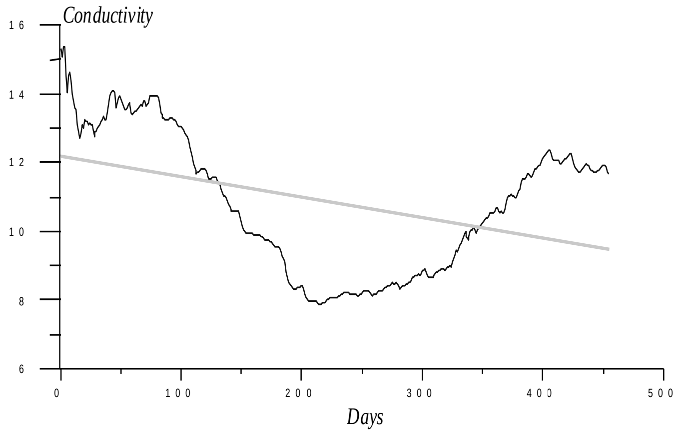


Fig.2a. Dependence of the electrical conductivity $C = C(t)$ (mS/cm) on time t

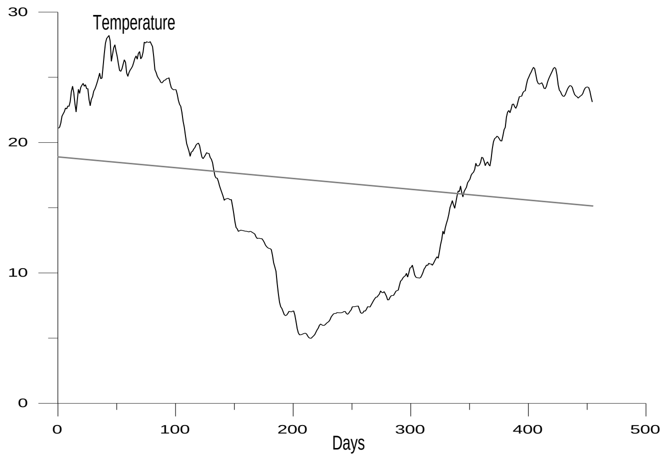


Fig.2b. Dependence of the temperature $T = T(t)$ (C^0) on time t

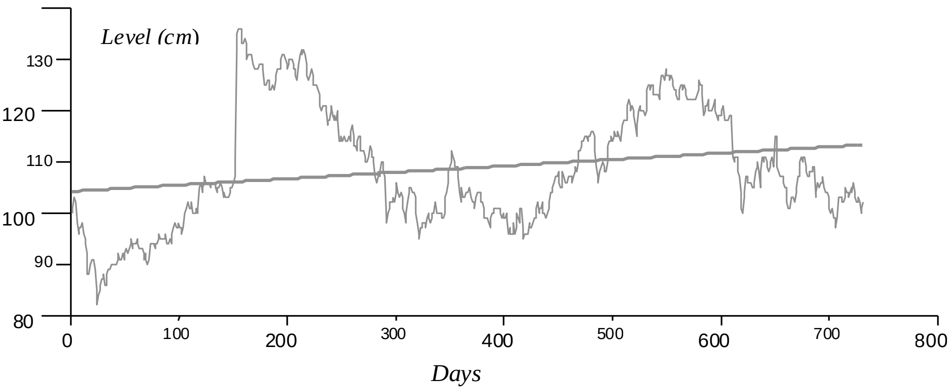


Fig. 3a. Dependence of the sea level $L = L(t)$ (cm) on time t

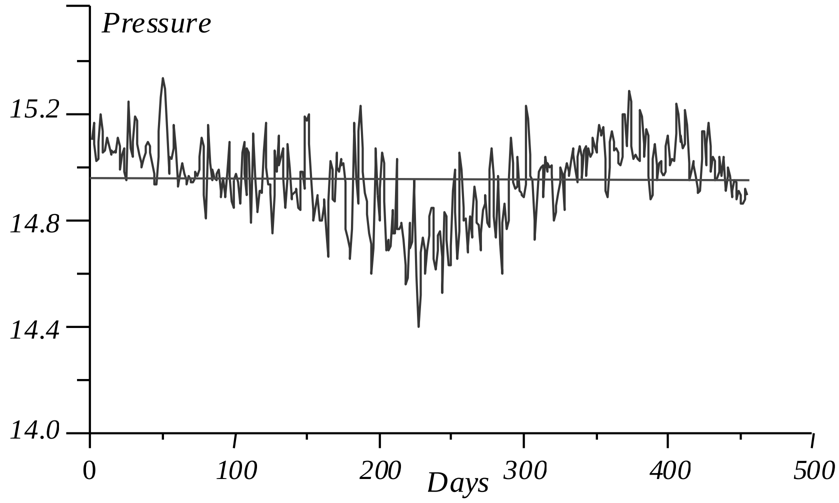


Fig. 3b. Dependence of the pressure $P = P(t)$ (dBar) on time t
(1-st day corresponds to 163 day in Fig. 3a)

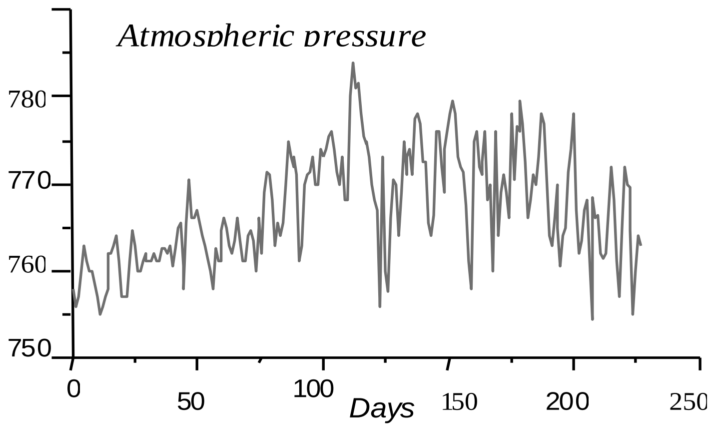


Fig. 3c. Dependence of the atmospheric pressure $P_a = P_a(t)$ (mmHg) on time t.
(1-st day corresponds to 35 day in Fig. 3b)

For the time series of the electrical conductivity $C_i = C(t_i)$ average value and the dispersions, calculated by the formulas (1) and (2), were $\bar{C} = 10.79$ (mS/cm), $\sigma_C^2 = 4.06$ (mS/cm)^2 and $\sigma_{C,Sp}^2 = \int_0^\infty S_C(\tau)d\tau = 4.05$ (mS/cm)^2. Closeness of the values σ_C^2 and $\sigma_{C,Sp}^2$ indicates the high accuracy of the calculations of the spectrum, $S_C(\tau)$, of electrical conductivity. The linear trend of time series of electrical conductivity during entire period of measurements (455 days) is small and is expressed by the equation:

$$\bar{C} = 12.136 - 0.0059256 \cdot t\,, \qquad (3)$$

where the time it is expressed a day ($0 \le t \le 455$ days).

In Fig.5 and 6 the spectra of temperature, $S_T(\tau)$, and pressures, $S_P(\tau)$, are given. As we see from Fig. 5, in the spectrum of temperature are weak and sharp peaks, which correspond to harmonics with the period of 12 h and 24 h, respectively.

For the time series of the temperature $T_i = T(t_i)$, average value and the dispersions, calculated by the formulas (1) and (2) were $\bar{T} = 16.97$ (C0), $\sigma_T^2 = 53.50$ $C0_2$. Linear trend of time series of temperature is also small and is expressed by the equation:

$$\bar{T} = 18.862 - 0.0082848 \cdot t\,. \qquad (4)$$

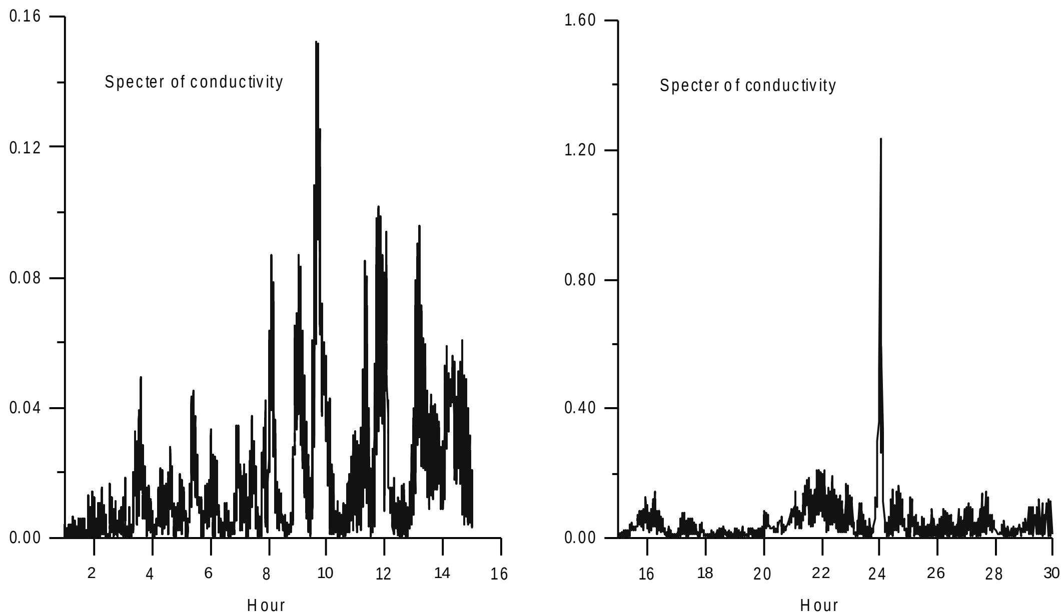


Fig.4. The specter of conductivity $S_C(\tau)$ $\left((mS/cm)^2/min\right)$

However, in the spectrum of pressure are a noticeable maximum at the period $\tau \approx 38\ min$, sharp peak at $\tau \approx 12$ h. and weak at $\tau \approx 24$ h. (Fig. 6). In addition to this there are noticeable maximums at $\tau \approx 12-14$ h. and $\tau \approx 16-18$ h. For the time series of the pressure, $P_i = P(t_i)$ average value and the dispersions, calculated by the formulas (1) and (2) were $\bar{P} = 14.95$ (dBar), $\sigma_P^2 = 0.02411$ (dBar)2 and $\sigma_{P,Sp}^2 = \int_0^\infty S_P(\tau)d\tau = 0.02410$ (dBar)2. Linear trend of time series of pressure is negligible and is expressed by the equation:

$$\bar{P} = 14.961 - 0.000030528 \cdot t\,. \qquad (5)$$

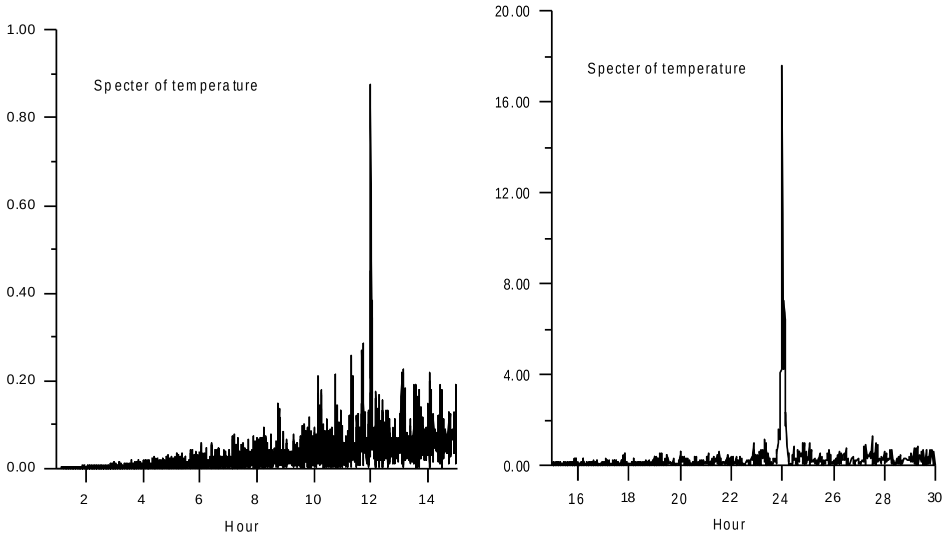


Fig.5. The specter of temperature $S_T(\tau)$ $\left(\left(C^0\right)^2 \big/ min\right)$

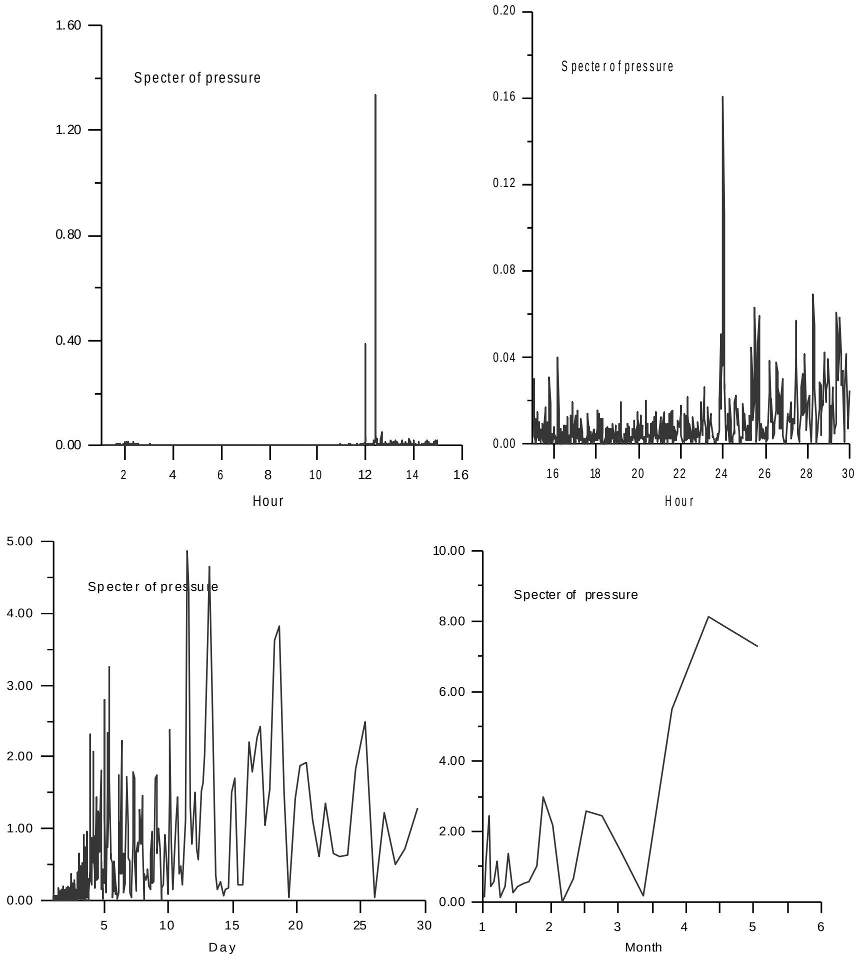


Fig.6. The specter of pressure $S_P(\tau)$ $\left((dBar)^2 / min\right)$

For the exposure of the influence of changes in the atmospheric pressure P_a to the pressure in the water P, thereby to sea level L, the correlation coefficients R_{P_aP}, R_{P_aL} and R_{PL}, correspondingly, between the time series [$P_a(t)$, $P(t)$]; [$P_a(t)$, $L(t)$]; and [$P(t)$, $L(t)$]; with the daily and monthly averaging, were calculated.

The obtained values of correlation coefficients are given in the table.

Table

Values of correlation coefficients

Averaging	R_{P_aP}	R_{P_aL}	R_{PL}
Dayly	–0.029	–0.447	0.568
Monthly	–0.489	–0.883	0.756

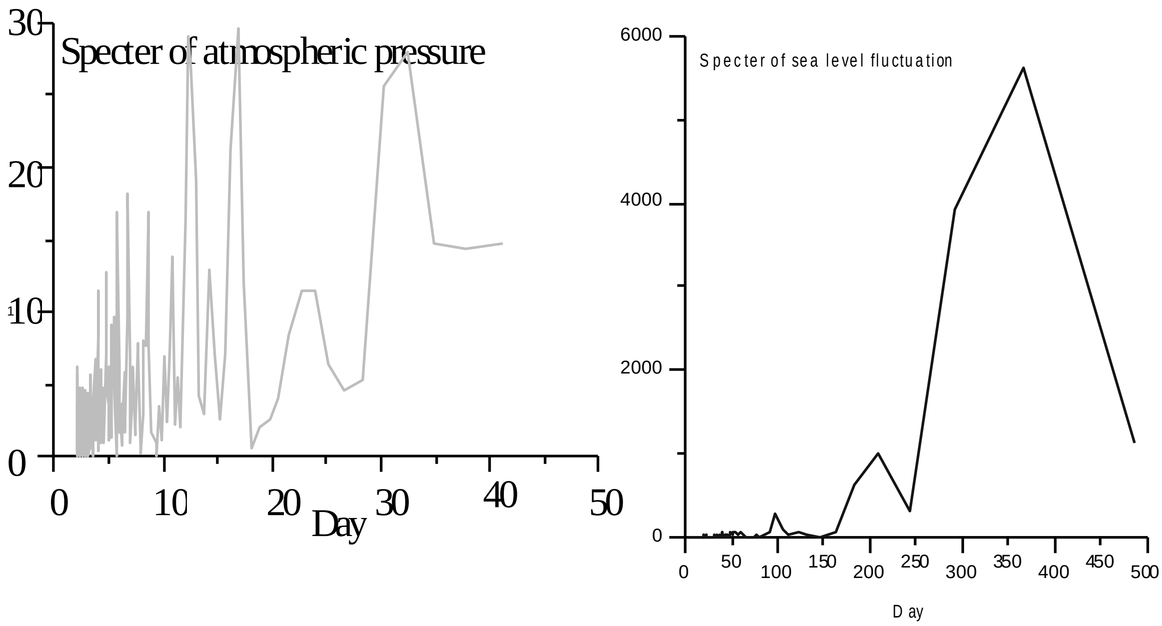
As can be seen from this table the daily variations of the atmospheric pressure $P_a(t)$ and pressure $P(t)$ on the bottom of the sea are very weakly correlated ($R_{P_aP} = -0.029$) quantities, while between the monthly fluctuations of pressures there is a noticeable correlation ($R_{P_aP} = -0.489$). Evidently this is connected with the fact, that the inertial body as sea does no reaction to short-term (day) fluctuations of atmospheric pressure; however, it gives response to its long-period (monthly, seasonal) changes. The negative sign of correlation indicates, that with lowering in the atmospheric pressure P_a, sea level, respectively and the pressure P, rises, and vice versa. This can be noted, also, from Fig. 3b and 3c.

Since, the sea level $L(t)$ and the pressure $P(t)$ on the bottom of sea are proportional quantities, then correlation coefficient between them must be very high. However, in terms of the daily average values of the quantities $L(t)$ and $P(t)$ (Fig. 3a and 3b) it proved to be: $R_{PL} = 0.568$. This, not very high value of R_{PL}, it is possible, is caused by two reasons. Firstly, the measurement of quantities $L(t)$ and $P(t)$ were conducted at the different points of the sea, where the local morphometric characteristics and hydrological regime were different. Secondly, the data about the level $L(t)$, taken from the tide gauge under the almost permanently existing waves, contains conspicuous errors. In terms of the monthly average values of the $L(t)$ and $P(t)$ the correlation proved to be: $R_{PL} = 0.756$. Evidently, the increase of R_{PL} was connected with the fact that with the smoothing decreases the contribution of the short-term fluctuations, which contain the uncorrelated errors of $L(t)$ and $P(t)$.

In the spectrum $S_{P_a}(\tau)$, the atmospheric pressure P_a (Fig. 7a) are obvious maximums at $\tau \approx 12$, $\tau \approx 16$ и $\tau \approx 32$ days. Comparing this spectrum with the spectrum of the pressure $S_P(\tau)$ (Fig. 6) we can assert that fluctuation in the time series $P(t)$ with the periods $\tau \approx 12$, $\tau \approx 16$ days are caused by synoptic changeability of atmosphere. Let us note that the period of inertia oscillations τ_{in}, is determined from the formula:

$$\tau_{in} = \frac{\pi}{\omega_E \cdot sin\varphi} \tag{6}$$

where $\omega_E = \dfrac{2\pi}{\tau_E}$ is the angular velocity of Earth rotation ($\tau_E = 24\ h$); φ – the geographic latitude of observation point.



a) b)

Fig. 7. a) The specter of atmosphere pressure $S_P(\tau)$ $\left((mmHg)^2/day\right)$ and b) the specter of sea level fluctuations $S_L(\tau)$ $\left((cm^2/day\right)$

Calculated according to (6), for the latitude $\varphi = 40^0$, the period of inertia oscillations was $\tau_{in} = 18.6\ hour$. In the spectrum of the pressure $S_P(\tau)$ (Fig. 6), in the hour interval are separated narrow, strongly and weakly expressed peaks that correspond, respectively, to fluctuations of semidiurnal $\tau \approx 12.4$ h. and daily $\tau \approx 24$ h. periods. As is known, these fluctuations are seiche [2]. The amplitude of semidiurnal fluctuation is about 2 cm, and of daily at the level of noise, 3 mm. In the spectra $S_P(\tau)$ and $S_{Pa}(\tau)$, in the daily interval are allotted the peaks, which correspond to harmonics with the periods near by the period $\tau_{in} = 18.6\ hour$ of inertia oscillations. In the spectrum of the level there are clearly expressed harmonics with the annual ($\tau \approx 365$ days), near by the half year ($\tau \approx 200$ days) and seasonal ($\tau \approx 100$ days) periods, apparently caused by the climatic factors: the annual changeability of inflow (in essence from the Volga), by the intra-annual and seasonal changeability of evaporation and precipitations.

CONCLUSION

Let us note that further thorough study of the results of spectral and correlation analysis will allow in more detail and to more deeply understand the physical factors, which influence the measured values.

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A FORECAST OF CERTAIN CHANGES IN THE PHYSICAL ENVIRONMENT OF SOUTH CASPIAN REGION

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Keywords: Caspian region, Iranian coast, physical environment, forecast

INTRODUCTION

Anthropogenic emissions of the major atmospheric pollutants, namely sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3), are increasing rapidly as industrialization proceeds and the use of fossil fuels increases in new geographical areas including the Caspian Region. This causes acidification or eutrophication far from the primary source of pollution, thus making it a regional problem and an international transboundary issue. Abatement strategies based on the critical load concept resulted in substantial decreases of acidic emissions within Europe, which have led to a lower degree of environmental degradation and even recovery in some ecosystems.

The rates of both dry deposition of particles and occult deposition are largely dependent on surface properties and in the case of deposition to forests are rather uncertain [Erisman et al., 1995]. Neither dry deposition nor cloud droplet interception is easily quantified and many studies have been devoted to an assessment of their contribution to total deposition to forests. However, there is a lack of large-scale, long-term measurements in this regard and there is a large gap between the results from field experiments, wind tunnel studies, and model estimates [Ruijgrok et al., 1995].

In the process of establishing critical loads, soil acidification in forests as well as the influence of upland forests on pollutant inputs to catchments needed to be taken into account. Thus, it is important to be able to quantify the atmospheric input to forests in a reasonable way. The quantification is necessary on a local level to make a linkage between modeled deposition estimates and soil loads. Moreover, if the intent is to help protect sensitive areas then there is no substitute for good on-site data [Hicks, 1995].

Wet deposition is known to be rather evenly distributed over large areas and its measurement is more straightforward than the measurement of dry and occult deposition by using precipitation collectors. The exception is in upland areas where orographic enhancement of rainfall occurs and an assessment of the extent of seeder-feeder effect has to be performed.

Several methods exist to estimate the dry and occult deposition to forests on small spatial scales. However, direct measurement of aerosols and cloud droplet deposition is difficult except by micrometeorological methods that suffer mainly from their limitation to certain terrain situations.

This paper reports measurements of the soil inventory of atmospherically derived naturally occurring radioisotope ^{210}Pb and the anthropogenic one, ^{137}Cs, to quantify the effects of aerodynamic roughness and orography on the deposition of atmospheric aerosols as particles and/or droplets. This independent technique may enable improved estimates of the effects of land use on long-term inputs of pollutants in precipitation, cloud droplets or as aerosol.

EXPERIMENTAL METHODS

Natural and artificial radionuclides present in the atmosphere have long been widely used as atmospheric tracers. These radionuclides are associated with nonradioactive aerosols and hence can serve to trace the fluxes of aerosols to various surfaces. Lead-210 and caesium-137 have been shown to be particularly useful because they are associated mainly with submicron-sized aerosols, which contain the bulk of the pollutant sulfur and nitrogen [Vahabi Moghaddam et al., 2000]. The 210Pb isotope (half-life: 22 y) is the decay product of 222Rn, which readily diffuses from soil into the atmosphere. When scavenged from the atmosphere along with carrier aerosols, 210Pb and the atmospheric origin 137Cs (half-life: 30 y) are retained by the surface horizons of soil that acts as an efficient integrating collector. In soils that are not physically disturbed for several decades, its inventory is at steady state. However, a correction has to be made to the inventory to compensate for any 210Pb that is produced by the *in situ* decay of 222Rn.

The long-term average ^{210}Pb concentration in the atmosphere may be considered reasonably constant. Thus, variability in the soil inventory of ^{210}Pb provides a direct measure of the local variability in deposition of aerosols (by wet, dry and cloud deposition). In the case of ^{137}Cs, the area of study should be much more limited.

When a steady state between atmospheric supply and radioactive decay exists, the flux of ^{210}Pb from the atmosphere (F_{Pb}) may be obtained as the product of the decay constant (λ) for ^{210}Pb and the inventory of *unsupported* (atmospheric) 210Pb in the soil profile (I):

$$F_{Pb} = \lambda \quad x\, I$$
$$\text{Bq m}^{-2}\ \text{y}^{-1} = \text{y}^{-1}\ \text{Bq m}^{-2}$$

Its *unsupported* inventory in undisturbed soils may then be used as a measure of total aerosol deposition averaged over about 30 years, approximately the mean nuclear lifetime.

Split-level sampling technique were applied to determine the profiles of ^{210}Pb and ^{137}Cs to a depth of 30 cm at selected locations from within the canopy as well as the adjacent open land in Scotland, Sweden, and Southern Caspian Region over years. The specific activities of ^{210}Pb and ^{137}Cs in dried soil samples were determined by non-destructive γ-spectrometry using high resolution HPGe detectors. Measurement of ^{214}Pb inventories were also conducted in order to make corrections for the *supported* ^{210}Pb [Branford et al., 2004].

RESULTS AND DISCUSSION

Measurement of radionuclides inventories at Dunslair Heights, Scotland, revealed an average canopy enhancement in deposition of approximately 37% (see Table 1), which is found to be consistent with deposition estimates obtained from a long-term continuous record of cloud frequency and meteorological variables, and is also in good agreement with the UK model deposition estimates for the site [Crossley, 1988].

The measured ^{210}Pb inventories at ten sites along a transect in Southwest Sweden (Figure 1) show that the deposition increases quite markedly with distance inland to a maximum in upland sites, (G, H & I) roughly 20-30 km from the coast and decreases by almost 30% relative to the maximum, at a site about 60 km from the west coast (site J). This follows the trend in long-term precipitation variation along the transect. The trend in sulfur wet-deposition calculated from data on its average concentration in rainfall [Granat, 1990] and sulfur deposition estimates by a regional atmospheric dispersion model developed by Langner et al. [Langner et al., 1995] show a similar overall pattern.

The measured radionuclide inventories at six sites along Asalem-Khalkhal transect in the South-west Caspian Region show that the deposition decreases with distance from Caspian Sea shore (-20 m asl) up to 20 km inland at an elevation of about 1000 m asl (locations A – D in Figure 2), then a quite markedly increase of around 70% is observed roughly 30 km from the coast at an elevation of 2050 m asl (location E), and decreases by almost 25% relative to the maximum, at a site about 35 km from the coast at an elevation of 1950 m asl (location F). This follows the trend in long-term precipitation variation along the transect [IMO, 2009]. Considering the topography and meteorological condition of the site, the increase in deposition at locations E & F could be mainly due to seeder-feeder effect and occult deposition enhancement. Location E is a highly exposed site close to the summit looking towards sea, whereas F is located on the opposite front of the mountain, which could have been less affected by occult deposition.

Table 1

^{210}Pb inventories at Dunslair Heights

	Open moorland	Inside the forest canopy		
Sample location	DH1	DH2	DH3	DH4
210Pb inventory (± σ) in Bq m-2	2325 (114)	3121 (557)	3252 (436)	3211 (44)
Increase under canopy		34%	40%	38%
Average increase		37%		

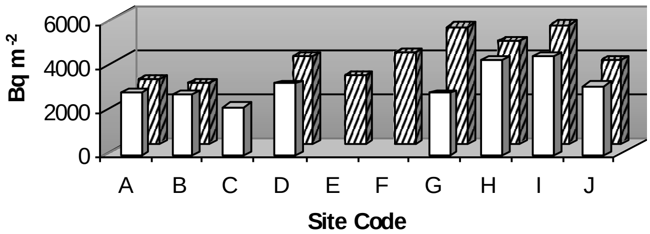

Fig. 1. Mean atmospheric ^{210}Pb soil inventories in the open field (front row) and inside forest canopies (back row) along the SW Sweden transect

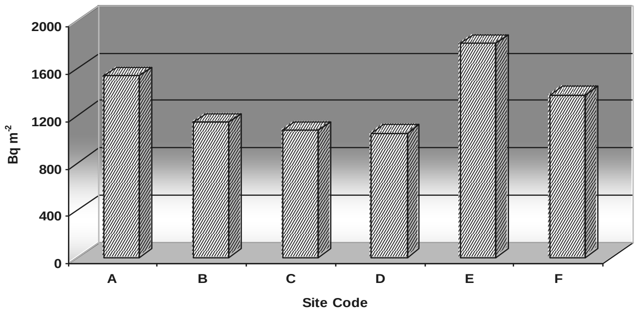

Fig. 2. Mean atmospheric ^{210}Pb soil inventories along the Asalem-Khalkhal transect in the South-Caspian Region

CONCLUSION

The depth profiles of ^{210}Pb in more than 500 collected soil samples demonstrate the efficient immobilization of the radionuclide in the surface horizons of soil and show no evidence of a significant accumulation of atmospheric ^{210}Pb below 10 cm depth. The soil inventories of ^{210}Pb provide a measure of long-term variation in deposition rate of atmospheric aerosols as particles and/or droplets that is operationally easier to carry out than the direct measurement by artificial collectors over extended period of time. It appears to be particularly valuable in quantifying aerosol and wet deposition processes at sites where conventional methods are not applicable.

Based on measurements carried out in this study, it may be concluded that ^{137}Cs has the potential of comparisons within a limited region, but definitely not in-between sites largely as a consequence of the patchy deposition of this radionuclide associated with the Chernobyl ^{137}Cs deposited in 1986. Moreover, it is found that it has a high mobility in highly organic and acidic soils.

Radiotracer study in the South-Caspian Region reveals the susceptibility of high elevated forests of the region to increasing levels of atmospheric pollutants due to anticipated enhancement mechanisms in deposition.

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FORECASTS OF CASPIAN SEA LEVEL AND CLIMATIC CHANGE

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Keywords: Air–sea interaction; climatic change; Caspian Sea level; model; forecast

INTRODUCTION

Investigation of the formation and redistribution of water resources on the Earth's surface is getting more important as recently some catastrophic changes occurred in water resources in some regions, including the Caspian Sea region. The top-priority question understands of the sea level changes causes and possibility of its long-term fluctuations prediction. Fluctuations of the Caspian Sea level (CSL), in its turn, are also a point of interest as an index of a regional climate change, which is connected with the global change. The report evidently demonstrates that present changes of the Caspian Sea level are caused by certain variance of the water balance components and mainly by the river runoff and visible evaporation. That is, to our opinion, the point for the choice of method of the long-term Caspian fluctuations prediction.

ANALYSIS OF VARIATIONS IN THE CASPIAN SEA LEVEL

Analysis of a wide spectrum of publications on the subject of the sea level fluctuations made it possible to specify three main groups of methods.

Methods based on use of correlation connections between the sea level fluctuations on one hand and meteorological, geophysical or heliophysical processes on the other. Prognosis in this case is accomplished when it is possible to reveal temporal shift between the sea level (or components of the water or heat balance of the sea) and the predictor (process which is fit for connection). This group could also include the works on research of the future Caspian Sea level changes using the method of pale analogies and the works studying connections between sea level and the Sun activity characteristics (e.g. with the Wolf numbers) or neotechtonics. Those approaches do not exclude the necessarily for a forecasting of accounting the increasing influence of human economic activity on the Caspian level regime.

In spite of some or other connections being evident, their mechanism and theoretical side of the question still seem to be unclear. Dependences between the sea level and the atmosphere circulation characteristics also not always give an opportunity to make prognoses for a perspective. At the same time it should be noted that in most of the works of the above group the prognosed sea level changes coincided with reality for certain time intervals, i.e. predictions are often successful. But periods of quite close connecting of the average Caspian level magnitudes with, for instance, corresponding indexes of the solar activity or atmospheric circulation indexes are followed by periods when such connection is broken, changes its sign or is absent at all. Actually in spite of quite representative number of publications it is still difficult to expect success in predicting by this way of research. Lower we will make certain that change of the sea level and its water balance components depend on quite a number of factors, i.e. multifactorial processes for prognosing are often connected with just one predictor (though it is quite possible to receive a high correlation between the analyzed processes at some separate sectors of the curves). Forecasting methods connected with use of the Earth rotation angular velocity change as predictor seem to be quite perspective [Sidorenkov, 1982]. Changes of the rotation angular velocity might take place due to redistribution of mass on the Earth and in the atmosphere in time. Being a reflection of some or other mass redistribution the angular velocity could be considered as an integral index of changes of main processes going on the Earth. At least sharply definite changes of 1978 and 1996, when the certain Caspian level changes took place, are clearly seen on a curve of the astronomical day duration change.

Second group of forecasting combines stochastic and dynamically-stochastic models, the essence of which is the probable description of the sea level fluctuations based on understanding of generating climatic and hydrological factors as the stochastic processes. Stochastic water body model is usually considered as mathematical model of the water level fluctuations in a reservoir interpreted as a hydrological system with two income processes – river inflow and visible evaporation from the water surface. Modeling of those characteristics rows allows to study the sea level variability in natural conditions of the hydrological regime forming as well as under its different irregularities. Linear dynamically-stochastic model is widely acknowledged for description of the Caspian Sea level fluctuations (supposition of the linear dependence of the sea surface area on its level, what in case of the Caspian Sea is accomplished according to A.V.Frolov [2003] with sufficient approximation).

Not less important assumption for that models class is hypothesis about stationary of the river inflow and visible evaporation, though bringing to strongly unstationary realization of the sea level fluctuation. Stated should be that the determinant for the predicted conditional mathematical expectation for the sea level is admission of some or other average water balance magnitudes relationship.

Long-term prognosis of the Caspian Sea level fluctuations should be based on prediction of the main sea water balance components: summary river flow, subsoil flow, visible evaporation from the sea surface, irretrievable losses from the water flow into the sea. Stochastic character of the long-term fluctuations of the sea-water balance components presumes only probabilistic estimation of the sea level regime parameters for perspective, and these estimations should be considered as tentative.

Decrease in the Caspian Sea level was predicted by Ratkovich [1994], contrary to that, of Golitsyn et al.[1998] (where a similar approach is used) the sea level was supposed to rise up to 2010.

Probably the nature of the (CSL) change is too complicated to solve the problem of its variability prediction within the frames of the linear dynamically-stochastic model. At the same time we should mention that the followers of stochastic modeling seem to feel rather critical towards the first group of publications (though they motivate this criticism rather logically).

Principally new ways for the long-term Caspian level change forecasting become possible with the use of the big climatic models, which are being actively developed during a last decade due to solvation of problem of the global and regional climate changes. With that modeling of the Caspian level fluctuation changes of a regional basin climate are considered according to the global climate change.

Global modeling studies of the Caspian Sea level (CSL) response to climatic forcing are reported by Mokhov et al. [2003, 2005], Arpe et al. [2000], Arpe and Roeckner [1999], and Golitsyn et al. [1995].

Using results from future GHG scenario experiments performed with the MPI-ECHAM4 AOGCM, Arpe et al. [1999] analyzed changes in the hydrological cycle over several basins, including the one of the Caspian Sea. They estimated a rise in CSL because of increased runoff from the Volga basin resulting from a change in the winter circulation bringing more precipitation over the region.

However, the authors were careful to note that the robustness of their results was limited by the relatively coarse resolution of the model (2.5º horizontal grid resolution) and the fact that the Caspian Sea was not represented at this resolution. Similarly, using 21st century simulations from global climate models, Mokhov et al. [2003, 2005] found increases in winter precipitation over northern Eurasia including the Volga and Caspian basins.

Later Elguindi and Giorgi [2006] calculated possible changes in CSL for the 21st century under different greenhouse gas (GHG) emission scenarios (the IPCC A1b and A2). The majority of models predict a steady decreasing trend in the CSL under both scenarios, with no period of stabilization or recovery. Only two models predict an increase in the sea level, the CNRM-CM3 (A2 and A1b) and the CSIRO-MK3 (A2 only). This large CSL response is due to a large increase in evaporation over the basin.

New climate change studies of this region (accomplished by Meleshko et al, 2008) show that according to the 7- models' (IPCC) composition of the general atmosphere and ocean circulation there will be practically no change of the Caspian Sea level in the XXI century.

Evaporation over the sea is a very important component of the basin water budget [Panin, 1987, Golitysn et al., 1995], and for the ensemble average it comprises over 40% of the total evaporation-transpiration contribution to CSL change. Differences in how evaporation is parameterized in the models can have a significant effect on projected changes in the CSL.

The previous investigations [Golitsyn, Panin, 1989] have shown that changes in the water-balance components account for only 90% of the current sea-level variations of the Caspian Sea. There may be a number of factors that induce the indicated imbalance, but we supposed that it could have been caused by an insufficiently correct calculation of the evaporation from the shallow northern Caspian. An overview of the methods of calculation of evaporation and the heat and energy exchange has demonstrated that the state-of-the-art models of the heat and mass exchange between a basin and the atmosphere do not take into account the small-scale interaction between the shallows and the atmosphere. The point is that waves in shallow water are steeper than in the open and deep-water parts of the sea and break earlier (at lower wind speeds). These peculiarities must lead to an increase in the aerodynamic roughness of the water surface and, consequently, to a more intense turbulent exchange of momentum, heat, and moisture. It is possibly due to these conditions that the Kara-Bogaz Gol, after it became isolated from the Caspian in 1980, was drying up almost twice more rapidly than expected. The overview has also shown that a reliable method of estimation of the evaporation and heat exchange of shallow lakes and coastal areas does not exist so far. Investigations have been carried out both experimentally and theoretically.

We now consider the new estimates of the role of the depth in evaporation from the northern Caspian. According to ([Panin et al., 2006]1), in natural conditions (within the range of actual wind velocities) evaporation and friction velocity from shallow waters theoretically might exceed by more than 1.5 times its usual magnitudes for deep waters.

Overall, our theoretical generalizations and experimental investigation of the role of the basin depth in the intensification of evaporation, heat exchange, and water-surface friction and first estimates of the role of this factor in the evaporation from the northern Caspian strongly suggest that the new model is universal. On the one hand, the results indicate a significant influence of the basin depth on the intensity of energy exchange in natural conditions. On the other hand, the examples presented illustrate a good agreement of the model calculations with experimental data. In real conditions, with the use of direct data on the depth, area, and wind frequency, the correction for the shallow-water effect gives an increase in the resultant evaporation from the northern Caspian above 10%.

Principal features of rearrangement of the surface atmospheric circulation in the Caspian Sea region. Here, it is supposed to develop investigations of temporal variability of local hydro-meteorological characteristics and of their possible connection with global climate changes.

Let us write the system of two equations:

$$dH/dt = RF + P_L - E_L + GF, \tag{1}$$

$$dW/dt + AF1 - AF2 \approx P - E \tag{2}$$

Equation (1) characterizes the water balance of the closed water body. Equation (2) characterizes the region water balance, including the water body itself and its basin. In equations: RF- river run-off, GF – underground run-off, W – moisture content of atmosphere above the basin, AF_1, AF_2 – horizontal moisture fluxes.

Let us assume, as in the case of the Caspian Sea $GF \approx 0.01E_L$, we find that the water level change may be determined from:

$$dH/dt \approx dW/dt + AF_1 - AF_2. \tag{3}$$

From (3), in particular, it follows that the water level change essentially depends on horizontal transfer of the air mass, and the direction of its transport.

Thus, as we have shown, the above analysis in combination with the trend of wind velocity value, gives us a basis to assume the possibility of the certain trends existence and wind direction changes in the environments of the Caspian Sea. Clarifying of these circumstances is the primary task of new investigations to find out the causes of the Caspian basin evaporation, precipitation and sea level changes.

The investigations of Panin et al. (2003) allowed diagnosing the formation and development of steady directional changes in the intensity processes of interaction between the underlying surface and the atmosphere (including evaporation) in the Caspian Sea region during nearly the 20-year period of the sea level rise. It is found that the global climate nonstationarity manifested itself in the Caspian Sea region during the last decades in the essential rearrangement of the surface atmosphere circulation. In the region as a whole, a tendency towards a decrease in the wind speed in the surface layer of the atmosphere is observed.

Against this background, trends in the mean monthly wind speed vary with wind direction and season. A steady, statistically significant trend towards a decrease in the speed magnitude of the winds of zonal directions is found. The above results show that in the studied region a steady, statistically significant decrease is observed in the speed of surface winds of meridional directions, where speed is about 20% higher than the speed of winds of other directions. This rearrangement of the atmospheric dynamics in the interaction layer is the physical basis for the formation and development of present tendencies in the rate of interaction between the atmosphere and the underlying surface and, as a consequence, in the Caspian Sea water regime.

Summing up the results we note that for predicting of the sea level change it is important to consider not only the temperature influence but also the cyclic specifics of the air fluxes movement (changes of direction and velocity of the surface wind). Moreover, transfer of the atmosphere circulation brings to even more significant evaporation changes (approximately by 3 times) than those of the regional warming in the 21-st century.

The estimates of possible climate changes in the current century made with the use of numerical models of general atmospheric and oceanic circulation, which yield a linear or logarithmic dependence between changes in air temperature and the concentrations of greenhouse gases in the atmosphere can be essentially modified if the formation mechanism of climate changes connected with round-robin mechanism is accounted for in the models. This approach to the problem of the Caspian level changes prediction is rather laborious method though quite promising.

Our new scenario [Panin 2009, Panin et al. 2009] of possible climate changes during the XXI century, based on composition of the “greenhouse” and “cycling” effects practically represents the linear temperature growth which is complicated by quasi-periodic changes of the 30 years period. From it follows that differing from the IPCC prediction according to which continuous temperature increase should be expected in the northern polar zone, there already came the period of temporal cooling, which according to our scenario, would be in approximately 30 years replaced by the drastic warming. The amplitude of quasi-periodic fluctuations should decrease with moving away from the poles and, getting closer to the tropical zone, the suggested scenario of the temperature change will practically not differ from the IPCC prognosis.

Such a scenario will most likely be realized also for the Caspian Sea. It could be expected that approximately up to the 2030 year the sea level will slightly go down, after what a new 30-years sea level increase will start.

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CASPIAN SEA LEVEL CHANGES AND ECONOMIC ACTIVITY (IMPORTANCE OF GEOMORPHOLOGICAL INVESTIGATIONS IN SOLVING THIS PROBLEM)

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INTRODUCTION

Caspian Sea level has long been a subject of scientific interest. It received special attention after 1929 due to a fast and significant sea-level drop (between 1929 and 1977 the sea-level dropped from -25,9 m to -29,02 m absolute scale, that is by more than 3m). Later in the 1980s and 1990s, this interest was caused by a rapid and significant sea-level rise (2,36 m between 1978 and 1995 reaching an absolute level of -26,66 m in 1995). Such sea-level changes could not but influence the infrastructure of the economic activity and living conditions for people in the coastal areas. In fact, the sea-level drop in 1930-70s caused the exposure of a territory of more than 48 km^2, which exceeds the entire area of countries such as Denmark or Estonia. The subsequent sea-level rise in the end of the century caused flooding of territories larger than the size of Belgium or Moldova.

The sea-level drop in 1930-70s led to a number of negative consequences (7). Fisheries suffered the most due to sharp decrease in the fish feeding areas and decrease in natural spawning grounds. In the 30s when sea-level was -26 m on the absolute scale, out of the entire fish yield, which comprised about 500 thousand tons, almost 90% were fishes of high commercial value (sturgeons, ordinary large fish, Caspian roach, herring). In the 70s, when Caspian Sea level was -28,5 m on the absolute scale, out of the same fish yield, valuable fishes comprised slightly more than 20%, mainly due to artificial breeding of sturgeons. The forecast was for further sea-level decrease. This was the dominant scientific standpoint in those days, which was officially accepted by decision of the special section of the USSR Academy of Sciences (1933), which was devoted to the problem in the Volgian-Caspian area. Accordingly a plan was developed to block the connection via the strait of the Caspian Sea and the Kara-Bogaz-Gol Bay.

This was implemented only in the 1980s, when the Caspian Sea level already started to rise. Another project planned in those days aimed to partially re-direct the northern rivers runoff to the Caspian Sea basin, and this one also had just commenced in the 80s. Another example demonstrates the existing predictions of the 70s. According to a feasibility study for the re-direction of the water flow from Pechora to the Volga River (Gidroproekt, 1975), the calculated sea-level values of the Caspian Sea were: -28,95 m absolute scale for 1985, -29,3 for 1990; and -30.1 for 2000, while in reality the sea-level was at an absolute level of -27,1 m, that is 3 m higher than forecasted.

Nonetheless, much worst damage to the economic activities was caused by the Caspian Sea level rise in the 1980s to early 90s (7). Large territories, especially in the northern (flat country) part of Dagestan, Kalmykia and Astrakhan regions became the flooding and underflooding zones. Sea-level rise negatively impacted the cities of Derbent, Kaspiysk, Makhachkala, villages of Sulak, Kaspiyskii (former Lagan') and other smaller populated areas. Major areas of the farmlands, situated on the inundated areas after the 1929 sea-level drop, were flooded or underflooded. Roads, power lines, engineering structures of industrial plants and public utilities were washed-out and underflooded. Fish farming in the Volga Delta was on the brink of collapse. Dominance of negative consequences over the positives (such as increase in the catch of the Caspian roach, herring and pikeperch as a result of the improved conditions for their reproduction) made many people talk of the ecological catastrophe. Measures to protect the national economic property and settlements from the advancing sea were starting to be developed.

CAUSES OF SEA-LEVEL CHANGE

Analysis of recent sea-level changes in the Caspian Sea and their economic consequences result in three major questions: 1 – How unusual are these sea-level changes? 2 – What are the reasons for sea-level change? 3 – Is it possible to forecast the Caspian sea-level for the nearest and distant future and how important are geomorphological investigations in solving this problem?

Paleogeomorphological reconstructions, based on multiannual detailed geologic and geomorphologic investigations of the Caspian coast, show that temporal sea-level changes of the Caspian Sea is a normal phenomenon of the unstable state of the enclosed body of water with changing conditions at its outer boundaries. Therefore, there is nothing unusual in the recent sea-level changes of the Caspian and, from the viewpoint of natural history such changes are not leading to an ecological catastrophe.

Among the mechanisms influencing the Caspian sea-level change are geological and climatic forces. Geological mechanisms include, on the one hand, processes leading to the changes in the basin volume (tectonic activity, sediment accumulation), on the other hand processes affecting the Caspian water balance (submarine discharge of groundwaters, or the other way around, absorption of the waters by the underground layers during the alternation of tectonic phases of compression and expansion).

There are no grounds to consider that Caspian Sea level changes as a result of sediment accumulation decreasing the basin volume. Firstly, this is a one-way process, while sea-level change is an oscillating process. Secondly, the rate of sediment accumulation in the basin is several times slower than the observed rate of the sea-level change. According to available data, modern sedimentation rate is 1 mm/yr, and average rate of the Caspian Sea level rise in 1978-1995 was 13 cm/yr and in certain years (1979, 1991) exceeded 30 cm/yr. As one can see, these values are incomparable. (By the way, it is noteworthy, that the increasing water use from the rivers supplying the Caspian in the first part of the XX century was to have influenced sea-level and could led to its decrease and not to its rise, which started in 1978.)

Seismic deformations, which are registered only in the vicinity of the earthquake epicenter, and become weaker with increasing distance, cannot have any significant influence on the volume of the Caspian Sea basin (2). Similar to seismic deformations, changes in the bottom surface occur as a result of the mud volcano activity, but they occur locally and cannot affect the sea-level.

Among geological factors, controlling the sea water balance is the groundwater outflow. The majority of researchers consider that the groundwater outflow comprises an insignificant part out of the total (the surface outflow is 4-5 km^3) and cannot significantly affect the sea-level, especially, since according to the available data, the total outflow amount is a relatively constant value. However, in a number of publications (8) there is a hypothesis that the alternation of tectonic compression and tension in the rocks underlying the Caspian Sea floor leads to either squeezing of the waters out or to their absorption, which results in changing sea-level. At the moment there is no evidence supporting this hypothesis.

According to (1), there is a contradiction, which is undisturbed stratification of the silty waters, pointing to the absence of major migrations of the water through the bottom sediments. Secondly, for the flows to possibly change the sea-level, we need to allow for such high volume and speed for squeezing the water out, as well as for their own different temperatures, degree of mineralization, brine content (during the period of sea-level rise more than 900 km were added, R.G.), that in these areas there must be massive hydrological, hydrochemical and sedimentation anomalies. And, as far as we know, there have not been registered any of such anomalies on the Caspian bottom waters. It is also noteworthy that the mechanism of periodical large-scale groundwater unload into the Caspian has not been yet explained according to geologists themselves (4).

The question of the tectonic influence on the Caspian Sea level is more complex. Undoubtedly tectonic activity played the defining role on the initial stages of the sea basin depression formation. Tectonic activity was also important in its later evolution, which is evidenced by the deformation of the ancient Caspian marine terraces and location of synchronous layers of shallow-water marine sediments at different hypsometric levels, or for instance the east-western shift of the Caspian basin within the Quaternary period by tens of kilometers. Anomalies of the geodesic and sea-level measurements support the tectonic hypothesis. According to these anomalies, tectonic movement rates can reach 5-7 cm/yr, and can significantly contribute to the sea-level change. However, if one takes into consideration, that the Caspian basin depression is located within the geologically heterogenous territory, and as a consequence these movements will have a non-linear, periodical character with multiple changes in direction, that is not very likely that it will lead to high amplitude changes in the volume of the basin. Such type of movements will eventually lead to self-compensation.

The fact that coastal forms of the New Caspian transgression along the entire Caspian coast (except for some brachyanticline folds within the Absheron Archipelago) are located at the same hypsometric level evidences against the tectonic hypothesis. Stability of the volume of the Caspian basin depression during the Holocene was confirmed by another special investigation (5).

The main factor defining the Caspian Sea level in the Holocene and during the last decades is the climate change within its basin and water area. Multiple data from field and laboratory studies prove this.

Thus, comparison of transgressive and regressive horizons of the bottom sediments in the Caspian Sea shows that they were accumulated in different environments: during the transitions from warming or cooling, increasing or decreasing humidity (1). There is a tight link between the components of the water balance, which was pointed out by many researchers, and also supports this point of view. Climatic or water-balance concept of sea-level change in the Caspian is supported by quantitative data. Within the centennial period of observations of the Volga River runoff, the correlation coefficient between the sea-level and the differential integral curve of the Volga runoff was 0,73. Volga runoff comprises not less than 80% of the entire river runoff to the sea and about 70% of the incoming part of its water balance. If we exclude years with small sea-level changes (1900-1928), then the correlation coefficient will rise up to 0,85. But if for the analysis we select periods with fast sea-level drop (1929-1941) and sea-level rise (1978-1995), then the average correlation coefficient will be 0,987 (3). According to calculations, these results will remain the same even if we start our estimation of the runoff and sea-level not from the year 1900, but from any other year. That is, to prove the causes of Caspian Sea level change, at least during the periods of its fast rise or drop, it is sufficient to analyze the link between the levels and ordinates of differential integral curve of the Volga runoff and there is no need to use geological hypothesis. Quantitative link of the sea-level with water balance is well traced when comparing the calculated values with actual increment of the level: it varies between 0,3 and 1,8 cm/year. All abovementioned does not imply that there is no need to study other factors, which in the interaction between each other in different circumstances can influence the sea-level.

PREDICTION OF THE SEA-LEVEL STAND

We still need to answer the third and the most important question about the forecast of the Caspian Sea level. As a result of recognition of the climatic nature of the Caspian Sea level changes within the last century, the forecasts of the sea-level were mainly based on water balance estimates. There were a lot of such forecasts, but since they were based on probabilistic methods, they did not achieve good results for the lack of the theory and absence of training in long-term forecasts of climate change on vast territories. The same way, consequences of the supposed climate warming are clear neither for the Caspian basin depression, nor for its water area. Slightly more reliable are the forecasts based on Solar-Earth linkage and the changes of the global atmospheric circulation.

To solve the question of the Caspian Sea level we are using the paleogeomorphological approach, based on the detailed study of the geologic and geomorphological structure of the coast. Upon studying the areas close to the mouths of the river valleys in the Dagestan and Azerbaijan coastal areas of the Caspian, and upon establishing the absolute levels of the basal horizons of the ingressive New Caspian terraces, which include marine and alluvial sediments, we came to the unpopular conclusion in the 1970s that the Caspian Sea level, which at the moment was at the level of -29 m, was not going to go down any more and was more likely to rise. This forecast, as we know now, proved to be correct (this method is described in detail in chapter 6).

In the last decades of the XX century, when the Caspian Sea level started to rise, in the majority of studies the forecast was for almost linear or even accelerating sea-level rise reaching -25 or even -22, -21 m on the absolute scale for the beginning of the XXI century. The paleogeomorphological method in this case also allows a definite point of view. Based on our data on hypsometry and structure of the ingressive terraces in the mouth areas of the rivers falling into the Caspian, together with tacheometric levelling of the New Caspian marine terraces and the data on the absolute geochronology, we came to the conclusion, that within the last 2,0-2,5 ka, that is from the beginning of the Subatlantic chronozone of the Holocene, the Caspian Sea level was never higher than -25 m on the absolute scale. It is well-known that at about 2,5 ka there was a transition from Subboreal to Subatlantic chronozones. Since then the formation of the modern natural environment for the territory of the Caspian basin started, and correspondingly also of the modern or similar to modern water balance properties, which allows us to extrapolate our paleogeographical data to the modern epoch and to come to the following conclusions:

CONCLUSIONS

1. In the nearest future the Caspian Sea level will not exceed -25 m on the absolute scale, and considering economic activity and peculiarities of the coastal relief it is not likely to exceed -26 m on the absolute scale. This forecast is being confirmed: since reaching the level of -26,6 m in 1995, the Caspian Sea level

has dropped by 0,55 m, although there were minor oscillations, and by the beginning of 2010 it is at the absolute level of -27,21 m.

2. In the climatic conditions typical for the Subatlantic time interval of the Holocene, the Caspian Sea level oscillations between -30 and -25 m on the absolute scale represent a normal phenomenon and from this point of view it does not lead to an ecological catastrophe. When planning and developing economic activities in the coastal zone this range of oscillation ("hazardous area") needs to be taken into consideration (of course, wind-induced sea-level changes in the shallow-water areas must be considered also). The reason for loss of resources for the national economy is not the sea-level rise, which started in 1978, but thoughtless developing of the coastal zone exposed after the sea-level drop after 1929, that is the area below –26 m on the absolute scale.

To support the abovementioned we can refer to the situation that occurred on the Caspian coast in the beginning of the XX century (when the sea-level was more than 1 m higher than modern) and at the end of the XIX century (when the level was 2 m higher than modern) and it was not interpreted as an ecologic catastrophe. During these high level stands neither of the cities of Makhachkala, Derbent, the village of Kaspiyskii (former Lagan'), nor other settlements located at the parallel laterally extended ridges were negatively affected. Along the Caspian coast there were tens of fisheries, and more than 0,5 million tons of commercially valuable fishes were caught. Higher sea-levels compared to modern occurred in the XIII-XIV and in the XVII centuries. Meanwhile, Astrakhan for example is known since the middle XIII century and in the XIII-middle XIV centuries there was a capital for the Golden Horde – Sarai Batu.

This and many other settlements on the Caspian coast did not suffer from the high sea-level stand, since they were thoughtfully built on the elevated locations. It is possible to give more examples of the "guiltlessness" of the Caspian in the negative consequences observed today. Thus, the intensive wash-out of the coast in the city of Kaspiysk is caused by the unreasonable construction of the port at its southern end, its wharfs are blocking the southward alongshore movement of the alluvium.

The stairs and other constructions, which changed the natural slope incline, also contribute to the wash-out. Intensive abrasion of the isthmus of the Agrakhanskiy Peninsula is mainly caused by the fact that after the manmade straightening of the riverbed of Sulak River in 1957 this part of the coast no longer received marine alluvium. The Astrakhan-Kizlyar railroad is under the threat of wind-induced shallow-water sea-level rise, since it was built without allowing for the sea-level rise. And there are more examples of unreasonable economic activity.

3. With average water balance parameters in the Caspian for the XX century: the river runoff – 288 km^3/yr, visual evaporation – 77,3 cm/yr (taking into consideration the geomorphological structure of the Caspian basin and coast), its sea-level will tend to reach -27,5 (±1,5m)

4. The paleogeomorphological method does not give precise chronological reference points of the Caspian Sea level stand, however, this is true for any other method. Though this method is based on the detailed analysis of the geologic and geomorphologic structure of the coast that is on the actual data, reflected in the landforms and the sediments they are made of, in its information value it is not a less, but in fact a more reliable method to forecast the Caspian Sea level for the nearest and distant future, than calculated probabilistic ones.

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SESSION I.

PALAEOCLIMATIC AND PALAEOENVIRONMENTAL CHANGES IN THE CASPIAN REGION

LEVEL MODE OF THE CASPIAN SEA AND THE NEW SIGHT AT THE ISLANDS OF THE NORTHERN CASPIAN

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There is an opinion that a number of islands in the Northern Caspian (Tyuleny Island, Maly Zhemchuzhny Island, Nordovy Island, Chechen Island and Chistaya Banka Island) were formed comparatively not so long ago – the end of the 19th – the middle of the 20th centuries. «The important feature about all these soils is their "youth", i.e. their age does not exceed 150 years that is limited by the age of the island itself» (Leontiev, 1957; Badyukova, etc., 1995; Gennadiev A.N., etc., 1998).

Tyuleny Island is located in the western part of the Northern Caspian, in hundred kilometers from the coast of Daghestan (N: $44^0\ 28^{/}\ 25^{//}$, E: $47^0\ 28^{/}\ 59^{//}$). Tyuleny Island has the oblong form focused from the north to the south. Its diameter is about 5 km on the average. The northern part of the island is a little bit raised and there is a ring-shaped shelly sand bar on its relief which consists of two sickle curved bars of 3-5 m in height. From the north the bar is bordered with sickle curved ridges. Downturn between the ridges usually has a flat surface and, as a rule, they represent an original surface of shells but sometimes they are occupied by saline soils.

Nordovy Island is located in the Kizlyar Gulf, about 18 km. to the east from the coastline. It is a reed zone of several square kilometers with a small firmament in the form of seashells on the eastern tip of the island. The size of the land depends on the level of water in the sea. In turn, the water level varies according to the direction and strength of the wind. To the east of the island there is a shallow extending to several hundred meters. Tyuleny Island is located in 40 km to the east.

For the first time biocomplex scientific researches were carried out at Tyuleny Island from June, the 5th till June, the 20th, 2009 and at Nordovy Island in 2010. 12 persons participated in the expedition among which there were experts on botany, zoology, soil and ecology. The primary goal of the expeditions has been devoted to biodiversity study and geomorphologic and soil-geochemical researches. The researches covered all typical areas of the islands. While collecting the material they used modern traditional techniques (manual gathering, mowing, light traps and digging traps). They also laid soil cuts under the standard. To determine the dynamics of fly of different species light traps with quartz radiators were set in 4 extreme points of the island and hourly shootings were made. However the biggest emphasis in the researches was made on Barber's traps with the intensification of the light source. Digging traps operated for 14 days (all day and night long) and were changed every 3 days. 966 Barber's traps were set in the center and in the tip of the island. During the expedition 13678 species of various invertebrates were collected with the help of Barber's traps (Table 1).

Table 1

The quantitative analysis of some insects in Barber's soil traps at Tyuleny Island

Regular Groups	Barber's Trap	Barber's trap with intensification of the light source
Mantis	1	3
Diptera	2	9
Coleoptera	938	6206
Ticks	4	-
Molluscs	6	2
Wood lice	20	4
Spiders	308	517
Hymenoptera	855	1490
Hemiptera	6	1038
Orthoptera	90	160
Homoptera	4	162
Neuroptera	8	38
Staphylinidae	11	130
Dragonflies	3	35
Earwigs	96	1
Lepidoptera	16	1515
Total	**2368**	**11310**

Table 2

The quantitative analysis and comparative characteristic features of the fly of nocturnal and crepuscular insects

Group of Insects	Tyuleny Island	Nordovy Island
Lepidoptera	3942	10299
Neuroptera	5	2
Coleoptera	12664	8164
Diptera	13084	39011
Hymenoptera	385	1
Homoptera	210	2
Orthoptera	3	18
Dragonflies	231	263
Spiders	2	-
Staphylinidae	327	626
Hemiptera	105	760
Total	**30958**	**59146**

During the expedition comprehensive biological studies on biodiversity were carried out including nocturnal and crepuscular insects. For these studies they used a model of the light trap proposed by Abdurahmanov G.M. (1967).

Expedition survey and selection of soil samples were made in different areas of Tyuleny Island. In total 13 cuts were laid. It is necessary to agree with the detailed description and the characteristic of soils which are close to our data presented in Gennadiev A.N.'s work, etc., 1998.

Soils of the island can be divided into the following groups:

1. Underdeveloped aeolian sandy soils of autonomous position locating on sandy bars;
2. Sulfide saline soils (Kasimov N.S., 1988), soils of subordinate positions locating on the edges of desiccation lagoons;
3. Underdeveloped sandy ferruginous soil locating at the foot of sandy bars;
4. Underdeveloped meadow saline soils formed in shallow downturns after regression of the sea;

5. Underdeveloped hydromorphic sandy soils formed at flooding on the flat or raised areas;
6. Underdeveloped hydromorphic sandy saline soils formed during strong flooding near lagoons on sloping areas or small downturn.

Due to the fact that automorphic soils develop under arid climate (semi-desert), on a poor sandy substratum and accordingly under the poor vegetation growing on transplanted sands humus content in them is extremely small and the humus horizon is only 1 – 2 cm.

In our opinion the increase of heavy metals content in soils at Tyuleny Island can be explained by the fact that in connection with the surge processes a large territory of the coastal part of the island is annually flooded that leads to ecological changes. The top horizons of flooded soils in comparison with not flooded ones contain high quantity of heavy metals (Zn, Cu, Pb, Cd, Ni).

Our researches on Tyuleny Island revealed 148 species of higher plants. In structure of vegetation cover can be distinguished the following features: availability of areas both with dense vegetation and with very sparse. It is necessary to point out that all the leading families are specific to the Iran-Turanian and Mediterranean floristic region Besides there are families that are specific to the Central Asian deserts. They are: Tamaricaceae, Frankeniceae, Elaeagnaceae, Apiaceae, Boraginaceae and types – Artemisia, Salsola, Suaeda. At the same time a number of desert sorts that are typical of the Central Asian deserts in general is absent (Haloxylon, Acantolimon, Ammodendron, Krasheninnikovia, Cousinia). Such families as Ranunculaceae, Cyperaceae, Caryophyllaceae make related the flora of the Caspian region with areas of the Boreal floristic region.

Biotopes of the island are strongly contrasting in terms of moisture and soil salinity. In this regard the species are characterized by significant environmental adaptability. Thus, in conditions of excessive moisture the group of water and shoreline aquatic plants from the Ceratophyllaceae, Hydroharitaceae, Lemnaceae, Najadaceae and Typhaceae families is widespread. Many types of Chenopodiacea family are adapted to the terms of the excessive salinity.

In general the eastern part of the island is characterized by the dominance of the Poaceae family species. Hydrophilic part of the island is not characterized by high variety of species or particular structure complexity of the communities themselves. The predominant part of the island is represented by solid monodominant thickets of Phragmites communis. These thickets basically grow on the lower parts of the island which are flooded with water at the south-east winds. Sometimes the dominant of plant communities of this part of the island are species from the Cyperaceae family such as Bolboschoenus, Juncus and Schoenus.

Plant communities on the periphery of the western part of the island (except for its north-west coast) are similar to ones described above. Since the western part of the island is the most elevated zonal types of vegetation communities typical of the eastern coast of the Caspian Sea are widely spread there. In general they can be called semi-desert type of vegetation.

The vegetation of the desert part grows on the sands and consists of the groups of halophytes: Halocnemum strobilaum, Kalidium foliatum, Halostachys caspica, Solicornia europea, Suaeda confuse, Frankenia hirsute etc.

Sagebrush communities that occupy about 75–80% of the western territory of the island are the most common semi – desert in this part of the island. Sagebrush groups grow on the non-saline, slightly saline and saline sands. Sagebrush communities are presented by a great number of pure sagebrush groups that are adapted to the different habitat conditions (with deep-seated groundwater), mixed groups such as Botriochloa, Stipa, Koeleria and other cereals and saltwort on saline areas.

Sagebrush halophytic, sub-shrub and minor-shrub and semi – desert groups are widespread in the central part of the island. They develop on the soil with a close bedding of mineralized groundwater and salt marshes. They are presented by formations with different species of Artemisia and sub-shrubs of the Sueda and Solsola families.

The variety and areology of animal groups of the present time (spiders, Coleoptera and Lepidoptera) is sufficient enough to evaluate the various opinions of authors mentioned above on the age and origin of these islands.

Fauna of spiders of Tyuleny Island includes 74 species belonging to 49 types and 16 families. 8 species were identified but not yet described as new ones for science. 8 species turned to be new ones for the fauna of Daghestan. They are Simitidion, Hypsosinga, Singa, Evippa, Devade, Liocranoeca, Leptodrassus, Mendoza and 23 species – Simitidion simile (C. L. Koch, 1836), Hypsosinga pygmaea (Sundevall, 1831), Larinioides folium (Schranck, 1803), Singa hamata (Clerck, 1758), Singa nitidula C.L.Koch, 1844, Evippa apsheronica Marusik, Guseinov et Koponen, 2003, Devade tenella (Tystshenko, 1965), Liocranoeca spasskyi Ponomarev, 2007, Cheiracanthium seidlitzi L.Koch, 1864, Clubiona juvenis Simon, 1878, Gnaphosa cumensis Ponomarjov, 1981, Haplodrassus minor (O.Pickard-Cambridge, 1879), Leptodrassus memorialis Spassky, 1940, Trachyzelotes cumensis (Ponomarjov, 1979), Zelotes segrex (Simon, 1878), Philodromus glaucinus Simon, 1870, Tibellus utotchkini Ponomarev, 2008, Ozyptila simplex (O.Pickard-Cambridge, 1862), Xysticus mongolicus Schenkel, 1963, Mendoza canestrinii (Ninni in Canestrini, Pavesi, 1868), Sitticus ammophilus (Thorell, 1875), Yllenus albocinctus (Kronederg, 1875), Yllenus caspius Ponomarjov, 1978.

18 species of scarab (Coleoptera, Scarabocidae) were identified in the area of research belonging to 11 families of Amaladera caspia, Amaldera euphorbiae, Anoxia pilosa, Aphoclius (bodilus) lugris, Aphoclius (evytus) klugi, Aphoclius klugi, Aphoclius kraatzi, Aphoclius vittatus, Chaetopteroplia segetum, Codocera ferruginea, Copris hispanus, Glavesis rufa, Onthophagus furcatus, Pentoclon bidens, Pentoclon idiota, Polyphylla alba, Scarabaeus typhon and **22 species of tenebrionidae** (Coleoptera, Tenebrionidae) belonging to 17 families of Anemia dentyres, Belopus crassipes, Blaps lethifera, Blaps parvicollis, Cripticus guisquilius, Cripticus zuberi, Gonocephalum granulatum pussilum, Gonocephalum rusticum, Leichenum pictum, Melanimon tibialis, Nlassus faldermanni, Omophlus pilicollis, Opatrum sabulicolum, Oryctes nasicornis, Oxytherea cinctella, Penthicus dilectans, Phtora quatricollis, Pimelia capito, Scleropatroides hirtulum, Scleropatroides seidlitzi, Tenebria obscurus, Tentiria nomas). It should be noted that one of Turkmen subspecies – Pentoclon bidens – discovered on the island may be endemic of this island.

A significant number of Pentodon algerinum bispinifrons were also captured on Tyuleny Island (Pic. 1). Tyuleny Island is the most northern and most western boundary of the range of this subspecies and probably represents relict island populations. Separation from the main range of the subspecies in Central Asia is about 500 km. It is significant that other species common for the rest of Daghestan is absent on the island.

Fig. 1. Habitat map of Pentodon algerinum bispinifrons Reitter, 1894 (by Endrцdi, 1985, modified)
The filled circles are the range of subspecies, the black square is the population

Tyuleny Island is the habitat area of 56 species of noctuids (owlet moths) shovel belonging to 40 families and 15 species of which occur in a single specimen (Drasteria picta (Christoph, 1882), Macdunnoughia confuse (Stephens, 1950), Phyllophila obliterate (Rambur, 1833), Tyta luctuosa ([Denis&Schiff] 1775), Cucullia tanaceti ([Denis&Schiff] 1775), Helicoverpa armigera (Hьbner, [1808]), Chazaria incarnate (Freyer, 1838), Chilodes maritime (Tausscher, 1806), Phothedes extrema (Hьbner, [1809]), Mythimna straminea (Treitschke, 1825), Leucania L. zeae (Duponchel, 1827), Agrotis desertorum Boisduval 1840, Rhyacia simulans (Hufnagel, 1766), Chersotis rectangula ([Denis&Schiff] 1775), Noctua comes (Hьbner, [1813])). In large quantities by the number of specimen the following 13 species are found: Odice arcuinna (Hьbner, [1790]), Drasteria flexuosa (Menetries, 1848), Grammodes stolida (Fabricius, 1775), Autographa gamma (Linnaeus, 1758), Schinia scutosa ([Denis&Schiff] 1775), Caradrina albina (Eversmann, 1848), Discestra trifolii (Tausscher, 1809), Discestra stigmosa (Christoph, 1887), Mythimna pallens (Linnaeus, 1758), Mythimna vitellina (Hьbner, [1808]), Leucania obsoleta (Hьbner, [1803]), Noctua orbona (Hufnagel, 1766), Noctua pronuba (Linnaeus, 1758).

Thus the material on the biological diversity of these islands and the availability of autochthonous elements on them as well as a large number of not found species on the mainland do not allow to agree with the opinion of many authors on the age and origin of these islands.

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CLIMATE AND CHANGE OF THE CASPIAN SEA LEVEL DURING THE LATE 10,000 YEARS

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INTRODUCTION

For the history of the Caspian Sea in the late of 10 thousand years it is characteristic to free considerable changes of its level (in some tens metros). The reason is clear, this is the climate change. However, the unity of opinions concerning changes and the sea level, and a climate while is not present. Accordingly, there are also no uniform representations concerning interaction of these representations.

CLIMATE CHANGE

The late 10 thousand years allocate 5 periods (dating from [Hotinsky, 1989] in thousand years) : Preboreal (10,3-9,3), Boreal (9,3-8,0), Atlantic (8,0-4,6), Subboreal (4,6-2,5) and Subatlantic (2,5-0). To these five periods often limited the Holocene. But the boundary of 10,3 thousand years is expressed not so sharply. Therefore it begin and with earlier boundaries. We true V.K.Gudelis [1961] opinion who offered as such boundary of 16 thousand years ago, when was started the beginning of "radical reorganization in development climatic and geographical conditions on the Earth". It was preceded by late coldest phase of a freezing (with 23 to 17 thousand years ago), and after there has come an epoch of warming and thawing of glaciers [Velichko, 1991].

In the Western Caspian by palinologic data the listed periods Holocene are characterized by following conditions and temperatures and an amount of precipitation (on mid-mountain belt). For comparison it is cited the data and on two epoch proceeding to them.

1. 23-17 thousand years ago. Conditions were very severe and dry. Borders of mountain belts passwhether on 1500 m more low, than now, and on plains deserts and semi-deserts dominated. Mid-annual temperatures fell to-2ºC, January – to-13ºC, July – to 5ºC.

2. 16-9.3 thousand years ago. It was characterized gradual, with breaks (during the periods Drias), but steady (during the periods of Raunis, Bøelling, Allerøed and Preboreal) increase of temperatures and humidity [Velichko, 1991]. Forests occupy almost all mid-mountain and a lot of part low-mountain and foothills. The area of arid light forests extends.

3. 9.3-8.0 thousand years ago (the Boreal period). Is a climatic optimum of the Holocene. Temperatures and humidity have reached maximum in Holocene values. Mid-annual temperatures have risen to 6-8Cº, January – to-5-8ºC, July, to 14-16ºC. 600 mm of the atmospheric precipitation dropped out a year. Full thawing of the late concerns the end of this period in Europe the Scandinavian glacial cover also.

4. 8-4.6 thousand years ago (The Atlantic period). It is considered to be it climatic optimum of the Holocene. Actually it is characterized by simultaneous fall, both temperatures, and dropping out precipitation. Average annual temperatures have decreased to 4-6ºC, January to 8-11ºC, July to 13-14ºC, and an amount of precipitation to 200-250 mm a year. Reduction of a share of tree species testifies to it i.e. of almost all cuts, and in groups wood and grassy – reduction rather warm and hygrophilous kinds. In the end of the period warming which conceded to boreal warming is marked.

5. 4.6-2.5 thousand years ago (the Subboreal period). New increase distemper-round and precipitation is marked. Average annual temperatures have risen to 8-12ºC, on January above –5ºC, July to 12-16ºC. Again 600 mm of the atmospheric precipitation dropped out in a year. One-time increase in temperatures and precipitation has led to strong expansion of the area of forests.

6. Late 2.5 thousand years ago (The Subatlantic period). Temperatures and an amount of precipitation fluctuate in certain limits. For average annual temperatures it between 4 and 8ºC, for the January, between-5 and-11ºC, for the July between 12 and 16ºC, for precipitation between 500 and 650 mm a year. In general, there was a process of aridization as, in general, temperatures were rising, and precipitations were decreasing.

CHANGES OF LEVEL OF CASPIAN SEA

In late 16 thousand years two epochs allocated – Late Khvalyn and Novocaspian. Their deposits contained the same fauna of modern *Didacna.* Them separate the friend from the friend on absence (in Upper Khvalyn) and to presence (in Novocaspian) *Cerastroderma glaucum Poir. (More low C. glaucum)*. Before it was named *Cardium edule L*. These epochs are considered to be transgressive, come after very deep (to-45-50 m) regressions (Leont'ev et al., 1977). But the absolute dating analysis of the Caspian precipitation and heights of their arrangement [Arslanov et al., 1978, 1988; Badinova et al., 1976; Kuptsov, 1980; Parunin et al., 1989] testify about not-how many other history of Caspian Sea.

For Late Khvalyn transgressions are considered as the most ancient of dating 15100±300 (on 14C) and 16510±710 (on 230 Th/234U). But they occur with maximum for this transgression – nearby 0м height. Lifting of level to this mark about-40-50 m height should late not less than 2-3 thousand years. From this it follows that Late Khvalyn transgression has begun 19-17 thousand years ago, during time a maximum of development of glaciers, also has ended with 16-15 thousand years ago, when glaciers have started to thaw. Besides all specified and other dating are more senior 12 thousand years ago are received from *Didacna delenda Bog. D. parallella Bog., D. protracta Eicw.* and another Early Khvalyn didacna. They, as marked [Arslanov et al., 1988], basically, are strongly rejuvenated.

The most ancient for actually Late Khvalyn deposits i.e. with modern fauna, but without, are dating 11340±160 (14C) and 12900±350 л.н. (Th/234U). They occurs with-13 m height. Having added to it the same 2-3 thousand years, we receive to start transgression 16-15 thousand years ago, i.e. time of the beginning of warming and thawing of glaciers. Radio coal-native dating of layers Late Khvalyn transgressions 9560±60, 8500±100 and 7700±250 years ago, received on marks about 0 m, shows that it has come to the end with 10 thousand years ago, also kept on these marks to 8 thousand years ago. Then regression has begun. At an initial stage it was very fast. Radiocarbon dating 7840±90, 7720±70 and 7530±160 years ago with -16 and-18 m height show that in a current of all of half-thousand years, 8-7.5 thousand years ago, level of Caspian Sea has fallen almost to 20 m.

Believe that during this regression named Mangyshlakskaya, during very short time (no more than 1-2 thousand years) level of Caspian Sea has fallen to 30 m, to-50m height, then the Novocaspian transgression when level has risen on the same of 30 m, to-20m has begun. [Leont'ev et al., 1977]. But, if the specified fall of level still somehow can be admitted, for sharp lifting then no conditions were exist. As Shnitnikov marked [1956], by then the flat freezing in Eurasia has completely disappeared, and mountain was strongly reduced. We believe, what all "proofs" of deep regression between the Khvalyn and the Novocaspian epochs, are actually left by the Enotayev regression which preceded the Late Khvalyn transgression. To it testifies "mangyshlakskaya" fauna that the deposits revealed at the bottom of Caspian Sea on marks of -43-53 m height. It is presented was *Didacna,* as early (*D. subcatillus Andr., D. delenda Bog.),* and late (*D. trigonoides Pall., D. barbotdemarnyi Gr.) khvalina* [Artamonov, Maev, 1979]. This structure says that at accumulation of the given deposits occurred transformations Early Khvalyn fauna in Late Khvalyn fauna, and, means, it were formed between Early and Late Khvalyn transgession during the Enotayev regression.

After Late Khvalyn transgressions a regression occurred, but after 7.5 thousand years ago it slowed down and proceeded all subsequent time. In 7.5 to 6 thousand years ago according to radiocarbon dating (6350±110, 6100±80 and 5940±100 years ago) level of Caspian Sea has fallen only on some meters – to-21-22 m height. And then, according to the subsequent dating, level of Caspian Sea fluctuated between-21 and-31 m with the general tendency to the lowing.

This tendency is well shown on layers in a cut Turali-sulphate in Dagestan. Here 5 layers are allocated with *C. glaucum* [Rychagov, 1974; Leont'ev, Chekalina, 1980]. These layers settle down in steps. The maximum heights of the first layer – -20 m, the second – -21, the third and the fourth – -22-22,5 m and the fifth – -23-24m. Radiocarbon data are available for the second (5390±390 л.н.) and the fourth (3400±170 л.н.) layers. Proceeding from [Shnitnikov, 1957] 1850-year-old cycle, G.I. Rychagov has defined age of the first layer about 8 thousand years ago. We was by 1850-year-old cycle have defined age and other layers. It for the first layer has appeared 8-6, the second – 6-4, the third – 4-2, the fourth – 2-0,2 and fifth – late 0,2 thousand years ago.

Thus, it is found out that *C. glaucum* into Caspian Sea has got 8 thousand years ago, when level of Caspian Sea stood on a mark about 0 m. After as we have shown, regression has begun, and, means, all Novocaspian epoch was a regression epoch, instead of transgression.

CONCLUSIONS

Comparison of the climate changes revealed by us and level of Caspian Sea shows accurate interaction between them. An epoch of late coldest phase of a freezing (23-17 thousand years ago) was necessary on deep Enotayev regression between Early and Late Khvalyn transgressions. When thawing of glacial covers transgression has begun the Late Khvalyn has begun. During it about 10 thousand years ago level of Caspian Sea has reached 0 m height (it is possible, hardly bigger or hardly a smaller mark). In our opinion, it has occurred because this height then had the Manych watershed, and Caspian Sea on Manych passage-river surplus of the waters gave vent to Black sea. On this passage-river also has got into Caspian Sea *C. glaucum* [Veliyev, 1994].

On a mark about 0 m level of Caspian Sea has held on to 8 thousand years ago. Then late Scandinavian glacier in Eurasia has thaw, and inflow of water to Caspian Sea has sharply fallen. Within a half-millennium it has fallen almost to 20 m and about 7.5 thousand years ago and has stopped on-16-18 m height. Then rates of falling have decreased, but the tendency of decrease in level remained. To 6 thousand years ago the average level of Caspian Sea has gone down to-20m height. After level fluctuations in the big limits are fixed. But the average level continued to fall, than heights of layers of a cut Turali-sulphate testify. Late maximum of level of Caspian Sea is necessary on first half of XIX century, when has ended “a small glacial age”. Now there is a warming process, and level of Caspian Sea for late two centuries has fallen to a few metros. Will this mini-regress proceed some more decades? Up to the middle of XXI century.

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RADIOCARBON AGE OF THE LAST EPOCH OF THE MANYCH PASSAGE EXISTENCE

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Keywords: Manych, molluscan assemblages, radiocarbon dating, Khvalynian transgression, Neoeuxinian basin

INTRODUCTION

The major paleogeographical events of the Pont-Caspian region during the end of Pleistocene and Holocene are very disputable. One of them is the problem of “absolute” age of last epoch of the Manych strait existence. It is established during the peak of the Khvalynian transgression Caspian waters flowed via the Manych Strait into the Neoeuxinian basin (Svitoch, Yanina, 2001; Yanina, 2005; and other). Faunal composition points to a one-way migration of molluscs from the Caspian to the Black Sea (Fedorov, 1978; Popov, 1983; Svitoch, Yanina, 2001 and other). The age of Manych Strait function during Lower Khvalynian epoch is estimated from 60 ka (Rychagov, 1995) to 30 ka (Popov, 1983) and to 11-14 ka (Svitoch, Yanina, 1997), 11-12 ka (peak of Khvalynian transgression), 10.5 ka (closing of the strait) (Svitoch, 2007). The aim of this paper is to present the last data on radiocarbon dating of Manych Khvalynian fossil molluscs and, on this basis, to present a conclusion about the “absolute” age of Caspian – Black Sea connection during Khvalynian epoch.

MATERIAL AND RESULTS

Several locations of Khvalynian fauna (Fig. 1), analyzing which by radiocarbon dating method allowed us to educate some 14C dates and to update the Manych Khvalynian history. Radiocarbon dating was realized in the Laboratory of Quaternary paleogeography and geochronology of the Saint Petersburg University. Calendar age meanings are found on the base of calibration-programme "CalPal" (2006) of B.Weninger, O.Joris, U.Danzeglocke from Cologne University (www.calpal.de).

In the Manych Depression, the marine Lower Khvalynian sediments are bedded on the Burtass-Gudilovian lake’s deposits with deep erosion. They include numerous fossil slightly brakish mollusks *Monodacna caspia, Adacna vitrea, Hypanis plicatus, Dreissena*, and brakish *Didacna protracta,* and *D. ebersini* – index fossils for Lower Khvalynian deposits of the Caspian Sea.

On the right coast of Vostochniy Manych river near the Chogray dam the structure of a terrace is found. Lower Khvalynian deposits contain dominating *Hypanis plicatus*, numerous *Monodacna caspia* and rare *Didacna protracta*, *Dreissena polymorpha*. 14C date of *Hypanis plicatus* shells is 11.47±0.18 ka BP (LU-5768), calendar age is 13.36±0.20 ka cal BP. To the west, near village Zunda-Tolga in an abrasion escarp of the northern bank of the Chogray reservoir Lower Khvalynian deposits contain dominating *Didacna ebersini* and *Didacna protracta*, rare *Monodacna caspia*, *Dreissena polymorpha*, *Hypanis plicatus* and *Adacna laeviuscula*. The different index fossils were dated. 14C date of *Didacna ebersini* shells is

11.42±0.22 ka BP (LU-5726), calendar age is 13.32±0.22 ka cal BP. 14C date of *Didacna protracta* (depressed small shells) is 10.67±0.14 ka BP (LU-5725), calendar age is 12.57±0.17 ka cal BP. On the western end of Leviy Island (Manych Lake) Khvalynian deposits contain bivalve shells: *Didacna protracta* prevails, *D. ebersini*, *Monodacna caspia* and *Dreissena polymorpha* are rarely found and *D. subcatillus*, *Hypanis plicatus*, *Adacna laeviuscula*, *Dreissena rostriformis distincta* are singular. 14C date of *Didacna protracta* is 10.93±0.37 ka BP (LU-5769), calendar age is 12.75±0.46 ka cal BP.

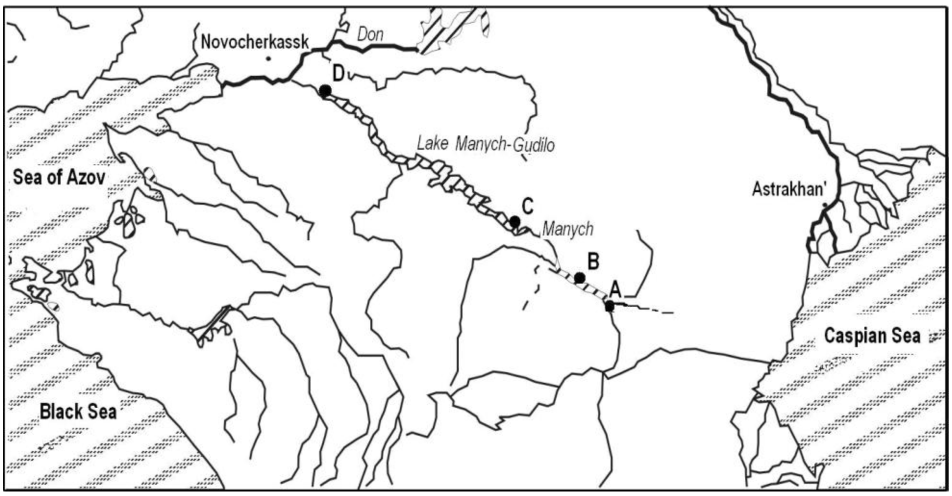

Fig. 1. Plan of location of sections within the Manych Valley A – Chogray Dam; B – Zunda-Tolga, C – Leviy Island, D – Manych-Balabino

For answer on the question about Khvalynian history of the Manych, our investigations of Manych-Balabino section (Svitoch, Yanina, 2001; Yanina, 2005) are very important. The Khvalynian deposits of the section include abundant fossil molluscs: brakish species (as Caspian origin and Black Sea one), slightly brakish species, fresh-water species and eurihaline marine species. Most of them are re-deposited. Numerous shells of *Monodacna caspia, Adacna laeviuscula, A. vitrea, Dreissena polymorpha*, and rare *Didacna ebersini* (Early Khvalynian species only!) are "in situ". Khvalynian shells were dated in the Laboratory of Pleistocene paleogeography of Moscow State University by O. Parunin. ^{14}C date is 14.3±0.68 ka BP (MGU-1491). ^{14}C date of shells composite (Khvalynian shells with *Cerastoderma glaucum*) is lots older – 25.69±3.0 ka BP (MGU-1489). It proves our conclusion on the mixing of shells from different basins in the thanatocoenosis, and on "young" age of the Khvalynian fauna.

DISCUSSION

Two subassemblages are distinguished within early Khvalynian assemblage. There representatives occur at different stratigraphical position. We have dated the shells from younger subassemblage, corresponding to establishment of "balanced profile" in the passage at the 20 m asl. There 14C age is 10.93±0.37 ка BP – 11.42±0.22 ка BP. The delicate early Khvalynian shells from 9 sections from different areas of the Caspian region (Dagestan, Azerbaijan, Lower Volga, Lower Ural) have analogic 14C age (Arslanov et al., 1977, 1988). At the same time the late Khvalynian thick shells have the similar age. We obtained the similar 14C data – 12.65±0.16 ка BP, 15.01±0.30 ка cal BP (LU-5801) for late Khvalynian *Didacna praetrigonoides* from Azerbaijan. According to expertise of Prof. Arslanov, the perfect preservation of shells, the dating of inside part of shells, the commonality of calibrated ^{14}C age (the calendar-age) with ^{230}Th/U dates provide the reliability of late Khvalynian dates. They correspond to ^{14}C chronological interval Belling-Allered.

The chronological data guess the ^{14}C age of delicate early Khvalynian shells is understated. It may be generate by younger carbonates ingrained in shells by isotope exchange. There are two ways of carbonate pollution of unrecrystallization shells: isotope exchange and diffusion of polluted carbonate inside crystal structure of shells. The isotope exchange is a fast process. It is characteristic for delicate shells. The pollution of thick shells by younger carbonate intervenes too, but the rapidity of diffusion is small. Generally the thick shells comprise about 2% of recent carbon (Arslanov, 1987). We dated by radiocarbon method the thick shells of *Didacna praetrigonoides* from lower Khvalynian deposits (+20 m asl) of Mangyshlak peninsula. The carbon dating of outer fraction is 12.02±0.13 ка BP (ЛУ-5800А), the dating of inner fraction is 12.55±0.21 ка BP, the calibrated age is 14.84±0.45 ка cal BP. Such age can be cleared by small pollution of thick shells by recent carbonate. The inner fraction of shell is steady to pollution, and it has older age than outer fraction. The radiocarbon dating of inner fraction is most real age (a little too young perhaps, on the opinion by Prof. Arslanov).

CONCLUSIONS

The obtained data evidence an opening time of Khvalynian Manych Passage during the late Valday glaciation (the beginning of late Valday deglaciation). The epoch of the Manych Passage existence was ended from ~12 ka BP, ~14 ka cal BP – at the close of early Khvalynian stage and the beginning of late Khvalynian stage of Khvalynian epoch.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF THE TURALI REGION (DAGESTAN COAST) IN LATE HOLOCENE ACCORDING TO GEOLOGICAL, GEOMORPHOLOGICAL AND GEOPHYSICAL DATA

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Keywords: Turali section, Late Holocene, geomorphology, geophysical data, development of the coast

The rapid rise of the Caspian Sea level in the period from 1978 until 1995 by almost 2.5 m led to increased attention among researchers to the problem of the coast development under the transgression conditions. One of the most studied parts of the Caspian Sea coast is the Turali area, which is located on the Dagestan coast to the south of the town of Caspiysk and formed by the zone of intensive modern sedimentary accumulation.

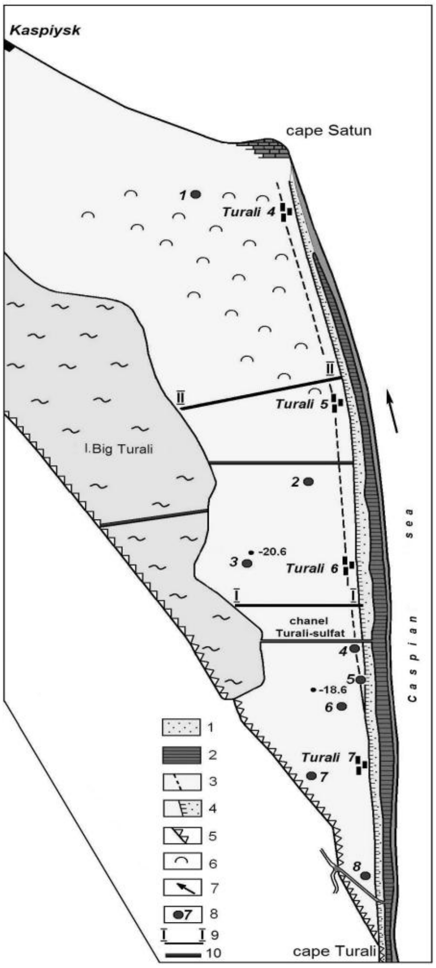

Fig. 1. 1-beach, 2-lagoon, 3-bar, 4- erosion escarp, 5-cliff, 6-dunes, 7- longshore driftin, 8-yellow sand, 9- geologic profile, 10-georadar profile

The coastal territory before the recent rising of the Caspian sea-level included the generation of beach-ridges adjacent to each other. The beginning of its formation is connected with the regression after the Caspian sea-level peak, which reached the mark of -25.8 m in 1929. As a whole, the surface of this terrace is flat and weakly inclined toward the Caspian Sea coast. Near Turali 7, this occupied approximately one kilometer during the lowest sea-level. The terrace is composed of relatively coarse-grained material that is why the eolian forms on this surface, except for the low dunes near some separate bushes, are absent.

Since the end of the 1970s, the rapid rise of the Caspian Sea contributed to the height accretion of the beach bar with simultaneous movement inland. At the early stages of the Caspian sea-level rise, the coastline retreated with a rate of up to 30 m per year. As a result, the modern terrace, where an extensive lagoon formed, was reduced in area more than twice. In 1995, the level reached -26.5 m and then it fell up to 40 cm. This led to the formation of the regressive beach-ridge joined to the initial one; that is, there was formed a bar consisting of a series of beach-ridges. The bar is composed mainly of middle and coarse-grained sand with detritus, shells, and rare pebbles.

The modern accumulation surface joins to the terrace located on the higher hypsometric marks and formed earlier during the Novocaspian time. In this area, the terrace represents the bar separated Lake Big Turali from the Caspian Sea. Along the almost whole length of this terrace from the sea side, the clearly manifested erosion scarp is located with a slope of up to 10–15° and a height of 2–3 m (Fig. l).

It is considered that the eolian forms in the Turali area were formed during the regressive stage since 1929. This confirms to the widespread opinion about the fact that the eolian process is strengthened during the sea level fall. In this case, a series of low beach-ridges is formed composed of more fine-grained sandy material in comparison with the transgression stage. However, this does not bring, as we consider, to the formation of large eolian forms [2]. The regularities of the development of the eolian forms on the seacoast are correctly discussed taking into consideration the character of the natural coastal processes. The basic element of the eolian relief in the coastal zone is an avandune, whose formation is described in detail in the literature [5, 6].

The sea retreat leads, in turn, to the beach retreat, and in the back beach avandune appears, as it is always associated with this place. Therefore, under the condition of the continuous sea regression, series of avandunes parallel and stretching to the coast is consecutively formed. As a result, the sandy material is practically not transported inland, since it is intercepted by the sequential newly formed eolian form. The absence of a large volume of sandy material and also the proximity of the ground water, which prevents the formation of deep blow-outs, do not contribute to the formation of large dunes.

We have carried out the granulometric analysis of the eolian sand sampled both in the Turali area and in some other regions of the Dagestan coastal plain. The resulted triangular diagram shows the high degree of the eolian sorting of the material (Fig. 2) since one fraction (0.25–0.5 or 0.1–0.25) dominates in all the samples.

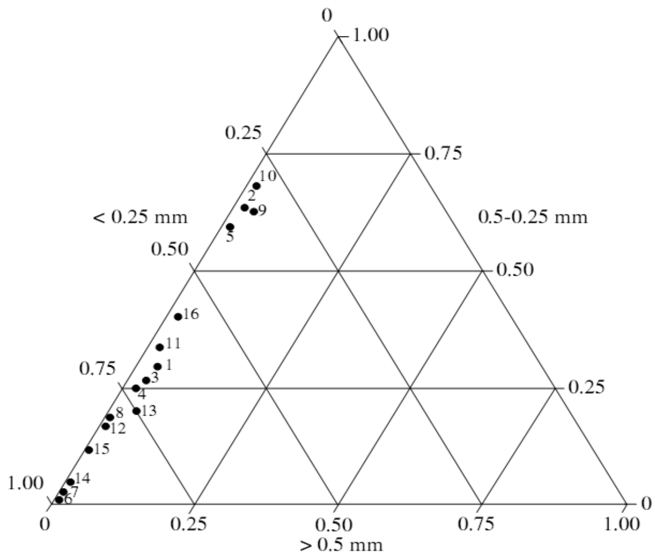

Fig. 2

At the present time, there are no large eolian forms on the bar. All the large dunes associated with the Novocaspian terrace surface. It is true that, at the present time, the sand has been practically mined for construction needs. At the beginning of the 20th century, the eolian forms occupied much larger areas. As an example, to the northwest from Cape Satun, dunes with a height of up to 12 m were earlier located. They gradually lowered and disappeared near Turali 6.

Thus, all the eolian forms described above are located not on the modern regressive terrace but on the higher Novocaspian terrace. On its edge, a wide bar was formed during one of the finale stages of the Novocaspian transgression, approximately 2–3 m above the surface located behind it (Fig 1). Lately, the bar was partly eroded over the whole length from the seaside. Behind the bar, the low dunes extended to the inland along the dominant wind direction. It is important to note that the dunes are lower in height than the bar surface; that is, the bar lock up them from the sea. Both the relief of the bar and the nature of the dunes testify to the absence of the modern transportation of sandy material to the Novocaspian terrace. The dunes are reworked by soil processes and partially covered by grass and bushes. All facts allow one to assume that the dunes being considered are not modern. They are more ancient than bar and the contemporary regressive terrace as well.

The bar is followed by the surface that previously was the lagoon bottom. According to the geomorphologic situation and the geologic data available, the lagoon was very extensive and it was formed at a sea level of approximately -24 m. It stretched further to the north across the town Caspiysk to the town of Makhachkala. To the west from Cape Satun, it was connected with Lake.Big Turali (Fig.1). This lagoon is also clearly distinguished in the georadar profiles made perpendicular to the coastline through the barrier complex (Figs. 3a, b). Consequently, this extensive lagoon was formed 2603 ± 33 yr BP (cal. 2300 yr BP)[2] probable during the so-called Ulluchaevskaya transgression **[**3] on the surface of the regressive terrace composed of the yellow sand with the top at -25 m. For a long time, sand was located under subaerial conditions, so the well reworked soil is on its roof in all pits.

In the lagoon loams there are a lot of small *Cerastoderma glaucum*. The upper parts of the loams are well reworked by soil processes too, which points to the subsequent draining of the lagoon as a result of the sea-level fall. Later on, the dunes were moved on the surface of this former lagoon bottom. According to this fact, the dunes are considered to be younger than lagoon.

The yellow sand was of great interest for us, since it occurs in numerous pits and outcrops in the territory of the Turali polygon, actually everywhere it underlies the younger and more coarse-grained deposits that form the top of the Turali barrier complex (Fig. 1). Thus, the coastal landscape earlier was different from the modern one: the sandy deposits were predominant. It seems likely that, in the initial stages of the barrier complex formation, the coastline was stretched approximately from the northwest to the southeast towards Cape Burun. This is confirmed by the location of beach-ridges on the Novocaspian terrace. Gradually turning out, they incline towards a cliff in the seaside of the bar.

Consequently, during each sea-level fluctuation, the possible turn of the coastline took place. As a result, in the south, the coastline displaced inland; in the north, on the contrary, it displaced towards the sea side. The intensive erosion in the south led to the formation of the Manasskiy gulf, and then the erosion of

[2] The radiocarbon age (AMS) was determined by Kh.V. Vonkhov in the laboratory of the Free University of Amsterdam in the Netherlands.

the ancient alluvium of the Manas River represented by gravel–pebble material began. This coarse-grained material was transported to the northwest due to longshore drifting, where, at the sequential sea-level rise, the thick transgressive pebble beach-ridges started to form. They overlaided the more ancient yellow well sorted sand of the former barrier complex. This complex was here during all the Holocene and Lake Big Turali from the very beginning was the lagoon, but not the open sea (Fig. 4).

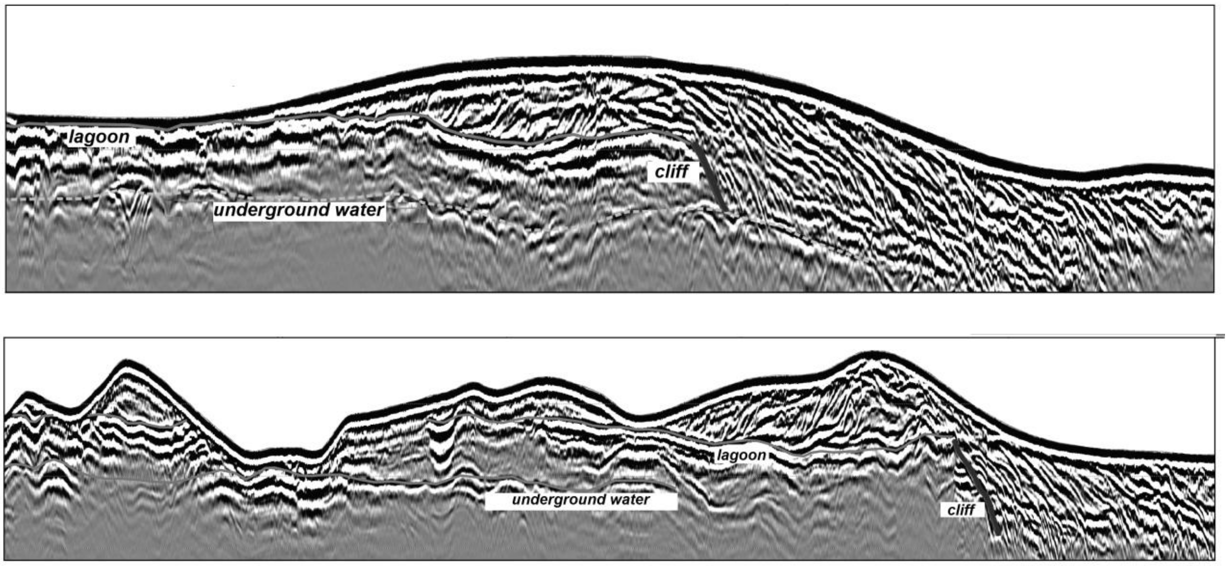

Fig. 3a, **b** Georadar profiles

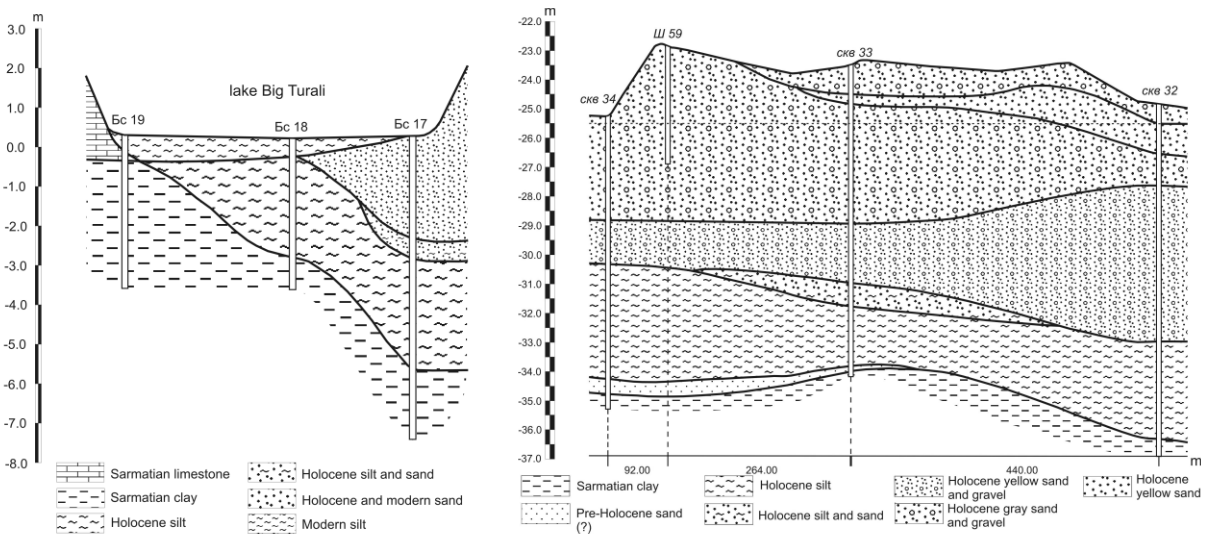

Fig. 4. Geologic profiles across the lagoon (Lake Big Turali) and barrier complex

Then there was the deep Derbentskaya regression with a maximum at 1300 yr. BP. The sea-level fell down to -34 m [4], or even more. The new geophysical data obtained during the study of the Kura River avandelta testify an erosion surface with an age of 900 yr. BP at -48 m [7]. Thus, the level lowered significantly during the Derbentskaya regression, which could have lead to a change of the relation between the inclines of the coastal plain and the nearshore slope. It is very important, as it determines the way the coast will be developed during the subsequent transgression [1]. It is quite probable that the land incline become steeper than those of the nearshore slope as this is confirmed by the structural-geomorphologic structure.

The Derbentskaya regression was followed by the sea-level rise and erosion in the Turali area. The regressive terrace composed mainly of yellow sand and thin lagoon loams was eroded. A large amount of eolian material from the beach could have been transported, as in the sand the fine-grained fractions are predominant**.**

The largest dunes were formed on the Novocaspian terrace near Caspiysk. At the sea level rise, the erosion scarp retreated further to the west and occupied the position determined in the two georadar profiles where this buried scarp is clearly visible. Subsequently, the erosion process was changed into accumulation, and the scarp was completely overlaid by the sediments. Just after, the bar was formed, which separated from the ea the dune massif near Turali 5 and Turali 4 (Fig. 3a,b).

CONCLUSION

1. The sea-level fluctuations played the dominant role in the development of the shore in the Turali area.
2. The type of coast has been changing repeatedly during the last two thousand years. During this time, it is regarded to have been accumulative with wide sandy beaches and a lagoon, accumulative with a beach composed of pebble material, then erosional one, and the accumulative coast again. At the present time, it is the lagoonal type.
3. The dunes on the Novocaspian terrace formed during the sea level rise after the Derbentskaya regression. They are significantly younger than the ancient lagoon but are more ancient than the bar on the Novocaspian terrace formed at about 300 yr. cal. BP as a result of the sea level rise up to -24 m.

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ENVIRONMENTAL AND CLIMATIC EVOLUTION OF THE LOWER VOLGA RIVER REGION DURING THE LAST 10 KYR

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Keywords: the Lower Volga, Holocene, climate and vegetation, environmental changes

INTRODUCTION

The Lower Volga represents a very interesting paleogeographic study area. This area has the most arid and continental climate not only in the Volga drainage basin, but in the whole of Europe. It is only here, in the Caspian Lowland, that desert plant communities form the zonal vegetation type.

When analysing data on the Holocene environments of the Lower Volga region, we see that many investigators (including P.V. Fedorov, O.K. Leontyev, G.I. Rychagov, S.I. and A.N. Varushchenko, A.A. Svitoch and others) have identified repeated fluctuations of Caspian Sea level and established their ranges and chronology. Thus, S.I. Varushchenko et al. (1987) distinguished at least 7 transgressive stages (with sea level rising above the present-day level) between 8000 yr BP and the beginning of nineteenth century.

Despite continuous efforts of palynologists (see works published in the 1970s & 1980s by Tatiana Abramova, Vladimir Vronsky and others who studied lacustrine, fluvial and eolian sediments on the land, as well as bottom sediments of the Caspian Sea), palynological results have not revealed large-amplitude climatic fluctuations and changes of vegetation which could be considered as congruent with repeated Caspian level changes as reconstructed by various methods (geomorphological, malacological, archeological, etc.). Only three stages have been recognized and characterized in the climate and vegetation evolution during the Holocene (Abramova, 1980), who ascertained that:

– semi-desert and desert environments prevailed in the coastal Near-Caspian regions during the Mangyshlak regression;

– semi-desert and steppe vegetation, locally with some forest communities, was dominant at the New Caspian transgression maximum (in the Atlantic period);

– somewhat cooler and wetter climate was recorded at the end of Subatlantic period (the 14th century).

When studying the Northern Caspian area, it was difficult to trace past climate and vegetation events in sufficient detail on the basis of pollen data, as there were no available sections with complete Holocene series exposed, adequately dated by radiocarbon and thoroughly studied palynologically.

To fill in the blanks in information, we turned to sections within the desert-steppe zone, though situated in another region – the so called “Pearl of the Volga”. It includes the Volga-Akhtuba floodplain and the Volga delta.

In this paper we present reconstructions of landscape and climatic changes in the Lower Volga area during the Holocene as obtained from palynological records and ^{14}C dating of sequences in the Volga-Akhtuba floodplain. The palynological data were first published (in Russian) by N.S. Bolikovskaya (1990).

RESULTS OF STUDIES OF THE HOLOCENE SEQUENCES IN THE VOLGA-AKHTUBA FLOODPLAIN

Following are the results of detailed pollen analysis of Holocene sediments of two sections located within the most palynologically indicative area in the Northern Near-Caspian region, that is, the Volga-Akhtuba floodplain. At this locality, the floodplain vegetation actively responds to climatic changes and related sea level fluctuations.

At present the Northern Caspian Sea region includes desert-steppe and desert belts. Sagebrush-grass assemblages prevail in the desert-steppe. Automorphous (zonal) landscapes of the Near-Caspian desert are dominated by various dwarf shrub forms of sagebrush (*Artemisia* gen.). Among shrubs growing on dune sands there are mostly tamarisk (*Tamarix ramosissima*) and *Calligonum aphyllum* of the Polygonaceae family. The coastal zone is dominated by saltworts (Chenopodiaceae), and the shoreline is fringed with dense stands of reed (e.g. *Phragmites*).

The Volga-Akhtuba floodplain is now covered with rich herb meadow communities as well as dense riverine forests. The latter, along with various willow species (*Salix* spp.), include poplar (*Populus nigra, P.alba*), maple (*Acer negundo*) and aspen (*Populus tremula*); there are also oak (*Quercus robur*), ash (*Fraxinus excelsior*), elm (*Ulmus laevis, U. carpinifolia*), birch (*Betula pendula, B. pubescens*) and black alder (*Alnus glutinosa*). Thickets in the Volga delta are dominated by willow.

The studied sections are situated near Solenoye Zaimishche village, 5 km south of Cherny Yar in the Astrakhan Region, (47°54′ N, 46°10′ E), about 19-20 m asl (above sea level). The first sequence penetrated by a borehole at an oxbow lake margin on the high floodplain is composed of a lacustrine series 5 m thick. The series was sampled for pollen analysis (50 samples taken at 10 cm intervals) and radiocarbon dating (5 samples). The palynological results confirmed by ^{14}C dates (un-calibrated) enabled a detailed subdivision of the sequence and proved that lacustrine clays had been accumulating throughout the Holocene.

Section 2 is a scarp (c. 6-7 m above the water edge) with fluvial sediments of the high floodplain exposed. Representative data have been obtained from the upper 3 m of the exposed sequence. On the base of pollen assemblages, it may be correlated to the late Subboreal–Atlantic periods of the Holocene. Pollen spectra of the floodplain sediments made it possible to specify zonal belonging of the reconstructed vegetation.

The palynological data formed the basis for a detailed stratigraphic subdivision of the studied sequence, and 26 phases in vegetation and climate evolution have been distinguished.

Two models of transgressive-regressive regimes of the Caspian Sea during the Holocene were developed, based on the interpreted climatic and vegetation successions. The models have been correlated with schemes of Caspian Sea level fluctuations developed using various palaeogeographic methods (fig. 1).

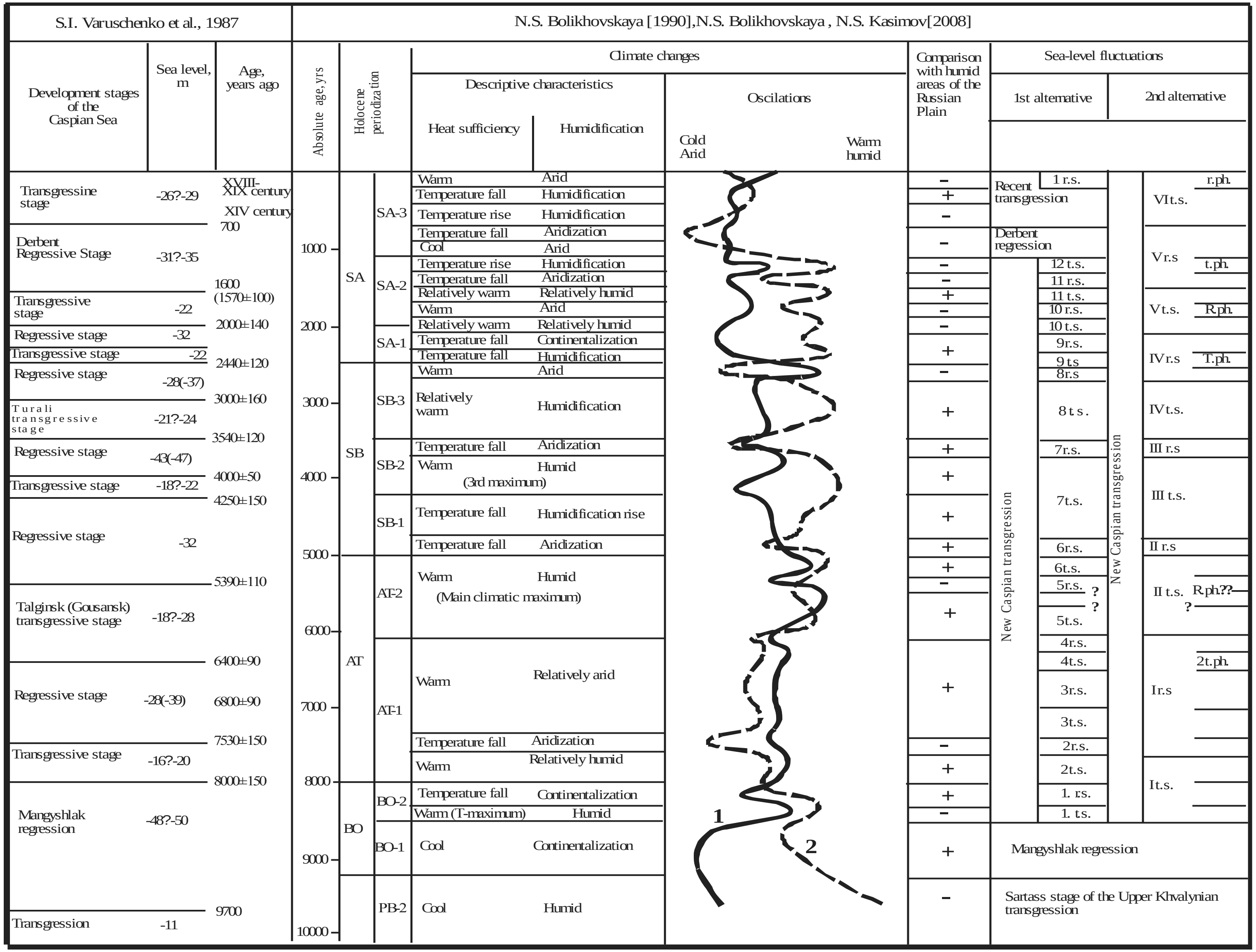

Fig. 1. Reconstruction and correlation of Holocene climatic events in the Lower Volga River Region
1 – fluctuations of heat sufficiency; 2 – fluctuations of humidification

SUMMARY OF HOLOCENE CLIMATIC AND VEGETATION EVENTS

Preboreal period (10000-9200 BP)

On the basis of climatic-stratigraphic schemes, position in the sequence and ^{14}C date of 9560±60 (uncalibrated) obtained for a sample taken at a depth of 4.75-5.0 m, the sediments of the 1st palynozone (formed under a cool continental and relatively wet forest-steppe climate) were attributed to the second half of Preboreal (corresponding with Pereslavl cooling of the central Russian Plain). They are dated as 10000-9200 BP and correlate with the Sartas transgressive stage in the scheme by S.I. Varushchenko et al. (1987)

Boreal period (9200-8000 BP)

The early Boreal was marked by increasing climate continentality (cooling and drying), which led to a dominance of steppe with scattered open forest stands of spruce and pine. The palynofloral composition, reconstructed vegetation, and radiocarbon date of 8500±100 (sample from 4.5-4.75 m depth), make it possible to correlate the interval with the first regressive stage of the Caspian Sea in the Holocene.

Two phases of vegetation evolution may be identified within the upper part of the Boreal sequence. We attribute the mid-Boreal phase, which shows a considerable climate warming and wetting, to the first climatic optimum of the Holocene in the Caspian region. It records the beginning of dominance by broadleaved species in the study area, and can be traced to the end of the Subboreal period. Using interpolation, this initial level is dated to 8500-8300 yr BP. It seems likely that the previous (Mangyshlak?) regression was of somewhat shorter duration than previously assumed and that the Caspian Sea level was at its lowest between approximately 9200 and 8500 yr BP.

A short "cold spell" recorded at the end of Boreal period corresponds to the late Boreal cooling (dated to 8300–8000 BP). At that time dark conifers completely disappeared from the region, while oak and elm stands were also noticeably reduced.

Atlantic period (8000-5000 BP)

Three phases in the vegetation and climate evolution may be distinguished within the early Atlantic interval. The earlier phase has much in common with the mid-Boreal warm phase, and suggests that a longer period of warmer and wetter climate occurred between approximately 8500 and 7600 -7400 yr BP, which was interrupted by a short cooling in late Boreal. This stage corresponds to the first transgressive stage of the New Caspian basin (according to Leontyev and Rychagov).

At about 7600 yr BP a phase of drastic aridization and cooling is recorded. Subsequently, improved thermal conditions led to enrichment of species composition in the forests, while relative drying suggests a sea level lowering in early Atlantic, at about 7600-6100 yr BP. The extent of the lowering, however, was less than that in the early Boreal regression.

The late Atlantic interval featured the greatest extent and diversity of thermophilic elements in the Volga-Akhtuba forests in the entire Holocene. In terms of warmth and moisture supply, the interval 6100 to 5000 yr BP was the main climatic optimum at the study area. It may be correlated with the Gousan transgressive stage of the New Caspian basin (according to S.I. Varushchenko et al., and Svitoch) with 14C dates of 6100±80, 5940 and 5390 yr BP. A short-lived increase in climate continentality was recorded by pollen analysis within this interval at about 5500 yr BP.

Subboreal period (5000-2500 BP)

Development of the early Subboreal environments (5000-4200 yr BP) was influenced by progressive cooling. At the Atlantic/Subboreal boundary the onset of cooling coincided with a short-term aridization (approximately within an interval of 5000 to 4800 yr BP) which initiated the next regressive stage of the Caspian Sea. Later, up to the end of the early Subboreal stage, moisture supply increased steadily and the sea level, in all probability, was rising. The palynological results, therefore, provide support for conclusions of S.I. Varushchenko et al. on the sea level dropping to -32m most probably within the 5000 to 4400 yr interval.

During an initial phase of mid-Subboreal warming (4200 to 3500 yr BP) the vegetation evolved under a warm and wet climate, relating to the 3rd Holocene optimum identified in the North Caspian region. This was somewhat cooler and of shorter duration than the main, late Atlantic, optimum. Calculations and interpolation place the peak of the mid-Subboreal warming at about 3900-3800 yr BP (slightly older than it was in the northern regions). It corresponds to a transgressive stage identified by S.I. Varushchenko between 4200-4000 yr BP. The sub-period ended with an episode of climatic drying at about 3700-3500 yr BP which may be correlated with an aridity phase in the Black Sea coastal regions and a regressive stage of the New Caspian basin between 4000 and 3500 yr BP.

The late Subboreal stage began with a wetter phase that lasted from 3500 to 2700 yr BP and resulted in forest-steppe returning to the Lower Volga region. This phase of humidity was synchronous with the late Subboreal cooling in the central Russian Plain and Turaly transgressive stage of the Caspian. We correlate the period of dry and warm climate at 2700-2500 yr BP with Alexanderbay regressive stage.

Subatlantic period (2500 yr BP – present day)

Throughout the last 2500 years the climate in North Caspian region was generally cooler and more continental than during the Atlantic and Subboreal periods.

The early Subatlantic (2500-2000 yr BP) is noted for climate and environment instability: a short-term cooling and wetting in the initial phase turned to an increase in the climate continentality and cooling at about 2400 yr BP. The process reached its peak at about 2200 yr BP, when broadleaved forests disappeared almost completely from the Lower Volga valley.

During the mid-Subatlantic time (2000 to 1100 yr BP) the climate became milder, and three phases can be distinguished. A warming in the initial phase (dated as 2000-1500 yr BP) may be correlated with Ullu-chai transgressive stage of the Caspian Sea (with radiocarbon dates from 2000±140 to 1570±100 BP; S.I.Varushchenko et al.). The subsequent cooling and aridization at c. 1500-1300 yr BP corresponds to the first phase of the Derbent regression. Renewed warming and increased humidity are recorded in the interval 1300–1100 yr BP.

The initial, dry-steppe phase of the late Subatlantic stage featured climatic cooling and drying at about 1100–900 yr BP. At its maximum, the environments showed absolute dominance of semi-desert and desert plant assemblages, while the Volga-Akhtuba floodplain forests disappeared almost completely. Pollen data indicate that the Derbent regressive stage of the New Caspian basin was interrupted by a sea level rise at about 1300–1100 yr BP; the lowest sea level presumably occurred between c. 900-700 yr BP.

In the most recent sediments, subsequent to a radiocarbon date of 900±60 yr BP, the study site has remained within the area of semi-desert, not unlike those of the present day in the region. Some cooling and wetting was recorded within the interval 400-200 yr BP. Most of the sub-recent pollen spectra in the Volga-Akhtuba region (studied for the purpose of interpreting the Holocene pollen assemblages) indicate that thermal conditions (warming) of the last century have led to an increase of broadleaf species in the Lower Volga floodplain forests more so than at any time during the last thousand years.

CONCLUSIONS

The following special features of terrestrial vegetation and climate changes have been established at the Lower Volga during the Holocene. They may be considered as indicators of the intensity and timing of transgressive and regressive Caspian Sea level fluctuations controlled by climate, and also as a climatostratigraphic framework for comparison with palynological and other studies of the Volga delta Holocene sections.

1) A specific feature of the Holocene within this region is the presence of three climatic optima, typically marked by peaks in heat and moisture supply.

a) The main optimum dated to the late Atlantic interval (6100 – 5000 BP) was a time of forest-steppe prevalence. The total of thermophilic tree species in the pollen spectra reaches 31%. The forest belt in the Volga valley consisted of mixed forests with hornbeam (*Carpinus betulus, C. caucasica*), oriental beech (*Fagus orientalis*), various species of elm (*Ulmus laevis, U. foliacea*), lime (*Tilia cordata*), birch and other trees as well as conifer stands.

b) The late Boreal (8500-8300 BP) and mid-Subboreal (4200 – 3700 BP) optima were also dominated by forest-steppe or, at certain times, by steppe. They differed from the Atlantic optimum, however, in that the conditions were less favorable for broadleaf trees and the proportion of the latter was considerably lower. Total broadleaf pollen does not exceed 21-23%, with noticeably lesser proportions of warm (and moisture) loving plants.

The three stages described could most certainly correspond to transgressive stands of the Caspian basin.

2) Transgressive Caspian regimes are also indicated by phases and sub-phases of a cool and relatively wet climate. The first is a forest-steppe phase recorded in the interval 10 000–9200 yr BP. At that time, forest stands dominated by spruce and fir occurred in North Caspian region along with open pine forests.

Another sub-phase of cooler and wetter climate, similar to the above in terms of climatic and vegetation characteristics, though of shorter duration, has been established on the basis of pollen data at the beginning of Subatlantic period of the Holocene, in the interval 2500-2300 BP.

3) Regressions of different rank might correspond to reconstructed minimums of heat and moisture supply, as well as intervals of noticeable warming and aridization.

a) Two conspicuous minimums of heat and moisture supply occur in the early Subboreal and in the first half of late Subatlantic. The first one corresponds to the first Holocene regression of the Caspian Sea (Mangyshlak, by Varushchenko); palynological studies and radiocarbon dates obtained for the Solenoye Zaimishche section place it within the 9200–8500 yr interval. The 2nd minimum is correlatable with Derbent regression (1500–700 BP).

Pollen data indicate that the Derbent regressive stage of the New Caspian basin was interrupted by a sea level rise at about 1300–1100 yr BP; the lowest sea level presumably occurred between c. 900-700 yr BP.

b) Within the interval 8500–1500 yr BP there has been one phase of sudden warming and aridization (about 2700–2500 yr BP) and five phases of drastic cooling and aridization identified; the latter are approximately dated as 8300-8000, 7600–7400, 5000-4800, 3700-3500 & 2300-2100 yr BP and might correspond to short-term, though significant, lowerings of Caspian Sea level.

The most important of them occurred about 7600–7400 and 3700–3500 yr BP. All the cool and dry phases were marked by dry steppe and semi-desert dominance in the region, with xerophytic assemblages of Chenopodiaceae and *Artemisia* occurring frequently.

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OBSERVATIONS OF TERRACING AND STRANDLINES IN AZERBAIJAN IN ASSOCIATION WITH MUD VOLCANOES AS INDICATORS OF PAST FRESH AND SEAWATER INUNDATIONS

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Fluctuations in the level of the Caspian Sea have greatly influenced coastal communities for millennia. This is due in part to a dynamic balance between regional climate, temperature, rainfall in the catchment areas of the rivers feeding the basin (principally the Volga), and evaporation from the surface of the sea. As an endorheic basin (i.e., having no outflow), and evaporation estimated to be just less than a meter per year, sea level will either rise or fall depending on climate and rainfall. Currently, sea level is around –28 m relative to mean sea level. In the present era, fluctuations are only on the order of a few meters, and while significant to those living near the sea, they are relatively minor compared to the dramatic regressions and inundations (transgressions) associated with the Ice Ages (Mamedov, 1997).

During ice ages, the sea greatly shrinks due to a cooler, drier climate. At the end of an ice age, meltwater inundates the northern watershed areas to drain via river systems into the lowlying basins of the Aral, Caspian, and Black Seas. In addition, ice cap melting from the Himalayas and Hindu Kush adds to the inflow. Significantly, it is further recognized that Arctic Ocean ice fronts advanced onto mainland Russia and blocked the north-flowing rivers (Yenissei, Ob, Pechora, Dvina, and others) that supply most of the freshwater to the Arctic Ocean (Baker, 2007; Grosswald, 1998; Mangerud et al., 2001 and 2004; Rudoy, 1998).

In consequence, large ice-dammed lakes formed between the ice sheet in the north and the continental water divides to the south. The lakes overflowed toward the south, and thus the drainage of much of the Eurasian continent was reversed. The result was a major change in the water balance on the continent, decreased freshwater supply to the Arctic Ocean, and increased freshwater flow to the Aral, Caspian, Black, and Baltic seas. The legacy of these inundations has left marks on the soft Azerbaijan landscape both above and below sea level in the form of terraces and strandlines. To complicate the picture further, the presence of marine mammals, such as the Caspian seal, demonstrates previous connection to the Arctic Ocean. Overall, it is a complex and poorly understood situation, and a detailed chronology of inundation and sea-level change has yet to be established for the Caspian Sea.

As an amateur archaeologist with a fascination for the prehistory of Azerbaijan, it became apparent that there were cultural similarities between Azerbaijan and the Caucasus to the Mediterranean region and, in particular, pre-dynastic Egypt. Examples include the presence of ‘cart ruts’ on the Apsheron Peninsula, near Baku, similar to those of the Mediterranean countries, especially Malta; petroglyphs of multi-oared boats at the Gobustan outdoor museum are identical to images from Egypt. Most notably, the father of Egyptology, Sir William Flinders Petrie, observed philological similarities in place names, peoples, and geography within the Egyptian *Book of the Dead* to the Caucasus and concluded (contentiously) that Egyptians owed some of their ancestry to the Caucasus region. These and other similarities are addressed in a separate paper. What seems evident, however, is that cultural connections may well have come about as a result of maritime transportation in a flooded landscape. (Petrie., 1926) The possibility of firm cultural connections has encouraged investigation of the Azeri countryside for evidence of inundation. In doing so, a number of observations have been made of terracing and strandlines that may contribute to archaeology and our understanding of Eurasian paleohydrology. Bivalve mollusk samples have been obtained for radiocarbon dating of a prominent 100m elevation mud volcano marine terrace. Results will be available in August 2010.

This paper presents observations on the water-etched landscape of Azerbaijan and considers possible circumstances that led to strandlines and terracing at greater than 200 m and marine water in excess of 115 m above mean sea level. Evidence points towards prolonged Eurasian glacial meltwater and diverted river drainage, and the possibility of oceanic ingress from the Barents Sea. Some archaeological evidence is presented that alludes to wider maritime connections between the Mediterranean and Central Asia.

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OBSERVATIONS ON LANDSCAPE IMAGERY AND THE PREHISTORY OF AZERBAIJAN AND THE CAUCASUS IN RELATION TO PERCEIVED CULTURAL CONNECTIONS WITH ANCIENT EGYPT

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Keywords: Caspian Sea, Black Sea, Manych, deluge, zoomorphism, rock art, anthropomorphism, cultural connections, Mt. Elbrus, Mt Kasbek, Kurgan, Petrie, Fessenden.

Azerbaijan and the Caucasus played a major role in prehistory, at the dawn of civilization when the landscape was very different from today. Due to (inundation of diverted northern Russian rivers caused by the Ice Age Arctic ice fronts, plus melt water from the northern ice sheets and Hindu Kush icecaps in the Late Pleistocene), the landscape was deluged. This allowed the Caspian Sea to connect to the Black Sea at the Manych Lake system via the Kuma-Manych corridor. (Baker.,2007), (Grosswald., 1998), (Mangerud et al., 2001 and 2004), (Rudoy.,1998). This significant waterway effectively connected the Caspian Sea to the Mediterranean, potentially allowing for ancient travel, trade and cultural transfer to occur in the Early Holocene, possibly as late as 6000 years ago. The waterway also served to link people across the Caucasus.

Observations of rock carvings found at Gobustan are of special interest for they indicate early inhabitants used large oared vessels that could have been used in long distance transportation between the Caspian Sea and into the Mediterranean Sea. Rock art images of boats and people from Gobustan show strong similarities to imagery of predynastic Egypt. ‘Cart ruts’, – long incised carved channels in bedrock, (possibly used in megalith transportation) are typically found in coastal countries around the Mediterranean, including Malta. ‘Cart ruts’ are obviously the product of a maritime culture and are oddly also found in Azerbaijan.

A number of archaeological discoveries have been made to indicate that the people had an animistic belief system, knowledge of astronomy and that they venerated the sun. Evidence of this is deduced from large anthropomorphic landscape carvings which have yet to be scientifically recognized and studied. Similar features are also to be found in Western Asia. Bekbasser, (2005). Marsadolov, (2005). Great effort evidently went into creating landform images and indicates that the ancient inhabitants had a strong social organization. Such organization combined with an animistic and sun worshiping outlook suggests regional cultural connections.

Tangible evidence exists in both mythology and in rock carvings to demonstrate connections to predynastic Egypt. For example, Sir William Matthew Flinders Petrie, the *Father of Egyptology,* and a renowned scientist Professor Reginald Fessenden pointed out that, in the *‘Egyptian Book of the Dead’* the mythological people, place names and geography all have counterparts in the Caucasus, and suggested it may be an ancient Egyptian homeland. Strikingly Petrie observed that there were only two places where the sun rose over the *Mountain of Bakhau* (Baku) and set over the Mountain of Tammanu; one was the Book of the Dead the other the Caucasus mountain range. Petrie (1926).

Fessenden also notes that the Caucasus mountain range is aligned at an angle of 23.5 degrees which matches the angle of tilt of the planet earth. The consequence of this is that the sun rises at the winter solstice to the South East and sets at the Summer Solstice to the North West, both in line with the Caucasus. Fessenden (1923). Such an observation where the ‘heavens’ seemingly joined with the earth (mountains) would be apparent to an astronomically aware and sun worshipping culture and would have great religious significance.

Curiously the iconography associated with the *Egyptian Book of the Dead* can be identified with specific locations in the Caucasus. For example Besh Barmak (or Mt. Barmak) to the north of Baku is a place of religious pilgrimage today; it is steeped in legend, is an archaeologically though unstudied rich landscape and also appears to be a huge zoomorph. The mountain further shares attributes with the Egyptian description of the ‘*Mountain of Bakhau of the Rising Sun’.* Its name – Barmak, bears a phonetic resemblance to the ancient Greek word for the Sphinx, – Harmakis. This suggests that the enigmatic Sphinx may have been carved in memory of this important landmark.

Europe's highest mountain, Mount Elbrus as seen from the North Caucasus city of Kislovodsk may be the source of the Egyptian Ahket sybol. At the winter solstice the sun appears to sit between the two peaks of Mount Elbrus, just as it appears with the Ahket.

Even more striking is a perceived alignment relationship between the Great pyramids of Giza and the Caucasus Mountains. Starting from the apex of the Pyramid of Menkaure and sighting over the apexes of the Pyramids of Khafre and Khufu the distant targets are respectively Mt.Elbrus and Mt Kasbek. The combined accuracy has a probability against chance of around one in a million and goes well beyond coincidence. These and several other intriguing alignments appear to indicate that the Egyptians, using their profound astronomical, mathematical and engineering abilities built the pyramids as indelible markers or signposts to important places to communicate to posterity who they were and where they came from.

It is further curious to note that the timing of early Egyptian dynasties coincides with the migrations from the northern Caucasus in the 3rd millennium BC, the – '*Kurgan Hypothesis*' as expounded by Maritja Gimbutas. It seems reasonable then to infer that some migrants left the Caucasus by boat to settle in Egypt: a place where long cultural connections may have been established.

It is therefore postulated that: with the loss of the Kuma-Manych waterway, due to diminishing meltwater, and subsequent deteriorating environmental conditions, the rich Kurgan culture that stretched across the Caucasus was driven to live in more environmentally reliable locations, one of which is the Nile Valley. In doing so technical know how was exported and may have been instrumental in kick starting the Egyptian civilization. Monuments were created in honour of, and to remind of an ancestral homeland. Over time, distance and with transportation difficulties the memory of the Caucasus faded only to be remembered in mythology.

It is salutary to note that Sir William Matthew Flinders Petrie challenged future archaeologists to research cultural connections, but for various reasons this has yet to happen. It is hoped that this paper and the information presented, provides sufficient evidence to support his conviction and serves to stimulate study into the theory of an ancestral Egyptian homeland in the Caucasus.

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A 3M SEA LEVEL RISE AT THE LAST CYCLE OF THE CASPIAN SEA ON THE IRANIAN COAST

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The Caspian Sea, the largest lake in the world, represents rapid sea level change. This provides a real physical model of coast against rapid sea level change in a period of just a few years which may take a millennium in the oceanic body. Between 1929 and 1995 Caspian Sea level passed the last cycle with a range of ± 3. This caused terrible effects along the coast and destroyed many buildings, roads, farms and other human properties. While the lowest fall lasted in a period of 48 years left marine deposits, developed residential zone, the rapid sea level rise occurred in a period of 18 years, representing disordered cycle, imposed landward shift. This paper reflects the last rapid sea level rise outcome along Iranian shoreline using landsat and filed data. In this study the south Caspian sea has been subdivided within 23 littoral cells and each cell also contains 4 transects over a 2 km distances. The results show that the coast reaction against rapid sea level rise in some parts is still experienced seaward due to strong coastal progradation and sediment supply. Beside of main coastal processes, a local factor (Local morphology) plays as a fundamental task on the near shore morphology.

RAPID HOLOCENE SEA-LEVEL CHANGES ALONG THE IRANIAN CASPIAN COAST

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The Caspian Sea is known due to rapid sea level change in the world. In the recent years its level experienced ±3m from 1929 to 1995 showing very rapid sea -level change in comparison with oceanic sea -level change therefore, it is a laboratory to study rapid sea level change and its influence on the coastal evolution. The main attempt of this study is to reconstruct the sea- level curve in Holocene by using core sampling and radiocarbon dating. The Caspian Sea is not only regional interest but also its level is affected by global change therefore, it reflects the global change including climate and tectonic effects. The stratigraphy evidence approves the number of cycles of the Caspian Sea towards late Holocene are being increased. The main rapid sea level- rise took place about, 2380, 5990, and 8800 BP in Holocene.The early Holocene was started with a big regression and lasted to 8800 BP. There is a thin distinct surface showing a big flooding around 8800 PB. Four Phases of long-term sea level rise as cycles of the Holocene period were identified. Other phases as smaller cycles were distinguished on nearshore core and can be ranged in periods of 250- 300 years as disordered cycles.

GEOCHEMICAL CHANGES OF THE CASPIAN SALT MARSHES UNDER CONDITIONS OF SEA-LEVEL FLUCTUATIONS

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Keywords: sea-level changes, salt marshes, transport and accumulation of chemical elements

INTRODUCTION

Global warming and the rise of the world ocean's level are among the most important present-day environmental problems. Within most of the world regions present-day sea-level change proceeds as a rule rather slowly and it is almost imperceptible in human life time scales. The Caspian Sea offers a unique opportunity to study the impact of sea-level change on the coastal zone for short-term period, because the Caspian sea-level change is much more rapid than that of the world oceans. For this reason, the Caspian Sea shores are perhaps the best sites to study the effect of sea-level changes on coasts (Ignatov et al., 1993; Gennadiev et al., 1998; Kasimov et al., 2000; Kroonenberg et al.,2000).

The Caspian Sea is well known for large and rapid sea-level fluctuations. The most recent cycle lasted only 65 years. Sea-level fell by over 3 m between 1929 and 1977 and rose again by 2,4 m until 1995, when it started falling again. Today it is stable at – 27 m below global sea-level, but it can be a short break in the transgression period or it can be the beginning of the regression period. The most dramatic consequences of the influence of rapid transgression were experienced by accumulative coasts (Ignatov et al., 1993).

The Central Dagestan type of coasts is rather suitable for studying the environmental change of the Caspian accumulative shores under sea-level fluctuations. During the sea-level fall (1929-1977) the coastline moved seawards. Small-scale retreats of the coast resulted in the formation of very low sandy-shelly bars with a height of 0.2±0.5 m (Kroonenberg et al., 2000). No lagoons were formed in this period according to monitoring data and aerial photographs.

The last transgression of the Caspian sea (1978-1995) caused the development of barrier coasts with adjacent lagoons at shores with intermediate gradients between 1-10 m/km (Ignatov et al., 1993). After 1978 the marine terrace is progressively drowned and barriers and lagoons move landward at an average rate of 20-30 m/year. Such type of the coasts is common for Dagestan. The formation of the barrier-lagoon system during the last transgressive coastal cycle is typically for different regions of the Caspian shore (Ignatov et al.,1993; Badyukova et al., 1993; Kravtsova et al.,1997). Lagoon coasts occupy about 10% of the world ocean shores (Recent global changes…, 2006).

MATERIALS AND METHODS

Field works were conducted near the Turali research and training station, which belongs to the Moscow State University and is located 30 km to the south of Makhachkala, the capital of Dagestan. The investigations were carried out in 1995-1996 when the sea-level rose (Gennadiev et al.,1998; Kasimov et al.,2000) and they were continued in 2001-2005 when it became stable.

The Turali key site stretches from the waterline across a modern constructional plain to the scarp of the New-Caspian Holocene terrace. The New-Caspian terrace is separated from the modern terrace by a relatively low scarp (up to 2 m high). The level of the terrace is 3.5 m higher than the sea level now.

The modern constructional plain varies in width from 100 to 500 m; a series of low bars of 1929, 1941, and 1956 can be distinguished within this plain. The field work was carried out at a cross-section (150×400 m) stretched from the New-Caspian terrace to the sea shore through the modern strand flat (Fig.1). During the fieldworks about 500 soil samples, 100 samples of bottom sediments, 100 samples of natural waters were collected.

The most important physical and chemical parameters of surface and ground waters and of each selected soil horizons were defined immediately at the sampling points: pH, Eh, total dissolved salts (TDS), the sodium content. The analysis of water samples, bulk and mobile forms of chemical elements in soils were done by the atomic-absorption method using the spectrophotometer Hitachi 180 (Japan).

In order to define bulk values of heavy metal content in soils and bottom sediments the samples were digested with a mixture of concentrated acids (HNO_3 and HF). For analysis of mobile forms of elements in soils and bottom sediments 1N (2N) HCl was used as the extraction agent. Water-soluble, exchangeable and amorphous forms of elements passes are extracted in this way, and also, in part, organic-mineral connections.

RESULTS

Inundation and waterlogging of the coastal zone have resulted in a considerable change of coastal soils. Former coastal solonchaks, weakly developed loose sandy hydromorphic soils, and meadow solonchakous soils are replaced by wet-meadow ferruginous solonchaks, marsh sulfide-gley solonchakous soils, and the submerged soils of the lagoon. The morphology, geochemistry and evolutionary sequences of these soils have been described in detail in our previous publications (Gennadiev et al.,1998; Kasimov et al.,2000).

The soils studied have close evolutionary links. They have undergone differently directed evolutionary stages. In dependence on particular site conditions, the soils and sediments of the coastal zone can be subdivided into three evolutionary groups with respect to their response to the advances and retreats of the sea (Gennadiev et al., 1998).

The first group includes the recent beach deposits (T-I). They occupy the most seaward position. The oldest evolutionary group includes soils on the sediments of the New-Caspian terrace (T-III) that are not affected by modern water table fluctuations. The concentrations of majority of chemical elements in weakly developed sandy soils of the New-Caspian terrace soils are low (Table 1).

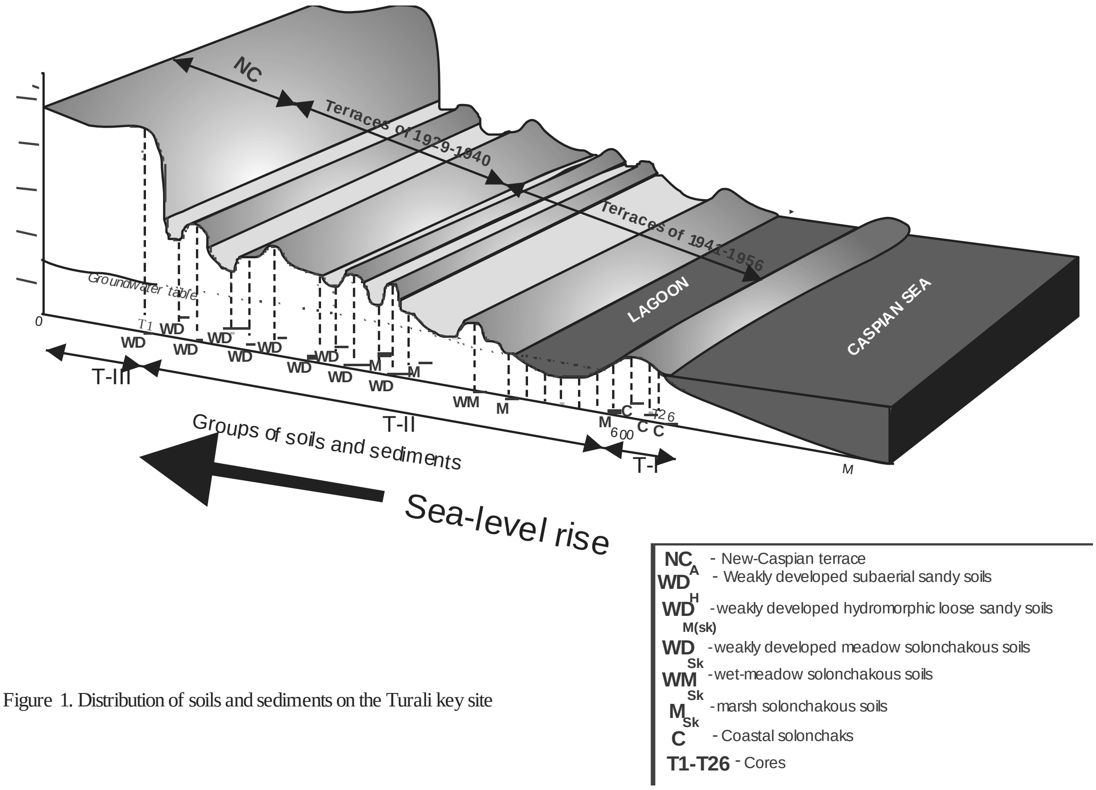

Figure 1. Distribution of soils and sediments on the Turali key site

Low geochemical background of the chemical elements is due to light granulometric composition of marine sediments composed of clean sand and shell detritus. Only Mo has an increased background concentration that corresponds to boron-molybdenum geochemical specialization of the Caspian region.

The middle evolutionary group (T-II) includes different soils of meadow avant-marsh and marsh-lagoon zone that are variably transformed by superimposed processes during the transgressive phase and the phase of the stabilization.

Transgressive phase. The flooding and waterlogging of the soils of coastal plains in Central Dagestan have modified the geochemical conditions in the coastal zone and altered the chemical composition of modern soils and sediments.

Table 1

Concentration of elements in slightly affected soils and sediments of the site, mg/kg (n=5)

Concen-tration	Fe	Mn	Ni	Co	Cr	Cu	Zn	Pb	Cd	Sr	Mo
Bulk	10000	155	5,3	2,6	2,2	2,9	18,8	5,7	0,07	405	6,7
Mobile	1382	87,7	0,3	0,5	0,65	1,1	4,6	2,6	<0,01	225	–

The changes of geochemical properties and concentrations of trace elements are shown in the Tables 2 and 3.

Phase of the sea-level stabilization. After the stabilization of the sea-level the movement of the bar-lagoon system has stopped, the lagoon has shoaled. The depth of the ground water table has decreased in the marsh zone. That led to the transformation of geochemical parameters and trace element's concentration in the soils of the salt marshes.

Table 2

Changes of geochemical properties in soils and sediments of salt marshes upon the fluctuation of the Caspian Sea level

Soils	Phase	Eh, mV	pH	TdS,mg/l
1	transgression*(23)	+150…+200	8.2-8.6	20-100
	stabilization **(30)	+150…+200	8.1-8.6	20-100
2	transgression (32)	-159..+150	8.4-9.2	100-1000
	stabilization (59)	-80…+120	8.3-8.7	200-5800
3	transgression (22)	-150…+100	8.1-8.5	500-2500
	stabilization (30)	-130…+150	6.1-7.4	1200-7100
4	transgression (14)	-50…-380	7.5-8.3	2000-6000
	stabilization (19)	-150…-300	6.1-7.3	3000-6000

Table 3

The concentrations of chemical elements in soils and sediments of salt marshes (site "Turali"), mg/kg

Soils	Phase	Fe	Mn	Ni	Co	Cu	Zn	Pb	Cr
1	transgression* (23)	9500[1]	152	4	1,7	2,5	15	5,8	2,5
		1500[2]	101	0,4	0,4	0,8	4,1	2,4	0,05
	stabilization** (30)	8700	144	3,7	1,5	2,4	13,5	6,3	2,3
		1850	121	0,6	0,5	0,7	2,9	1,8	0,05
2	transgression (32)	9300	163	3,8	2,0	2,0	14,8	4,1	2,8
		1200	109	0,5	0,6	1,0	5,6	2,6	0,14
	stabilization (59)	8900	189	4,3	1,7	2,2	15,2	4,5	2,5
		1500	118	0,9	0,8	0,7	4,1	2,4	0,09
3	transgression (22)	6500	227	3,9	2,2	1,9	15,6	4	3,7
		4200	131	0,7	0,9	1,2	7,3	3,2	0,15
	stabilization (30)	7600	248	6,2	2,4	2,5	17,1	5,7	4,4
		3100	161	1,4	1,5	1,8	9,2	2,7	0,12
4	transgression (14)	5950	136	3,2	2,2	3,0	13	3,5	8,8
		5400	102	2,6	1,2	2,9	12,1	3,2	0,9
	stabilization (19)	5200	176	6,5	2,6	3,3	14,2	4,5	6,6
		4400	110	1,6	1,6	2,7	13,0	3,0	0,11

Investigations: * – 1995-1996; **-2001-2003. (n) – number of samples. 1-bulk forms; 2 – mobile forms.

Soils: 1-weakly developed hydromorphic loose sandy soils of terrace of the 20-30-ies; 2-weakly developed meadow solonchakous and wet-meadow ferruginous solonchakous soils of meadow avant-marsh zone; 3-marsh solonchakous soils of marsh zone; 4-aquic soils of the lagoon.

DISCUSSION

Long-term monitoring of the shore zone landscapes of the Central Dagestan abrasion-accumulation plain (Turali site) allows to reveal the environmental changes due to the whole cycle of the Caspian sea-level changes (regression-transgression-stabilization). The first part of the cycle lasted for 50 years (1929-1978) and was characterized by the retreat of the sea, lowering of the ground water table, and general decrease in the degree of hydromophism of the territory. The second phase of the cycle (1978-1995) corresponded to the rise in the sea level and the depth of the ground water, and to increase in the degree of waterlogging of the soil cover (Gennadiev et al., 1998; Kasimov et al., 2000). The transgression of the Caspian sea caused the formation of bar-lagoon system along the seashore that moved landward at an average rate of 20-30 m/year.

The third part of cycle (1995–2006) is characterized by the stabilization of the sea, shallowing of the lagoon and lowering of the ground-water in the marsh zone. The movement of the bar-lagoon system landward has stopped.

The geochemical conditions in coastal soils were not various during the regressive period. The concentrations of the chemical elements were low and spatial distribution was homogeneous. From the beginning of the transgressive period the variety of geochemical conditions in coastal soils increased that affected the mobilization and availability of both major and minor metals. The distribution of trace metals in the sediments has been modified to a great extent by landscape-geochemical processes that caused the formation of geochemical barriers in soils.

The formation and gradual inland movement of the bar-lagoon system has led to additional accumulation of organic matter in low-marsh soils; the development of anaerobic processes in the presence of sulphate-rich water has resulted in the precipitation of sulphides in bottom sediments of the lagoon and in the soils of low marshes. The co-precipitation of iron and heavy metals together with sulphides and the accumulation of iron at oxidizing barrier are the main processes of the transgressive period (Kasimov et al., 2000).

After the stabilization of the sea-level the geochemical conditions of the marsh soils began to change slowly. The shallowing of the lagoon has resulted in partial oxidation of sulfides in the upper horizons of marsh soils and formation of sulfuric acid. This is accompanied by the acidification of coastal soils and increased the accumulation of iron in the upper horizons of the soils.

During the period of sea-level stabilization the redoxcline in the marsh soils has shifted below 10-15 cm that caused the higher mobility of trace elements in the upper 5-15 cm and accumulation of total forms on the oxygen geochemical barrier.

The development of meadow vegetation in the marsh zone increased the rate of humus accumulation in coastal soils. As a result in 2001-2003 the rate of humus accumulation in peaty horizons was 1,9 % per year.

If the sea-level begins to rise again that will lead to the movement of bar-lagoon system landward and the width of lagoon will decrease (Recent global change…,2006). It will lead to waterlogging of the weakly developed meadow solonchakous and wet-meadow ferruginous solonchakous soils within meadow avant-marsh zone. It will cause the development of the anaerobic processes, the accumulation of sulphides, humus and concentration of chemical elements.

The further stabilization or regression of the sea-level will be accompanied by the drainage of the marsh zone, the oxidation of the sulfides in the upper horizons, acidification of soils and the accumulation of iron in the soils. On the one hand, the accumulation of iron oxides and hydroxides, humus can cause the accumulation of other microelements. On the other hand, the acidification of soils may enhance the mobility of heavy metals and their removal from the soils. The proportion between these two opposite processes must be studied in the future.

CONCLUSION

The salt marsh environment is a complex system. Even small changes to the surrounding environment can significantly affect the overall cycling of the metal forms. Salt marsh sediments provide a valuable tool for the study of trace metal behaviour during different landscape-geochemical processes.

ACKNOWLEDGEMENTS

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FLUCTUATION OF THE CASPIAN SEA LEVEL AS INDICATOR OF GEODYNAMIC STRESS OF THE CRUST IN THE LIGHT OF THE GEODRIFTGENAL CONCEPT

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Keywords: vibration, indicator, geodynamics, geodriftgenal concept, correlation, morphogenesis, mantle, divergence, convergence, anvergence, rifting, spreading, subduction, collision, morphostructure, plate tectonics, conformity, disconformities, intralability, seismic dislocation, earthquakes, mud volcanism, stress, regime, compression, decompression, resorption, stabilization, verification

INTRODUCTION

The article deals with the indicatory property of the fluctuation of the Caspian Sea level as a recording media in the system of endodynamics-exodynamics from the point of view of geodriftgenal concept of relief evolution. It is suggested to use the correlation relationship in the given system to establish and predict the regime of geodynamic stress of the crust. The investigations carried out in this aspect show that periods of high stand in the sea level correspond to the periods of compression, whereas periods of low stand– to the periods of stretching, and the both periods – to the periods of relative stabilization of the crust tension. Thus, regime conditions are associated with intensification or weakening of earthquakes and mud volcanoes, as well as dynamics of oil and gas well flow rate.

The fluctuation level of the Caspian Sea in the light of the fundamental argument of its being isolated from the World ocean is determined by its autonomous response to exogenous and endogenous events, where climate and anthropogenic factors are traditionally preferred. However, but for some scientists, without neglecting the importance of these factors, we pay attention to the crucial role of phenomena determined by endogeodynamic processes such as ebb and float of intraformational waters into the sea, volume changes of its basin. Thus, the assumed relationship is considered in terms of geodriftgenal concept (geodriftgenal results from movements of tectonic plates of the Earth geomorphosystem), which develops on the basis of the principles of the theory of plate tectonics (mobilism) and representing geomorphologic concept (modified option for mobilism) as a theoretical basis for the study of mechanisms of relief formation and development from new points of view. According to this concept, the full cycle of the relief evolution from peneplain-to peneplain is divided into successive stages of divergence, convergence, anvergence as well as rifting, spreading, subduction, collision, relaxation, planation stages. (4, 6, 9, 11).

During the divergence period rifting stage is characterized by a split of lithosphere and development of rift systems, followed by formation of the ocean basin, and the formation of morphostructures of rift trough and continental destructive plateau margins, while the spreading stage is characterized by plate spreading, expansion of the ocean bottom and the formation of sequential-evolution number of primary conformal morphostructures of underwater non-volcanic uplands (mass), valleys, basins, mid-ocean ridges and other varieties.

During the divergence period subduction stage is characterized by mersion of one plate beneath the other in the mantle, the shortening and closure of oceanic basin and the formation of largely conformal morphostructures, abyssal plains and basins, volcanic mountains, subduction troughs (deep-sea basins), supersubduction island arcs, active plate margins (transition zones), and in the collision stage due to escalation of counter motions and restriction of the ocean floor there occur collisions of tectonic plates, which is accompanied by transformation of morphostructures of previous stages, there are formed heterogeneously and heterochronously built cover-scaly block infolded conformal and disconformal morphostructures of suture zones.

During the anvergence period in the conditions of dynamic and thermal relaxation stage of geodynamic stress, disseccation is characterized by exogenous dissection and destruction of mountain ranges, degradation of existing morphostructures and the emergence of their typological variations, while during the planation stage relief dissection in its low stable position is completed by its leveling to the peneplain and formation of platform morphostructures (4, 6, 9).

According to the above-mentioned geochronological scheme the relief of the region under consideration in the system of the alpine suture orogenic belt having gone through the Baikal, Hercynian full cycles and divergence stage of incomplete alpine cycle develops in the incomplete collision stage of its convergence period of relief evolution. Thus, such phenomena as complexity and homogeneity of geological and morphodynamic characteristics of topography, seismic activity, intensity of mud volcanoes, variations of geophysical fields, fluctuations of the Caspian Sea level, instability of oil recovery in time, quasiperiodicity of recent tectonic movements and other endogenously predetermined events generated by the geodynamic regime of tectonic plates and changeability of the crust tension stand in close connection with each other. This probably affects the density of solid and liquid substances of the crust and their geophysical properties, so that magnetic and gravitational fields depending on the current geodynamic situation undergo certain qualitative and spatial transformations(1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14).

Analysis of the above-mentioned situations connected with the laws of geodriftgenesis in terms of the relief of the Caspian Sea testifies to the fact that considerable complexity and diversity of geological-geomorphological structure and special geodynamic condition at the abutment joint of the tectonic plates display close relationship with the relief evolution conditions in the collision stage. As the relief evolution of Eurasian and Afroarabian tectonic plates predetermined formation of a wide range of heterogeneously built morphostructures, their heterochronic morphogenetic and typological varieties, as well as their regional and local spatial differentiation.

The presence of zones of magmatogenic rocks of ophiolites association**,** considerable horizontal displacement of thick layers of the alpine cover, with widespread development of overlapping-overthrust folding morphostructures, richness of magmatism products characteristic of compression and stress regimes of the crust, regular connection of overthrust plane and deep faults with the direction of subduction **(**subfluence), one-sided asymmetry of linear morphostructures, correspondence of the course of morphostructures with the course of margins of tectonic plates (microplates) and transform faults, traces of rotational kinematics of plates and blocks testify in favor of the given model**.**

However, zones of deep crustal stresses are projected onto its surface by morphostructures of significant dynamic activity. Due to this, there can be observed strict subordination of morphodynamic environment to a certain regularity, i.e. strengthening of deep geodynamic crust tension leads to intensification of gravitational and fluvial destructions of morphostructures and vice versa. There is observed intense degradation and destruction of young slopes of mountainous ranges and ridges as a response to endogenous deformation and particularly thrusting movement of plates of the alpine cover (4, 9, 11, 14).

As to seismic activity in the region it should be noted that as deep destruction of rock layers in the crust is closely related to the geodynamic tension of tectonic plates, the known models of earthquake preparation (diletation- diffuse and avalanche-unstable fracturing) are characteristic both for the periods of compression and of the crust extension. In addition, it is believed that intrusive body which according to the concept of intralability creates additional tension and by causing seismic dislocation plays a certain role in the preparation of the earthquake (5, 10).

Therefore, earthquakes which take place every year, as well as occasional intensification of mud volcanism testify to the geodynamical stress condition of the crust and its quasiperiodic nature of changeability. It is assumed that strong earthquakes which occur due to the rise of the sea level are connected with the compression regime and those which happen during the fall of the level are associated with the crust extension regime**.**

Statistical analysis of historical and archaeological data, and instrumental observations of the fluctuation of the Caspian Sea show that besides Qauternary and its more ancient large-scale transgressions-regressions alleged and fixed multiple fluctuations have been taking place throughout the history of the sea since its isolation from World Ocean. There is no doubt that this phenomenon happening with varying frequency and amplitude will keep on happening in the future as well, and apparently will continue up to the anvergence stage of the evolution of the relief and the final closure of relics of the Tethys Ocean. Therefore, the study of the relationship of sea level fluctuations with endogeodynamic factors, in particular, the regimes of the crust stress, remains a very challenging problem and its solution is of great importance in the economic and socio-environmental plan (13). The observed periodicity of the Caspian Sea fluctuation, which is certainly influenced by the eustatic factor, displays a close relationship with a quasi-periodic changeability of crustal tension and regime interchange**,** compression, extension and relative stabilization. Thus, during the periods of compression regime due to the crust compression there occurs thrusting of rock masses and withdrawal of interformational waters contained in them into the basin and constriction of its bath, and during the decompression regime there takes place extension of the crust, extension of rock formations and reabsorption of basin waters and expansion of its bath**.** Thus ,in the first case due to the increased water volume and decrease of the basin volume there takes place a rise in the sea level and in the second case due to the decrease of the water volume and increase of the basin volume there is observed a fall in the sea level. So, the established regularity allows us to use it as an indicator of changes in the geodynamic regime of the crust and thereby predict the time and terms of compression/extension regime and stabilization of the geodynamic stress. This taken into account allows us to state that periods of rapid rise and fall of the level of the Caspian Sea will be limited to the periods of intensification of compression and extension respectively, and long-term periods of high and low stand in the sea level – to the periods of relative stabilization of the crust tension.

It should be noted that verification of the validity of the doctrine under consideration can be carried out by space-monitoring or by high-precision re-leveling by means of establishing a remote connection between the special receiving-transmitting sets installed at ground-based control stations(light houses, surveying benchmarks, etc. and stationary satellites as well as by establishing precise geodetic triangulation network to cover the most characteristic geotectonic structures-blocks of the region. The results of the obtained information will make it possible to determine the character and quantitative parameters of recent tectonic movements and thereby make judgements of the geodynamic environment of tectonic plates and crust of the Caspian region (3).

Plate-tectonic concept of minerageny allows to stick to endogenous, deep mantle origin of hydrocarbons. At the same time it is assumed that expulsion of hydrogen-carbon-concentrated fluids in continental and marine depression of the mantle migrate from the deep subcrustal faults into the overlying rock layers and once reaching the impermeable shielding clay layers of sedimentary cover concentrate in sediments with reservoir properties and under favorable lithologic-structural and thermodynamic conditions form oil and gas fields. Herewith**,** geodynamic conditions and laws of their formation and location allow us to assume that the volume of oil and gas production should increase during the periods of compression regime and decrease during the periods of decompression regime of geodynamics of the Earth crust, which is evidenced by its quantitative indicators (2).

CONCLUSION

We believe that geodriftgenal concept will compensate for the theoretical crisis in geomorphology connected with the collapse of the doctrine of geosynclines and play an important role in understanding the mechanisms and regularities of formation and evolution of Earth relief. The possibility of correlation of the periodic fluctuation of the Caspian Sea level with the crust regime allows us to use this relationship as a geodynamic indicator: catastrophic rise/fall of the level will reflect intensification of extension and compression respectively, whereas high or low stand in the level will testify to relative weakening of tension.

This principle is of utmost importance**.** This principle has great importance for the forecasting of devastating natural phenomena connected with the fluctuation of the sea level rise, the rational use of natural resources of the Caspian Sea and the coastal regions, for insuring the sustainable functioning of the oil sector as well as and for tackling other scientific-applied issues.

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CASPIAN RAPID SEA LEVEL CHANGING IMPACT ON MIANKALEH SAND SPIT EVOLUTION DURING THE 10 K.Y.

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Keyword: Caspian, beach, evolution, sedimentary, Miankaleh

INTRODUCTION

The susceptibility of coastal lowlands, which affected by climatic process, water level changing of oceans and seas and impacts of anthropogenic activities, is very high. So that the ecological and morphodynamic characteristics of these regions become involved in a critical vulnerability due to the function of sea water level rise and down periods. In fact, slight slope of lands behind coast which have negative and reverse direction as compared with coastal berms, provide favorable conditions for marining on the occasion of water level rise and coastal aquifers piezometric level rise. Consequently, marginal wetlands appear. In view of biodiversity in these areas, habitat value and significance for conservation objectives is strongly considerable. Miankaleh wetland has such environmental importance so that according to the defined criteria by international union for conservation of wetlands has presented as a protective area [1].

The connection of this basin and Caspian Sea is established via marginal canals. Usually in the case of water level rise, vast parts of littoral zones could be submerged then territory of Miankaleh wetland will expand. The main question of this study is the impact assessment of natural and anthropogenic factors on morphodynamic deformation in Miankaleh lowland area. Environmental and erosive vulnerability conditions of this area have increased because of Low and reverse slope sandy shore, Caspian rapid sea level changing and hydrodynamic forces from it, furthermore economical efforts expansion (fishery, port, oil and gas, tourism, power plant and construction). The results of several surveys prove that this coastal significant area of Caspian Sea has permanently been impressed by environmental forces of Caspian Sea level changing throughout the Quaternary geological history [2]. Hence current morphological appearance is depended on hydrodynamic forces and Caspian Sea water fluctuations [3]. With the comparing the shoreline transpositions of Caspian Sea south-eastern coastal parts on the region between Torkaman and Gomishan ports in 40 recent years, we can find out the replacement rate and morphological deformation of Caspian Sea slight slope coasts along with rapid fluctuating periods[4].

Furthermore, it is proven that the wide sandy area evolved from flows parallel with coast in direction of west to the east throughout recent several thousand years [5]. Survey about native and immigrant bird biodiversity of mentioned wetland in addition to the benthic and fishes, show precious habitat value and excessive bio susceptibility of this area [5]. Recent accumulation of trading and commercial efforts in ports, water effluents from city and village communities and leading industries, solid waste disposal, toxicant concentrations generated from fertilizers and pesticides, is the main cause of increasing environmental vulnerability rate around Gorgan bay and Miankaleh wetland [6]. Therefore, this study aims to assessment of morphodynamic deformation which effected by both sea water level changing and anthropogenic activities in Miankaleh peninsula. To achieve this main goal, we have identified precisely the recent sedimentary morphodynamic characteristics of studied area. Then we have simulated the structural reaction encounter with the mentioned agents by taking advantages of aerial photos processing and field observations.

METHODS AND MATERIALS

Studied area

The slight slope and lowland, Miankaleh is located on the south – eastern regions of the southern coasts of Caspian Sea in the lengthwise direction around a canal between Torkaman port and Ashoradeh peninsula where is adjacent to the Amirabad port (fig.1).

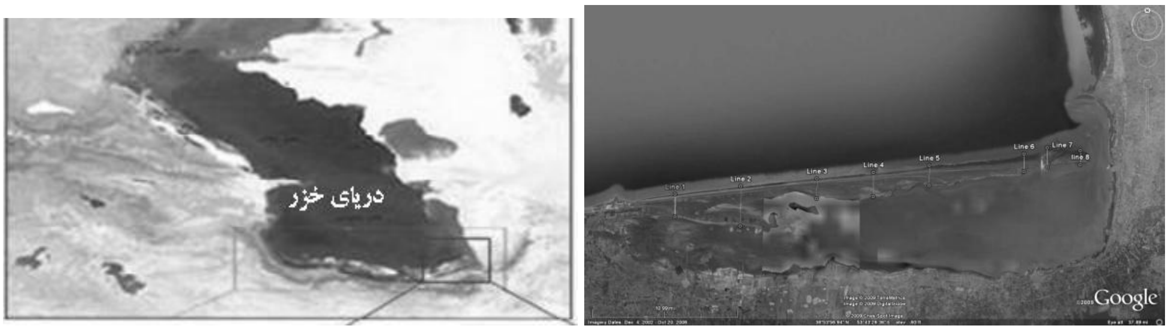

Fig. 1. Study area location map

It is situated in the widthwise direction between Gorgan bay and Caspian Sea (fig.1). This area is expanded as a sandy spit in the direction of western, eastern along with the Caspian Sea shoreline. The length is about 70 kilometers and the width is about 2 kilometers. There is one of the most important Caspian Sea ports (Amirabad port) in the western parts of this region. Also Ashoradeh peninsula, in the end of eastern parts, is considered as a main center for the sturgeons fishing. The aqueous connection of the Gorgan bay and Caspian Sea is feasible via marginal canals such as Ashoradeh and Khozeini canal. The vast regions of Miankaleh area is covered by maritime sandy sediments which appear in the intercalation shape of the microlithic and adhesive wetland sediments. This kind of sediments is seen in central parts of peninsula that contains lots of mussels. Also, the eastern parts of Miankaleh include sedimentary wetland environment and middle part where is concentrating location for the majority of the aquatic organism.

Methods

After collecting required data and documents on Coastal modification impact on the low land of Miankaleh from research centers and organizations, we surveyed in detail several references obtained from cross- referencing in papers and from internet researches. Then primary familiarity with studied area was taken place from the viewpoint of natural geology and environmental attributes. Thereafter, morphologic features and widespread morphodynamic phenomena conditions of this area were assessed with applying of satellite images (Google earth). Simultaneously, field observations and sampling transects were determined (fig. 1). Sedimentary morphodynamic structure condition of the area in the direction of vertical to shoreline between Gorgan bay and Caspian Sea was sampled and measured by field works conducted around eight transects where it was chosen in lengthwise direction of Miankaleh.

Moreover, to determining the impact of anthropogenic activities on geometrical structure and sedimentary morphodynamic along with 3 stations around Amirabad port, needed measurements were performed in western, central and eastern sections of coastal area. After preparing of sedimentary samples in the laboratory and accomplishing some required examinations, we analyzed the characteristics of sediments texture from the viewpoint of particle size and distribution thus related sedimentary environment. Subsedimentary environments and shorelines around peninsula were assigned by transferring data to the geological information system (GIS) and putting down them on digitized map. The transpositions of shoreline and submergence of coastal lands were verified by Interpreting and comparing of aerial photos belonged to a 40 years period of times (1965-2005) in a scale of 1:10000 which contains both water level rise and down conditions. After that, we achieved to identify vulnerable regions towards Caspian rapid sea level fluctuations. Finally bioecological conditions and the territories of paludic lowlands were assessed by comparing the sedimentary subenvironments in both Caspian Sea water level rise and down.

RESULTS

• Morphodynamic and morphological features of Miankaleh

The aerial photos processing and field works conducting around eight measurement transects (fig.1) specify that Miankaleh Sand spit possess morphologic sub-strata and sedimentary sub-environments in the direction of west to east.

• Morphodynamic structure transposition

The consequences of processing and comparing the aerial photos of Miankaleh coastal regions in a period of times (1965-2005) which contained Caspian Sea water level rise and down phenomena, show different dislocation of Miankaleh peninsula shorelines in western, central and eastern parts. The scope of the coastal lands submergence in the situation of water level rise has diverse features in the different regions. Besides the extension of coastal morphodynamic features such as: erosive bays, connecting canals, wetlands and sandy spit expansion happen more in the case of sea water level rise to sea water level down. In the time of Sea transgression period, the growth of vegetable coverage is seen more in berms and sandy dunes.

Table 1

Sedimentary morphodynamic and morphological stratification of Miankaleh Sand spit

Miankaleh Region	Sedimentary sub-environments	Morphodynamic Phenomena
Western Part	Aeolian environments, Primitive Berms,Wetland Fringe, Shoreline,Wetland Band Beam,Gorgan Bay	Erosive terraces, Beach cusps,Sand Dunes,Primitive beach and Fluctuation terraces
CentralPart	Shoreline, Wetland,Sand Dunes,marginal canals,Wetland Fringe,Gorgan Bay	Beach cuspsRipple marks,Scattered Sand Dunes,Strip Pool Pits,Sand Spits
EasternPart	Marginal lagoon,‹Primitive Sandybeach , Gorgan Bay	Pool Pits, Lagoon

Table 2

Geometric and morphodynamic structure characteristics of western coastal parts of Miankaleh

Station No.	Geographical position		Morphodynamic features
	x	y	
1	36,83575	53,22120	Delta, berm, Sand Dunes
2	36,85000	53,39999	Erosive terrace, beach cusps, Destroyed Sand dunes,
3	36,86837	53,47748	Sand bar, ripple mark, Small Beach cusps, Sand Dunes

• Anthropogenic impacts on coastal structure deformation

The evaluation of geometric and morphodynamic structures in sandy spit western parts of Miankaleh around the 3 measurement stations in the west direction to the east of Nekaroud embouchure to the end of Amirabad east part, confirms the erosive phenomena enlargement produced by anthropogenic activities like ports, sheep building, power plant and related oil and gas industries in centre of Miankaleh western regions (tab.2). So that shoreline has been retreated to 900 meters in this part of Miankaleh and the growing trend of erosion involves sandy dunes which caused coastal berms eradication. This event has influenced the locations of 20 kilometer radius from west direction to the east. The most important engineering constructions, which affected the erodibility of Miankaleh western parts, are coastal break water obstacles, groins and coastal guard constructions.

DISCUSSION

•Field observations and satellite images analysis

The conclusions from field observations and satellite images analysis indicated that sedimentary morphodynamic and morphologic features of Miankaleh peninsula have specific qualities as well as at the end eastern of Amirabad part to the central point of Tazehabad coast adjacency in Miankaleh sandy spit is formed of the Caspian primitive coastal sandy sediments. The coastal profile from Gorgan bay to the Caspian Sea shoreline orderly contains: lowland part of Gorgan bay with the dominant vegetable coverage of Xanthium shrubs and filled with calcareous shell of mollusks (bivalve and gastropod). After that we reach the primitive sandy coast of Caspian Sea with an altitude code of -24 that embraced microlithic sandy sediments and marine mussels (Cardium edule).

This part of Miankaleh sandy spit is covered by prairie, raspberry bushes and sour pomegranate. The surface of sandy sediments dressed in dark brown colored soil whose thickness is about 10 centimeters. After the wide area of primitive Caspian Sea berms, we arrive to the inactive sandy dunes which have extensive vegetative coverage. In the next area, active and semiactive sandy dunes could be seen. Ultimately, the coastal profile leads to a slight sloped beam which has reverse slope towards coastal berm along Caspian Sea shoreline with the coverage of halophytes such Xantium plants.

This kind of biomorphological state exists in whole of western parts of Miankaleh. In fact, the morphological feature assessment of western parts of Miankaleh shows the function of Caspian Sea water level rise excessive phases in the past whose altitude code is changed of -24 to present -26.5.

Coming a large amount of sandy sediments out of sea surface, is the cause of sandy dunes formation. The widthwise expanding of sandy dunes territory is strongly related to the vegetative coverage enlargement. Due to reduction of sandy sedimentary substances, coastal berms deform to marginal wetlands in central parts of Miankaleh coast. Faraway from shoreline, sand spits are formed by coast paralleled flows in west direction to the east. At the back of these sand spits, strip wetlands have been created with the average depth of 1.5 meters. The accumulation of vegetative coverage and the permeability of coastal lands in this area have been caused the decrease and dispersion of sandy dunes in Caspian Sea primitive coast.

On the other hand, marginal basins such as wetland appear strongly in eastern slight sloped parts, while coastal sands have been disappeared. Submergence situation of this part of Miankaleh coast has been so fragile that a vast part of this area has sunk since 1978 when Caspian Sea water level has increased 2.5 meters up to now. Consequently; Khozeiny canal and aquatic connection width between Gorgan bay and Caspian Sea has been developed. One of the morphodynamic features of this area is the creation of erosive bays in south- eastern part of Miankaleh. The penetration of sea brine is the cause of salty land generation in lowland around Gorgan bay. Salty crystals appear in the mentioned salty lands at aridity time. Therefore

Miankaleh contains 3 morphological features; coast, intermediate and wetland in direction of west to east. The erosive vulnerability in the edge of Miankaleh sandy spit is increasing from west to east.

Comparing of the aerial photos analysis conclusions:

The result comparisons of aerial photos processing during 40 years (1965–2005) which include two important Caspian Sea water level rise and down phases, prove deformation manner of Miankaleh sandy spit related to Caspian Sea water level changes. The collected data from limnograph stations show about 3 meters depression in sea water level from 1940 to 1979, whereas; Caspian Sea water level has got a rapid rise about 2.5 meters from 1979 to present. The examination of morphodynamic deformation rate in Miankaleh coast indicates that erosive vulnerability mostly exists close to the eastern regions between Torkaman port and Ashooradeh in the mentioned times. The slight slope of this region helps speed rate of marining and generally morphological features have been changed seriously as connecting canals (Khozeiny) and wetlands widthwise have been developed.

Morphodynamic deformation rate is more expanded in eastern parts in compare of western parts in as much as the shoreline has moved only 60 meters up to now. In consequence, marining is seen fewer in western parts. In the case of sea level regression, raspberry bush lands and sour pomegranate shrubs are expanded through the berm, however; owing to the water level rise and soil salinization, the mentioned vegetative coverage are destroyed and the bodies can be found under sediments. Meanwhile; it is proven that the most Vulnerability towards sea water level rise seems from the end of eastern to central part of Miankaleh peninsula. Other regions have fewer Vulnerability risk.

• Anthropogenic impacts on erosive vulnerability

Port constructions, groins building, coastal break water obstacles, coastal guard constructions, land surfacing and sand takings, increase erosive Vulnerability in western parts of Miankaleh close to the multipurpose Amirabad port. Actually Amirabad port (in the end western part) and Ashooradeh peninsula (in the eastern part) are affected more by anthropogenic activities. In addition; erosion phenomena has been seen more in Amirabad free zone in compare of eastern parts of Miankaleh.

The rest area of Miankaleh is under protection with no human access and damages. The measurements of geometrical structure in western coast of Miankaleh indicate that quay and coastal break water obstacles induce radically berm deformation and shoreline strike deviations (tab2). There is sedimentary accumulation in west of Neka power plant (station No.1). To the west, the affection of coastal flows causes coastal disruption and erosion of central parts (station No.2). The main morphodynamic features, which have been obtained from human activities, are known as appearance of vast erosive terraces, developed crescentic beach cusps and disappearance of berm and sandy dunes (station No.2). Dramatically the effect of constructions on coast is reduced by going far from central part (station No.3). Actually the impact of marine constructions is caused the movement of shoreline about 900 meters exactly in central regions.

Therefore; the western coast of Miankaleh is vulnerable and dangerous in view point of anthropogenic activity expansion. Finally; because of gentle slope in littoral zone which generated by coastal break water obstacles and quay, provide artificial condition of coastal land submergence.

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THE COMPARATIVE CHARACTERISTIC OF LEVEL CHANGE OF THE CASPIAN AND BLACK SEAS FROM LATE PLEISTOCENE UP TO NOW AND THE FORECAST

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INTRODUCTION

Well-known, that changes of the World ocean level, the seas, large lakes and other reservoirs strongly depends on a global and regional climate. The Earth's climate is an extremely complex nonlinear system with numerous feedbacks, the dynamics of which are not obvious. To define tendencies of the further changes and to reveal relationships of cause and effect of mathematical models absolutely insufficiently. It is necessary to study laws of variability of climatic parameters on the big time intervals.

The following problems have been examined in our research**:** (1) Analysis of the Black and Caspian Seas level change during tool supervision and over Late Pleistocene and Holocene; (2) Study of changes of three climatic parameters (temperature, precipitation, and atmospheric pressure) during the instrumental measurement period; (3) Definition of the degree of influence of these parameters on river discharge and sea level change in the Black and Caspian Seas by cross-correlation tests; (4) Study of the periodic structure in time series using trend-analysis, spectral and wavelet analysis **;** and (5) Analysis of the reasons given for sea level change of the World Ocean, the Caspian and Black Seas and the scenario of change predicted for the future in the Black Sea.

CASPIAN-BLACK SEA'S SEA-LEVEL OSCILLATION OVER LATE PLEISTOCENE – HOLOCENE

According to the known theory of fluctuation of World Ocean level (and the seas) and continental lakes level for Pleistocene and Holocene occur synchronously, but have an opposite sign. These fluctuations occur as the result of global changes of a climate (Feodorov, 1978; Richagov, 1997; Shmuratko, 2001).

On the long time periods of level change of the Caspian Sea and Black Sea as a whole occur under this law, really. However on rather short periods essential deviations from this law are sometimes fixed. On astronomical-climatic-eustatic models (Zubakov, 1986; Shmuratko, 2001) the level change of Black Sea lags behind fluctuations of World Ocean almost on the quarter of phase the millennium-cycle. What the reason of it?

Black Sea is midland though it is connected to Atlantic Ocean through system of narrow passages and the seas, as is known. Black and Caspian exhausting are removed on significant distances from the centers of origin of climatic changes: North Poles and Atlantic Ocean.

On data by Mikhaylov (2000) and Richagov (1997) Caspian Sea level in Late Pleistocene and Holocene had big fluctuations in amplitude. The Khvalinian stage included two transgressions in histories of Caspian Sea: the largest for the Pleistocene – Early Khvalinian (40-70 thousand years BP, a maximum level 47 abs. m, that on 74 m is higher modern) and Late Khvalinian (10-20 thousand years BP, rise of the level up to 0 abs. m).

These transgressions were divided deep with Enotaevian regression (22-17 thousand years BP), when the sea level has fallen up to – 64 abs. m also was on 37 m below modern. Significant fluctuations of sea-level occured and during Novocaspian stage of his history which have been concurrent with Holocene (last 10 thousand years).

After Mangishlak regression (10 thousand years BP, downturn of a level up to – 50 abs. m) five stages the Novocaspian transgressions divided small regresses were marked (fig. 1A).

Geological history of Black sea in the same interval of time tested also significant events on scales: Neweuxinian regression (Neweuxin-I, 30–20 thousand years BP when the level has decreased up to -100 …-110 abs. m), Neweuxinian transgression (Neweuxin-II, 18,0 – 9,5 thousand BP, the level has risen up to absolute marks of -25 m (shelf) and up to -17 m (Prichernomorian limans), about 6 thousand BP the level was higher modern +1-2 m. In Holocenian history of basin there were large enough regressions (maximum): about 8.2, 6.2, 4.0, 3.0-2.3 thousand BP (fig. 1B) (Konikov, 2007).

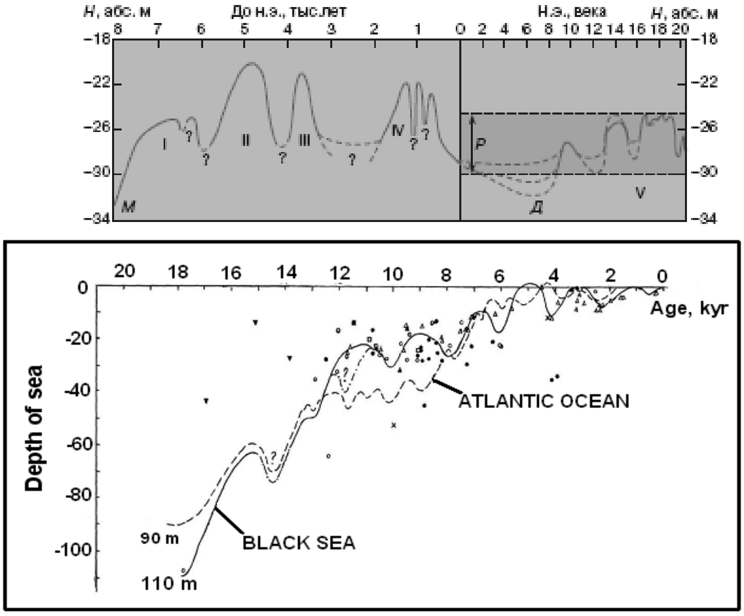

Fig. 1. (A) Sea-level change of Caspian Sea by Richagov (1997) (In Mikhaylov, 2000); (B) level change of Black Sea (Konikov, 2007) and Atlantic Ocean (Mörner, 1971)

Comparison of these events for the Black and Caspian seas shows some deviations from the general laws. Interest causes essential conformity Enothaevian regression with regression Neweuxin-I. The Mangishlak regression coincides with small amplitude regression of Black Sea (Shnyukov, edid., 1985). Regressions of Caspian Sea during prehistoric time (BC) between transgressions I, II, III and, in part, IV as a whole coincide with Early Drevnechernomorian, Tirasian and Khadzhibeian regression (Konikov, 2007).

GLOBAL AND REGIONAL CLIMATE CHANGE AND SEA-LEVEL OVER INSTRUMENTAL OBSERVATION

Boichenko and Voloshchuk (2006) have shown that there is an alternation of long periods of warming and cold snaps in the extra-tropical parts of the Northern Hemisphere during the last hundred years that can be considered as a component of natural variations. Climate change in the northwestern region of the Black Sea has shown an increased trend in mean annual surface temperature. Regional temperature changes, in comparison with global changes, are less pronounced. This results from the fact that warming has a width differentiation (amplifies at high latitudes). It is notable that from the middle of the 1920s, the global situation varied slightly: there is an insignificant increase in mean annual temperature and a substantial increase in precipitation.

A stronger link with these indicators (temperature, pressure and RSL) is found in the Caspian Sea. Analysis of the components of water balance in the Caspian Sea has revealed that the basic contribution (up to 72% of dispersion) in variability of sea level is attributed to inflow of river water within the Volga River basin (Mikhaylov, 2000; Arpe and Leroy, 2007). The reasons for the change in the Volga discharge include variability in atmospheric precipitation (largely during the winter) in the river basin. The precipitation regime, in turn, can be defined by atmospheric circulation. It has been shown that an increase in sediment discharge into the Volga basin is related to sub-latitudinal atmospheric circulation, and a reduction to a sub-meridional type of circulation. Other studies, however, have related changes in the Caspian precipitation regime to pressure systems in the Pacific Ocean (Arpe and Leroy, 2007).

The World Ocean is a system of an integrated kind reflecting changes of a global climate. Thus changes in global temperature reveal changes in sea-level change of the World Ocean. Interdependence between these factors is characterized by cross-correlation factors of 0.61 to 0.72. For the Black Sea, numerical values of atmospheric circulation even to a greater degree, than the temperature are connected with considered parameters (such as sea level, rivers discharge, and atmospheric precipitation).

The original source of the moisture in the Volga basin includes the influences of the North Atlantic Ocean. It is there that greater evaporation from the sea surface leads to an increase in the amount of moisture transferred to the Eurasian continent and, consequently, to increased atmospheric precipitation in the Volga basin.

Recent water level fluctuations in the Caspian Sea level have been influenced mainly by anthropogenic factors. For example, there was a reduction in discharge because of irrevocable losses to in-filling, sediment fill following dam-construction on water basins), evaporation from the surface of artificial reservoirs, and water extraction for irrigation. It is believed that since the 1940s, irreversible water consumption steadily increased, which has led to reduction of inflow of river water to the Caspian Sea and an additional decrease in its level compared with the natural trend. At the end of the 1980s, the difference between actual sea-level and the restored (natural) one has reached almost 1.5 m (Malanin, 1994). Thus, total water consumption in the Caspian Sea for those years has been estimated at 36–45 km3/year (the Volga accounting for nearly 26 km3/year). If not for the withdrawal of river water, the rise in sea level would have begun not in the late 1970s but in the late 1950s (Mikhaylov and Povalishnikova, 1998). Technogenic influence on water balance of Black Sea has begun in the late 50-years. Building of the water basins on the large rivers (Dniester, Dnieper, Danube) at this time has begun. The Dnepr discharge is reduced at the expense of withdrawal from water basins almost on 75 %. However thus level lifting in Black proceeds.

PERIODICITY OF VARIATIONS IN CLIMATIC FACTORS AND SEA LEVEL

Wavelet-analysis of a global temperature time series has allowed identification of cycles of around 10, 20-25, 55-60 years which are superimposed on longer periods (e.g. 100-130, 300-329 year cycles). These small-scale cycles are present throughout – the entire period of recorded observations of 1864-1984, including the industrial and post-industrial periods (Fig. 2).

Most climatic indices show a dominant influence of the 60-year-old fluctuation (e.g. Datsenko and Monin, 2004). Bojchenko (2007) made spectral analyses of temperature for the interval from 1000-1850 AD and also found quasi-periodical fluctuations with periods of 57±1 and 66 ± 2 years. The last observable 60-year cycle began in the 1970s. Its peak coincided with the beginning of the current 21st century. It is likely that the temperature maximum of the 60-year-old cycle has terminated and some stabilization and the tendency for temperature decrease will be observed in the future. The assumption of a pause in global warming within the next decades, similar to the pattern from 1940-1970, has been forecast by Datsenko and Monin (2004).

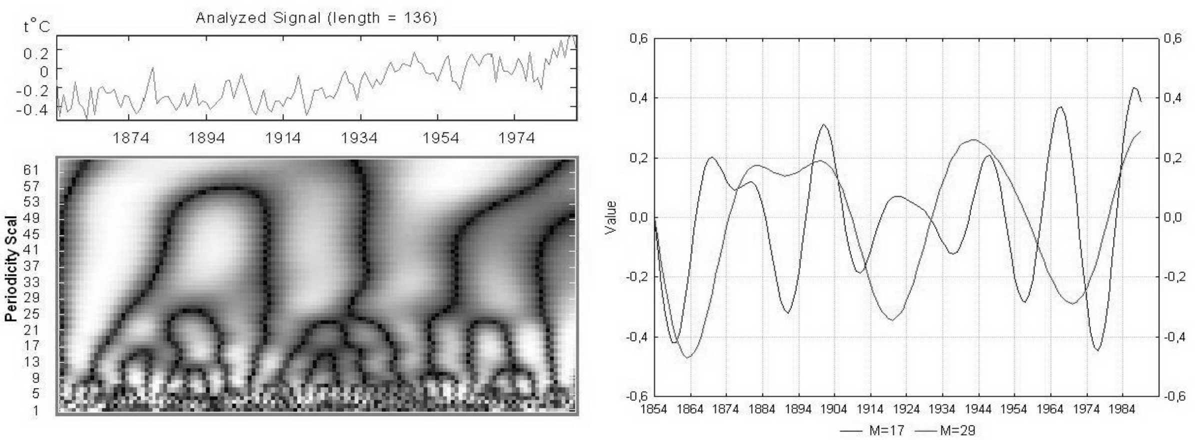

Fig. 2. The time number of cyclical change in global temperature and its wavelet transformation (left) and standardised wavelet values corresponding to scales 17 (~22 year period) and 29 (~60 year period).

THE POSSIBLE SCENARIO OF DYNAMICS OF THE BLACK AND CASPIAN SEAS

Considering the 60-year fluctuations of temperature, in the next 20-30 years, some stabilization of level fluctuations of Black Sea is expected, with a slow trend towards its increase. For the Caspian Sea after the increase period, after the middle of the 90-year cycle, a decrease is marked. The level of Black Sea (on statistical forecasting) may rise 15 cm by 2050 AD and 30 cm by 2100 AD. In the most adverse scenario, it could increase 40 cm by 2050 AD and 100 cm by 2100 (Konikov, Likhodedova, 2007). Last two decades when rising of Caspian sea level has begun, in the majority of forecasts accelerated growth of level to – 25 and even – 20 abs. m was predicted almost linear and above in the XXI-st century beginning. Decrease in mid-annual levels last four years in total on 0,34 m, probably, testifies that in 1995 level has reached the maximum (-26,66 abs.m), and about change in the tendency of a course of Caspian sea level. Anyway the prediction, that a sea level hardly will exceed a mark – 26 abs. m (Richagov, 1997), apparently, is justified.

CONCLUSION

By means of the statistical analysis, the relationship between relative sea levels (RSL) in the World Oceans and the midland Black and Caspian seas is linked with climatic parameters. Consequently, we show the statistical dependence of Caspian Sea water level with RSL in the World Ocean and changes in atmospheric circulation is greater than for Black Sea. Based on spectral and wavelet analyses for time series of climatic factors, river discharge and sea levels for almost 200 years of measured intervals, statistically significant periods are determined to occur at cycles of 10, 20-25 and 55-60 years. Short periodic cyclicity has been established for intervals of the following lengths: seasonal, 2-3, 5-7 years. Analysis of long data series for $d^{18}O$ stable isotopes in Greenland ice, and Dnieper discharge reveal quasi-600-year and quasi-300-year cycles. The scenario of change of in the climate and water level of the Black and Caspian seas during the next few decades and the long-term forecast is presented. Rise in the level of Black Sea water may proceed as early as 20-30 years ahead and will reach stabilization by the end of the 21st century. Then a regressive decrease in level may be expected according to influence Shnitnikov humidity cycle. The Caspian Sea level will continue to rise, that corresponds to model Arpe and Leroy (2007). For the big periods (it is more than 10 thousand years) the climatic mechanism and levels of the Black and Caspian seas accurately works are in an antiphase. On shorter periods there are deviations from this law.

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CLIMATIC ASPECTS OF CASPIAN SEA LEVEL VARIATION DURING THE HOLOCENE

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Keywords: climate change, global warming, water resources, paleoclimate scenario

INTRODUCTION

The Caspian Sea is a unique component of Earth's landscape, as it is the closed sea-lake with a huge catchment, which makes the Caspian a reliable moisture integrator reflecting both long- and short-term climate fluctuations within a vast territory. Historically the Caspian Sea can be considered in terms of permanent alternating transgressions and regressions, resulting from fluctuations in moisture content and water budget element relations in the past epochs.

Throughout more than 200 years scientists have been trying to discover the nature of the Caspian Sea level (CSL) fluctuations. The contemporary ideas about the CSL fluctuations are based on the structure of the CSL water balance that is determined mostly by the climatic factors. The amplitude of the CSL fluctuations does not exceed 4 meters during the instrumental period from the highest level (-25.2 m BS) in 1882 to the lowest level (-29.1 m BS) in 1977. Whilst the amplitude mounted to 8-10 meters during the New-Caspian transgression, some estimates suggest 12-19 m.

In the 1930s water-budget calculations revealed the relationship between CSL fluctuations and river's inflow from the basin; the last has been a climate-related factor. Interest to this issue has recently increased due to sea-level rise from -29.1 m to -26.5 m and progress of anthropogenic global warming at the same time. This sharp raise of the CSL for 2,45 m in 1978-1995 has lead to flooding and submerging of the Sea coasts and caused sufficient economic and ecologic losses.

CLIMATE CHANGE IN THE CASPIAN SEA BASIN FOR THE LAST DECADES

Since the late 19th century the mean annual air temperature has increased by about 1.29ºC for the Russian territory that surpasses the global annual air temperature increase. Recent years the tendency towards warming has grown significantly and in the period of 1990-2000 the mean annual surface air temperature increased by 0.4°C. 2007 has manifested to be the warmest year followed by 1995 and 2005 for Russia. Anomalies of mean air temperatures were positive for all the seasons, more pronounced in the winter-spring period (trend equals to 0.3°C/10 years), less – in the summer-autumn. In the autumn period, even, some cooling has taken place in western ETR up to 2000. Mean annual temperature has increased rather unevenly over all territory [Assessment report, 2008; Lemeshko, Speranskaya, 2006].

In individual regions, including the basin of the Caspian Sea the temperature rise has been also significant.

Air temperature and precipitation anomalies were evaluated for 1991-2000 (Efimova at. al., 2004) (table 1) for the Caspian Sea basin. Geographically the northern (the Volga River basin) and eastern (desert area) parts of sea basin exhibit warming for all seasons with most significant rise of winter temperature.

The Volga River discharge amounts to almost 70% (some estimates suggest 82%) of the inflow to the Sea. Runoff of three other large rivers (Ural, Kura and Terek Rivers) is about 1-6%. That is why we put the main emphasis on the Volga River runoff. For the last 50 years the Volga River was under the anthropogenic influence. 12 large reservoirs have been constructed in its catchment.

Significant CSL fluctuations have been recorded throughout more than a hundred-year observational period. From the beginning of observations till the end of 19th century the CS had a relatively stable level, fluctuating near -25.8 BC. The tendency to decrease in the mean annual Sea level was observed from 1882 and continued up to 1977. In 1978-1995 there has been sharp raise of the CSL for 2.45 m up to -26.5 m BS (Project "Seas", 1992; Frolov, 2003). Duration of these inter-century fluctuation periods is comparable with the duration of the Atmospheric Circulation periods. The index of the North-Atlantic Oscillation (NAO) is more frequently used now as a characteristic of the natural climate change [Hurrell and Van Loon, 1997]. Over the last three decades the index has been shifting to positive index values. The positive tendency of the CSL change coincides with positive phase of the NAO-index (Figure 1) and increase of Global air temperature during last decades of 20th century. For the period 1939-2000 the coefficient of correlation between the index of the NAO and CSL is 0.36 and between Global temperature and CSL is 0.74. Therefore, the CSL could be considered as the function of general atmospheric circulation and global temperature. Its importance as an independent indicator of climate system change becomes higher now than it was suggested before.

Table 1

Precipitation and air temperature anomalies for 1991-2000 from mean value of period 1951-1975 in the Caspian Sea catchment

	Precipitation anomalies, mm	Air temperature anomalies, ºC			
	Year	Winter	Spring	Summer	Autumn
Northern part	25	1,5	0,7	0,2	0
Eastern part	50	1,2	0,2	0,6	0,2
Western part	50	0,5	0	0,4	-0,2
Southern part	0	1,0	0,2	1,0	0

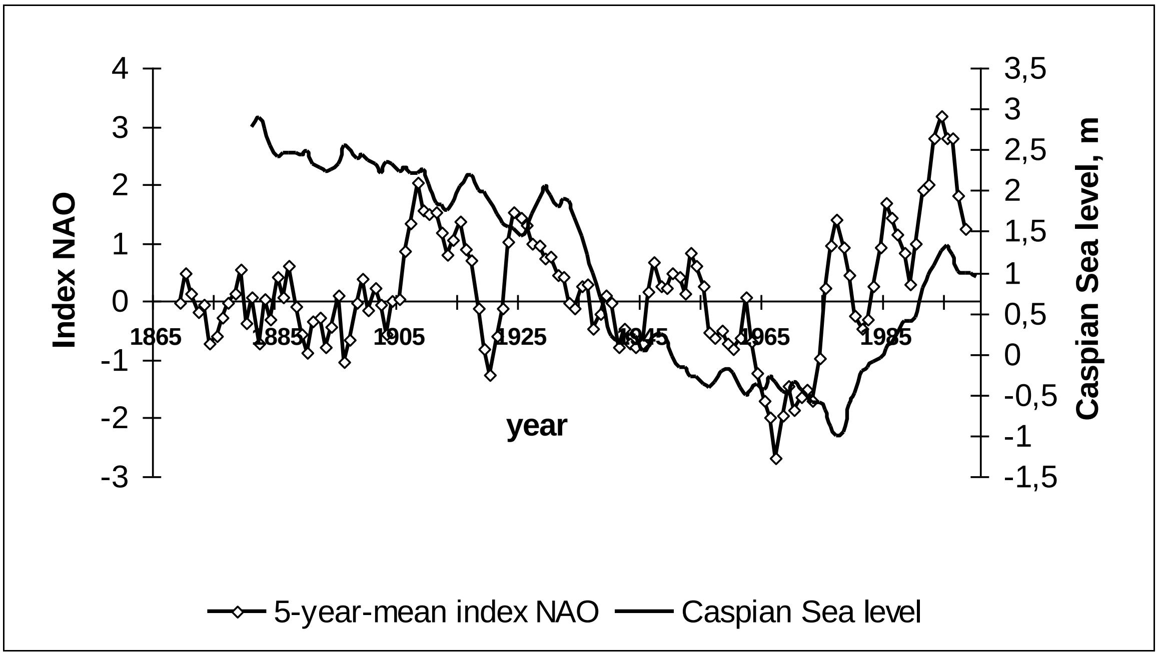

Fig. 1. Five-years mean values of NAO index and Caspian Sea level

THE COMPARISON ANALYSIS OF THE CSL CHANGE FOR THE WARM PERIODS OF THE HOLOCENE

The contemporary ideas about the CSL fluctuations are based on the structure of the Sea water balance that is determined mainly by the climatic factors. The amplitude of the CSL fluctuations does not exceed 4 meters during the instrumental period. Whilst the amplitude mounted to 8-10 meters during the New-Caspian transgression.

Modern environmental and climate change has been caused by natural and man-made factors. To study both natural and anthropogenic climate changes and their impact on the CSL change we should compare three periods of the Holocene: two periods without visible human impact and the third one – the last decades of the 20-th century with a considerable anthropogenic influence, both local and global scales (regulation of inflow by reservoirs and progress of global warming). But the main purpose is to analyze the impact of the climate variation to water balance of endoheric sea-lake.

Based on our previous study, have been investigated three warm periods: the Holocene climatic optimum (6.2 – 5.3 KA B.P.), the warming of 1930s and 1978-1995, in order to study ranges of the Sea level fluctuations.

The time period 1978-1995 was accompanied by the global warming and the growth of the CSL from -29.0 m to -26.5 m BS. For this period the Volga River basin was characterized by the following hydrometeorological conditions: air temperature anomalies was about +1.0°C for cold period and about +0.2°C for warm period; annual precipitation was by 2-6% and height of snow cover was by 11% higher than normal; number of days with anticyclones was by 13% less than normal and inflow to the Sea exceeded mean annual one on 24 cub.km [Meschcherskaya, 2002].

Up to 1970s all rivers of Russian part of the Caspian basin were artificially regulated. As a result, the inflow to the Sea decreased on 9.2 % from the Volga River, on 24% from the Ural River, on 60% from the Terek and Sulak Rivers and on 12.8% by the Kura River. In total, the inflow to the Caspian Sea decreased about 12%, it equals to 25% from the Volga River runoff. The losses of water resources by evaporation from the reservoirs was about 8-10 cub. km (about 3% of the Volga River runoff) [Shiklomanov, Georgievsky, 2002]. Under natural conditions (without human impact) the mean annual inflow should be equal to 343 cub km. Maximal volumes of the inflow by rivers have been observed in 1979 and 1985 (350 cub km per year) and in 1990 (360 cub km per year).

The next period which was very important in the Caspian Sea history is 1930-1941. During this period Sea level decreased on 1.8 m and it falling was observed till 1977. Trend of Sea level was equal to 16 cm/year for 1930-1941 and even for this short period of ten years it is statistically significant.

Climate conditions over the Volga River basin for warm 1930s differ from 1978-1995. Winter air temperature was colder on 0.2°C and summer temperature was warmer on 0.5°C. There was less than normal precipitation (by 17%), snow (by 6%) and river runoff (20 cub km per year). Number of days with anticyclones was by 16% higher than normal.

Comparison of water balance components shows that inflow by rivers was on 131 mm (40 cub km/year) and precipitation was on 75 mm less than in 1978-1995. Evaporation from the Sea was by 85 mm higher than for 1978-1995.

In the geological past of the Earth there were warm epochs and some of them had the global temperature anomalies similar to predicting in the nearest future [Borzenkova, 1992]. The climatic optimum of the Holocene (6.2-5.3 KA B.P.) was characterized by global warming at 1°C. During this warm epoch winter temperature would be higher on 1-2°C, and summer temperature would be higher on 0.5-1.0°C compare with 1881-1965 over the Volga River catchment. In the western part of catchment (Oka and Msta Rivers) precipitation would be lower on 25-30 mm per year, in the middle part precipitation would increase on 50 mm/year, in low Volga and over the Caspian Sea water surface annual amount would be on 100 mm higher (Fig. 2). The Caspian Sea level in the climatic optimum of the Holocene was about -21÷- 22 m BS according to estimates by Rychagov, 1994.

A hydrological model has been used to estimate the changes in the water balance of the Volga River catchment and to model the CSL response to climate change [Lemeshko, 1992; Borzenkova, Lemeshko, 2005]. The model is based on the semi-empirical calculation method and on paleoclimatic scenario for the Holocene climatic optimum, considered as analog of future conditions in some features.

The scenario consists of the regional data on deviation of annual precipitation, winter and summer air temperature.

Applied method allows to calculate the mean monthly values of evaporation, runoff and moisture content of active soil layer (1 m) using data on mean monthly values of surface air temperature, air humidity, precipitation, cloudiness, surface albedo and solar radiation, both for the modern climatic conditions, and for climatic conditions different from the present ones.

The obtained mean values of potential evaporation and evaporation (monthly, seasonal, annual), runoff (annual) have been compared with observed data. The comparison shows their good agreement. Calculating accuracy of annual potential evaporation and evaporation is 8-10%. Modelling annual runoff of the Volga River equals to 274 km^3 has been compared with data from the World Water Balance (1974) (254 km^3). It was shown that the model enlarges runoff for 9 %.

22 meteorological stations located in the Volga River catchment have been used for modelling of water balance components for global warming by 1°C. Changes in annual precipitation according to the scenario of the Holocene climatic optimum and river runoff are shown in the Figure 2 (a, b).

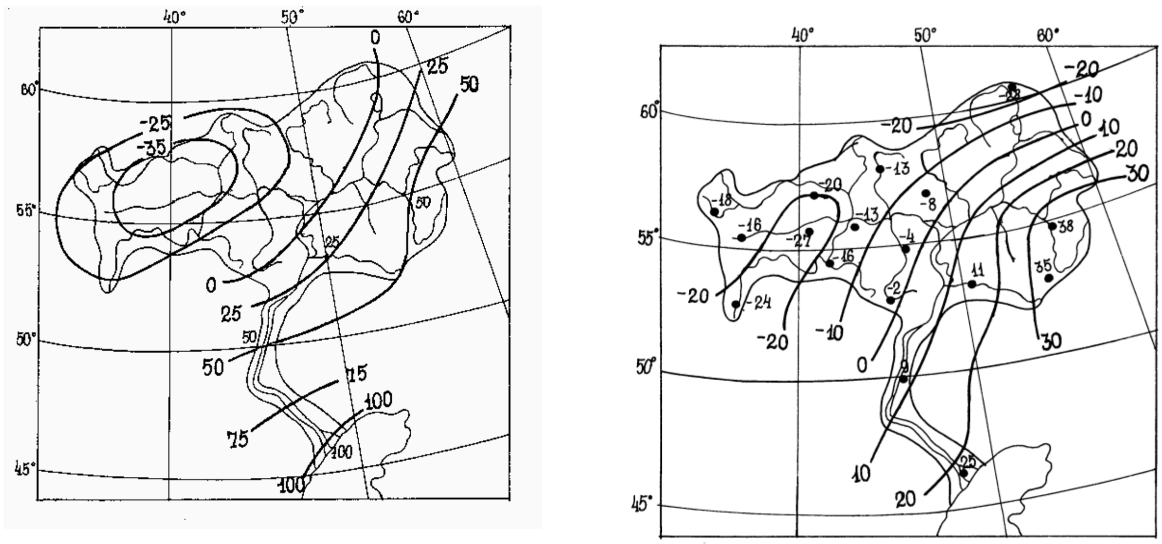

Fig. 2. Deviation of annual precipitation (left) and runoff (right) (mm) with Global warming by 1^0C.

Changes in precipitation and runoff in outline have a similar geographical distribution. Decrease in precipitation leads to decrease in runoff in the upper and middle parts of the Volga River catchment and increase of precipitation in the low Volga River leads to increase of evaporation and runoff, which are strongly affected by precipitation for Holocene period as the temperature changes are not large.

For the whole Volga basin mean annual changes of evaporation and precipitation are adequate and equal to 5 mm, and river runoff would not change. It means that additional amount of precipitation would be compensated by increase of air temperature in the study basin for this concrete climatic scenario. So, the sufficient changes of water balance parameters for the Volga catchment should not occur as the modeling values of evaporation and runoff are insignificant and are less than calculation accuracy.

CONCLUSIONS

Global climate changes influence natural and human systems and form new tendencies in the land hydrology, as well as in hydrological regime of inland water bodies. The paleoclimatologists usually consider the hydrological regime of closed lakes as the reliable indicator of changes in natural ecosystem and moisture regime for different epochs in the past. Now we have made first attempt to use paleoclimatic reconstruction to predict the hydrological regime with expected changes of climate.

The temperature and precipitation anomalies have been compared for 1991-2000 and the Holocene optimum. It has been concluded that quantitative estimates of the air temperature and precipitation agree between themselves for the Caspian Sea basin [Borzenkova, Lemeshko, 2005]. It means that the climatic optimum of the Holocene should be used for the near future climate scenarios as well as for assessment of the Caspian Sea level change.

Analysis of climate regime for the 20 century show that during warm periods of 1930-1941 (mean global temperature anomalies was $0{,}17^0$C) and 1978-1995 (mean global temperature anomalies was $0{,}32^0$C) behavior of the Caspian level was opposite. Duration of the CSL fluctuation periods is compatible with the duration of the circulation epochs. The atmospheric circulation is an important forcing phenomena of climate (precipitation, temperature, pressure) and hydrosphere (water level in the oceans, seas, lakes, river runoff) over vast areas, therefore, the circulation parameters for the remoter past epochs can form the basis for forecasting the future level of the Caspian Sea.

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GEOCHEMICAL INDICATION OF SEDIMENT FORMATION ENVIRONMENTS CAUSED BY THE CASPIAN SEA LEVEL FLUCTUATIONS

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Keywords: geochemical indication, Caspian Sea level changes, coastal zone, soils, sediments, heavy metals

INTRODUCTION

General rise of the World Ocean level in the 20th century causes world-wide concern on its impact on oceanic coasts. Predicting this impact is hampered by the slow pace of sea-level rise in the past, and the complexity of coastal processes. The Caspian Sea, having experienced sea-level changes of up to a hundred times the eustatic rate, offers accelerated real-world models of how soils behave under such conditions. These data can be used to calibrate and validate existing simulation models of soil behavior within coastal areas of other seas.

Long-term monitoring of the Caspian Sea shore zone soils allows revealing the changes due to the whole cycle of sea-level changes. The first part of the cycle lasted for 50 years (1929-1978) and was characterized by the retreat of the sea, lowering of the ground water table, and general decrease in the degree of hydromorphism of the territory. The second phase of the cycle (1978-1995) corresponded to the rise in the sea level and the depth of the ground water, and to increase in the degree of water-logging of the soil cover. Studying the geochemical changes in soils and sediments of the Caspian coastal zone for the last cycle of the sea-level fluctuations presents a key for the geochemical indication of sediment formation environments in the past.

MATERIALS AND METHODS

We have studied geochemical consequences of the sea-level fluctuations at two key-sites: Turali area (western coast of the Caspian Sea) and Damchik area (northern coast, Volga delta). The Turali coastal plain extends along 10 km between Cape Satun in the north and Cape Bakay-Kichklik in the south, about 20 km south of Makhachkala, the capital of the Republic of Dagestan. The main part of the coastal plain is formed by a New-Caspian (Holocene) coastal terrace at about -22 m below the oceanic level (Kronstadt gauge).

The terrace ends on its seaward side by a fossil cliff about 3 m high, and is separated from the sea by a contemporary terrace which includes a narrow coastal strip, a lagoon, and the present-day coastal barrier. It is the modern terrace that the effects of the recent sea-level cycle have been monitored. The field investigations at the Turali site were carried out along a cross-section (150x400 m) near the Turali-7 fish factory stretching from the New-Caspian terrace scarp to the sea shore. The cross-section was studied in detail, including the coastal morphology, soil cover, vegetation succession and geochemistry of soils, sediments, water, and vegetation.

Environmental changes in the Volga delta have been monitored in the Damchik area of the Astrakhanskiy Biosphere reserve in the western part of the lower delta plain. The Volga delta is one of the largest deltas in the world, and distinguishes itself from others by its extremely gentle gradient and by the impact of much more rapid sea-level fluctuations than at those along oceanic coasts (Kroonenberg, Rusakov, Svitoch, 1997).

In both cases the coastal development has been studied by compiling data from existing maps, aerial photographs, satellite imagery and field data. Sediment architecture has been revealed using ground penetrating radar profiles in Turali and geophysical survey using the Parametric Echosounder in Damchik area. This was combined with field description and sampling of a number of outcrops in Turali and augerings until 10 m depth in Damchik, which were studied in great detail for granulometry, pollen, geochemistry, malacofauna, and dated using AMS 14C techniques on mostly in-situ mollusks (Kroonenberg, Kasimov, Lychagin, 2008). Interpretation of the geochemical data was done on the base of the landscape geochemistry approach.

RESULTS

Our study showed that the environmental diversity of the coastal zone essentially depends on the Caspian Sea level fluctuations. Along accumulative shores the sea transgression gives rise to geomorphological, lythological, soil, biotic, as well as geochemical diversity of the coastal landscapes. This is caused by inundation and water-logging processes, with a corresponding rise of the groundwater table, and also simultaneous vigorous development of vegetation in newly-formed hydromorphic and semi-hydromorphic areas. On the contrary, the sea regression leads mainly to the passive drowning of the shore zone with a following decrease of the coastal environment variability.

Geochemical conditions of the coastal landscapes are also caused by the sea-level fluctuations. Regressive stages associate with a weak variability of geochemical environment in sediments and soils. They are characterized mainly by alkaline oxic conditions, and salinization as a leading geochemical process. Geochemical diversity of the coastal zone during transgressive stages is much higher. Conditions vary from neutral to highly-alkaline, and from oxic to highly unoxic. Newly-formed geochemical processes are presented by sulfidization, gleyzation, ferrugination, organic matter accumulation, and salinization. They cause a formation of various contrast geochemical barriers in soils and sediments with a consequent redistribution of chemical elements.

New-Caspian sediments in Turali area are presented by marine sediments of regressive stages, lagoon deposits, paleosoils, and coastal bar sediments. Among them the lagoon deposits were found of the most interest due to controversial opinions on their formation. Application of geochemical methods gave us an opportunity to clear up some arguable questions. We used a ratio Fe/Mn to indicate conditions of the lagoon sediment formation. These metals show similar behavior in the most of geochemical environments, but not in alkaline gleyic conditions, which are characteristic for subsoils and sediments of the seashore. Iron here shows a low mobility, since manganese migrates quite actively and accumulates in a rather high extent at geochemical barriers. This feature is characteristic also for the recent terrace. Present lagoon sediments and marshy soils are enriched with both Fe and Mn, but factor of enrichment for Mn is mush higher.

New-Caspian complex described in the outcrop TS-1 in canal Turali-Sulfat (Fig.1) includes sandy layer of the recent coastal bar (samples TS-1-01 – TS-1-03), lagoon sediments (samples TS-1-04 – TS-1-05), and a buried soil (samples TS-1-06 – TS-1-09).

Bulk value ratio Fe/Mn in a sandy layer is about 40, which is quite typical for New-Caspian sediments and close to the ratio of clarks of these metals in the earth crust. The ratio in lagoon deposits was found much lower: 10-20. According to data obtained for the present coastal marsh zone such a ratio indicates low salinity of groundwater in a strip adjacent to paleo-lagoon. This fact was interpreted as an evidence for more humid conditions in the area during a highstand of the Caspian Sea about 2600 BP (due to results of AMS-dating of bivalves found in the lagoon sediments).

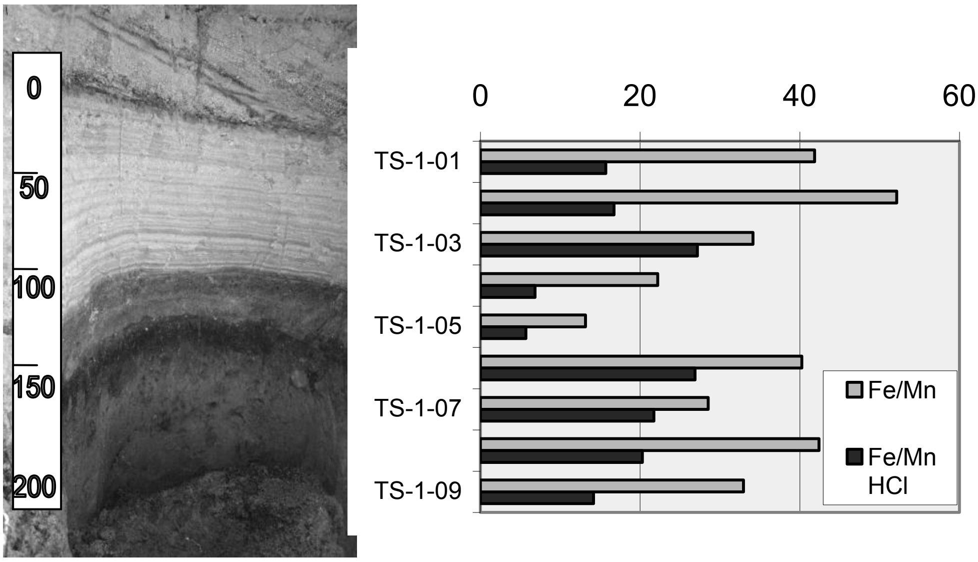

Fig. 1. Outcrop TS-1 and Fe/Mn ratios
(bulk values and forms extracted with 1N HCl) in sediment samples

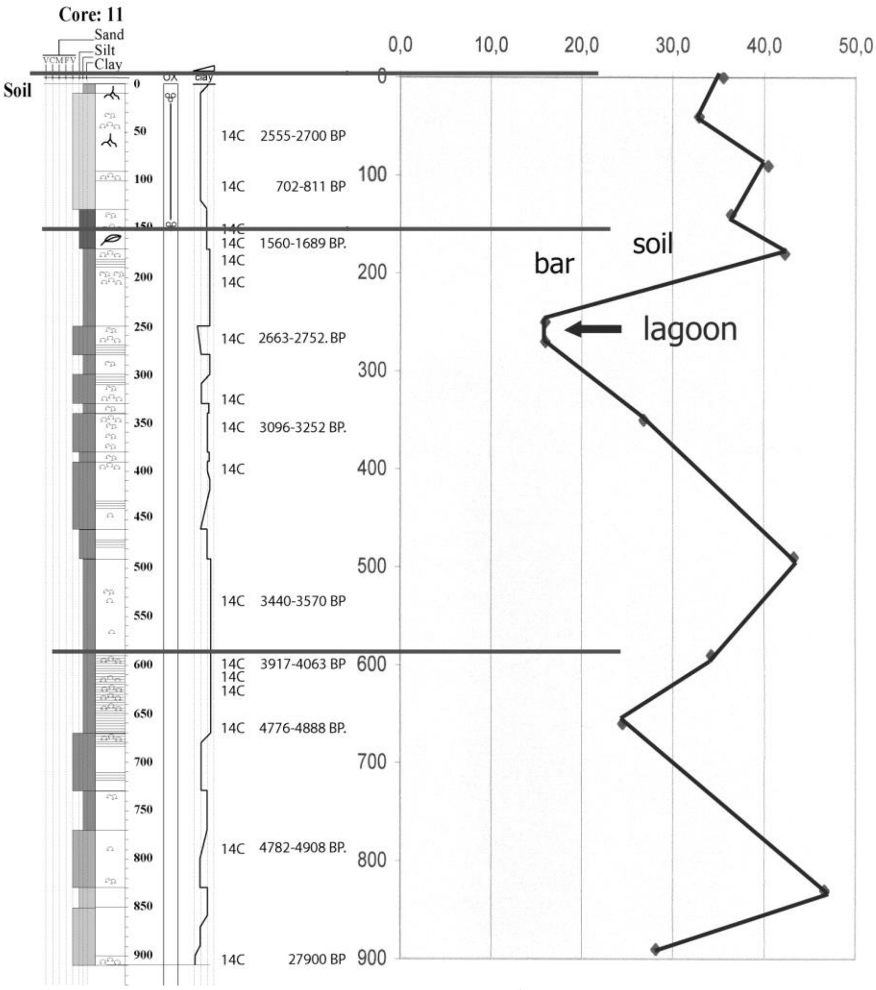

Fig. 2. Fe/Mn ratio in dated sediments of Core 11 (Damchik area)

Further research in Turali area and adjacent areas of Dagestan Republic confirmed these relationships. Lagoon layers in New-Caspian sediments from outcrops of Big Turali Lake and mouth of Shura-Ozen River showed enrichment with Fe and Mn accompanied with a low Fe/Mn ratio.

This peculiarity has been approved by our study of the Holocene sediments in Damchik area in the Volga delta. It can be shown on example of Core 11 drilled in October 2006 to the depth up to 9 metres. Chemical analysis of samples from this core has revealed the lowest Fe/Mn ratio in layers dated about 2600 BP (Fig. 2). It coincides with results obtained at the Dagestan seacoast and speaks about similar geochemical conditions of the sediment accumulation in both areas during the New-Caspian highstand when the sea-level reached -25 m.Analysis of data obtained for sediments samples from holes drilled in Damchik area presents different possibilities for the geochemical indication of paleoenvironments. Of a special interest are geochemical ratios Ba/Sr and Mo/Zr which can be used to distinguish buried soils and also to separate freshwater and marine sediments (Fig. 3).

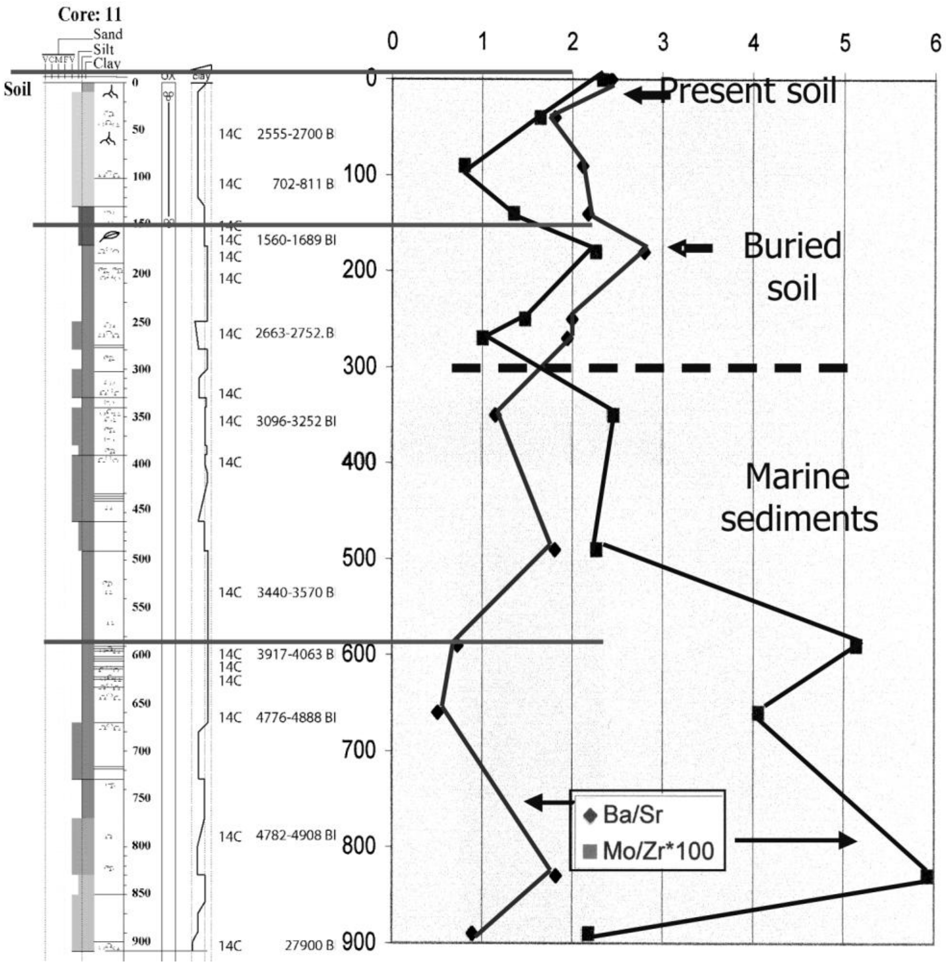

Fig. 3. Ba/Sr and Mo/Zr ratios in dated sediments of Core 11 (Damchik area)

CONCLUSIONS

Environmental diversity of the coastal zone essentially depends on the Caspian Sea level fluctuations: transgression gives rise to geomorphological, lythological, soil, biotic etc. diversity of the coastal landscapes, since regression leads to decrease of the coastal environment variability.

The sea-level rise causes a development in the coastal marsh of a number of epigenetic processes, which determine a formation of complex geochemical barriers; it results in a complication of the coastal geochemical structure, since sea-level fall leads to its simplification.

Studying the geochemical changes in soils and sediments of the Caspian coastal zone for the last cycle of the sea-level fluctuations presents a key for the geochemical indication of sediment formation environments in the past. A number of geochemical ratios can be applied for the geochemical indication of paleoenvironments: Fe/Mn, Ba/Sr, Mo/Zr, etc.

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MANGYSHLAK REGRESSION OF THE CASPIAN SEA: RELATIONSHIP WITH CLIMATE

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Keywords: Caspian Sea, Palaeogeography, bottom sediments, Holocene, level fluctuations, climate

INTRODUCTION

The Early Holocene Mangyshlak regression is a remarkable event in the history of the Caspian Sea. Data on this regression was first published by Zhukov M. M. Its traces in the form of specific erosive landforms (such as the Ural furrow) were established at the bottom of the Northern Caspian Sea. The age of the Regression was defined as post-Khvalynian, the amplitude of level recession is up to 22m below the current one (-50m abs. height).

Later, based on the analysis of the structure of the Caspian Sea bottom sediments, it was shown that the level of the Mangyshlak Sea fell significantly below the specified mark, and that the regression was multiphase. It was established that between 8.5 and 10.0 thousands years ago, there were at least three stages of regression with level delays at altitudes of about -50m, -70m and -90m abs. [Mayev, 2006, 2009]. In this paper, the lithological features of the Mangyshlak bottom sediments were considered, and their relationship with climate change was discussed.

STRATIGRAPHY AND LITHOLOGY OF BOTTOM SEDIMENTS

The characteristics of the condition during the Mangyshlak period outlined here are based on the analysis of materials in the structure of the Caspian Sea sediment cross sections. More than 150 sediment cores were investigated.

Long sediment cores, lifted from the bottom of the Caspian Sea with the help of large piston and direct-push sand samplers, showed a multi-layer structure of the cross section of the upper Quarternary bottom deposits of the Caspian Sea. The cross section includes a number of layers, whose properties are determined by changes in sedimentation conditions, first of all by cyclical nature of sea level fluctuations.

The cross section contains lithologically different layers formed, of course, under substantially different sedimentation conditions. Lithologic isolation of the layers has appeared to be consistent over a large area of the bottom of the South and Middle Caspian Sea, including the shelf and deepwater areas. This made it possible to take lithostratigraphic principles supported with a correlation of sedimentation stages with a known sequence of the major general Caspian paleogeographic events as the basis for stratigraphic partition of the cross section of the Caspian bottom sediments.

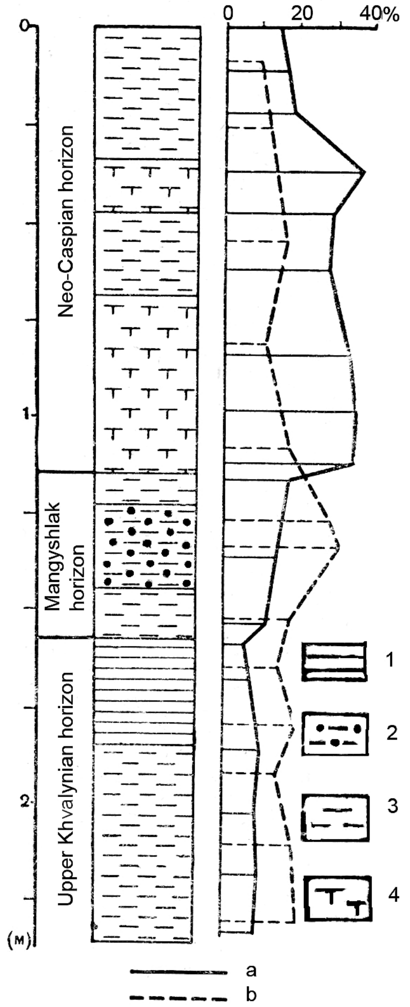

Fig. 1. Cross section of bottom sediments of the Caspian Sea (core No. 101, western South Caspian, sea depth 406 m)
a –$CaCO_3$ content; в – content of aleuritic fraction 0.1- 0.01 mm; 1 – clayey silt; 2 – aleuritic clayey silt; 3 – law-calcareous clayey silt; 4 – calcareous clayey silt

Within the exposed part of the cross section, four layers (horizon) are marked out, significantly different from each other by their lithological composition.

The top horizon – folded grey high-carbonate silts with shells of *Cardium edule L.* (= *Cerastoderma lamarcki, C. glaucum*) in the shallow parts of the shelf, has the medium and late-Holocene age (Q_4nk). This horizon corresponds with the neo-Caspian transgressive epoch. The main feature of neo-Caspian sediments is the significant content of chemical calcium carbonate – 2-3 times more than in the underlying older sediments.

The underlying second horizon is comparable with the Mangyshlak (early Holocene) regressive stage (Q_4mg). Its lithological differences were most clearly manifested in the cores, taken on the shelf. The main feature is in the coarsening of the granulometric composition of bottom sediments, right up to the appearance of inclusion of gravel-pebble material, which are weathered shelly detritus. There are also traces of erosion of underlying sediments. All these features match well with the characteristics of the regressive basin: lowered level and reduced depths, displacement of the coastline, etc. In the cores taken on the shelf, the joints of all Mangyshlak interbeds with underlying and overlying sediments are sharp, rough, and this indicates continually repeated erosion processes, and possibly, redeposition of sediments.

The above features, together with the coarse-grained composition of Mangyshlak sediments indicate the predominance of high-energy conditions in relatively shallow water with active wave impact on the bottom during their accumulation period. The depth of the sea during the formation of Mangyshlak sediments was several tens of meters lower than in the same places today.

The considerable scales of regression are suggested by the fact that changes in the structure of sediments, including an increase in their coarseness are apparent not only on the shelf but also in the deeper parts of the Middle Caspian and South Caspian basin. Within their limits, the influence of the regression had an impact in the substantial change of the ratio of pelitic and aleuric fractions of deposits causing a significant increase in the proportion of aleurite (fig. 1).

Also a feature is the relatively low carbonate content of Mangyshlak sediments. It is significantly lower than the carbonate content of the neo-Caspian sediments, but much higher than the underlying upper khvalynian deposits.

A special feature of the natural conditions of the Mangyshlak epoch was not only the extremely low position of the sea level, but also the presence of an additional source of entrance of terrigenous (fluvial) material from the eastern coast of the South Caspian into the sea. Lithological features of sediments and the distribution of their thichness indicate this. Apparently, this source could be the ancient Uzboy River. In the preceding (late-khvalynian) and subsequent (Neo-Caspian) period, this coast, as now, remains a closed drainage area.

Next, is the third horizon, the underlying sediments of the Mangyshlak age, are deposits of the late-khvalynian transgressive basin (Q_3hv_2), the most deep-watered among the ones considered, and this is due to the thin mechanical composition of predominantly pelitic low calcareous deposits.

RELATIONSHIP WITH CLIMATE

It should be noted that the composition of sediments of the studied part of the Caspian Sea bottom sediments is a clear proof of the connection between a change of transgressive and regressive stages with changes in climatic conditions in the Caspian Sea basin. Several features of the Caspian bottom sediments are subject to climate. We shall consider only two of them – calcium carbonate content and the composition of palynological spectra.

First, attention is drawn to a noticeable change in the content of $CaCO_3$ on the borders of Mangyshlak layers with the underlying upper khvalynian deposits and especially sharp change – with the overlying neo-caspian (see figure). The close link with climate bearing-out rates from land to sea of dissolved $CaCO_3$ is known: an abundant supply of carbonates in the sea and their accumulation in bottom sediments occur in warm and humid climates. It is also known that there are practically no calcareous components in the sediments of cold polar seas, and at the same time, their abundance in sediments of tropical seas. This explains the lowest carbonate content of the underlying upper khvalynian deposits compared to the time of their formation with the epoch of the Late Valdai Glaciation [Rychagov, 1997], which is characterized by fairly cold climate. A little higher than $CaCO_3$ content in Mangyshlak deposits, formed during the early stages of the Holocene – preboreal and probably boreal period with their relatively harsh climatic conditions and only had began with climate warming.

A much sharper, spasmodic increase in the carbonate content of sediments is observed at the border of Mangyshlak and neo-Caspian layers. This leap is associated with the onset of the Atlantic period about eight thousand years ago – the Holocene "climatic optimum" when the climate became much warmer and more humid. Palynological feature of the upper Pleistocene and Holocene deposits of the Caspian region emphasizes the climatic isolation of the Mangyshlak stage. Such isolation is clearly evident in the study of our cores [Abramova, Mayev, 1974]. In the upper khvalynian and neo-Caspian deposits underlying and overlying the Mangyshlak layers, spore-pollen spectra at the prevalence of herbaceous plants pollen still contain a significant amount of pollen of tree species. This suggests a significant involvement of forest coenoses in vegetative cover, which points to a relatively cold and humid climate. In contrast, the palynological spectra of Mangyshlak sediments are characterized by almost complete absence of pollen of tree species and the absolute dominance (95-97%) of herbaceous pollen, among which up to 87% are made up of xerophyte pollen. Such composition of pollen spectra shows a sharp xerophytization of the vegetative cover, continentalization and aridization of climate during the era of the Mangyshlak regressive basin.

CONCLUSION

Consideration of some features of the deposits of Mangyshlak horizon enabled us to clarify some palaeogeographical features of the relevant epoch, including the position of paleolevel ancient regressive basin. Of particular interest are columns, taken on the eastern shelf near its outer edge in the zone of reduced thickness of neo-Caspian deposits, where lithologic isolation of the Mangyshlak layer deposits is most clearly pronounced.

The investigation of bottom sediments showed that during the Mangyshlak regression epoch, the sea level decreased during the maximum stage to almost 100 meters below level of World Ocean. After a maximum regression and before the first stage of the neo-Caspian transgressive basin, there were very high rates of level rise – an average of about 20 centimeters per year. Note that close to this value, the speed of level rise was actually observed in separate years in the modern history of the Caspian Sea in the second half of the last century.

These discovered features of the Mangyshlak sedimentation conditions and other epochs of the late Pleistocene and early Holocene strongly indicate a causal link of transgressive-regressive sea-level fluctuations with a distinctly pronounced climate change.

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DEVELOPMENT OF VEGETATION AND CLIMATE CHANGE IN THE NORTHERN CASPIAN REGION DURING THE LATE PLIOCENE: THE POLLEN RECORD

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Keywords: Ural-Emba area, the Akchagylian, environmental changes, pollen assemblages

INTRODUCTION

Upper Pliocene (the Akchagylian) deposits are widely distributed within the southeastern part of the East-European Plain – especially in the oil and gas province such as the Northern Caspian Region. Economic activity, including environmental protection and management within oil and gas fields, requires geologic and palaeogeographic studies, the prediction of environmental changes and the discovery of analogs for the latter. Amongst the various palaegeographical methods, pollen analyses play an important role since they provide the information on the flora, and vegetation and climate changes. The purpose of this paper is 1) to present the Late Pliocene (the Akchagylian) stratigraphy; 2) to provide the complete information on the flora and the vegetation, and their changes through time; 3) to indicate the changes of ancient landscape and climate; and 4) to show the interrealationship of the changing climate and vegetation with the transgressions and regressions in the palaeo-Caspian.

This study uses material from the east of the Northern Caspian Region (between the Ural and Emba rivers), where the palynology of the Akchagylian has been studied very little (Fig.1).

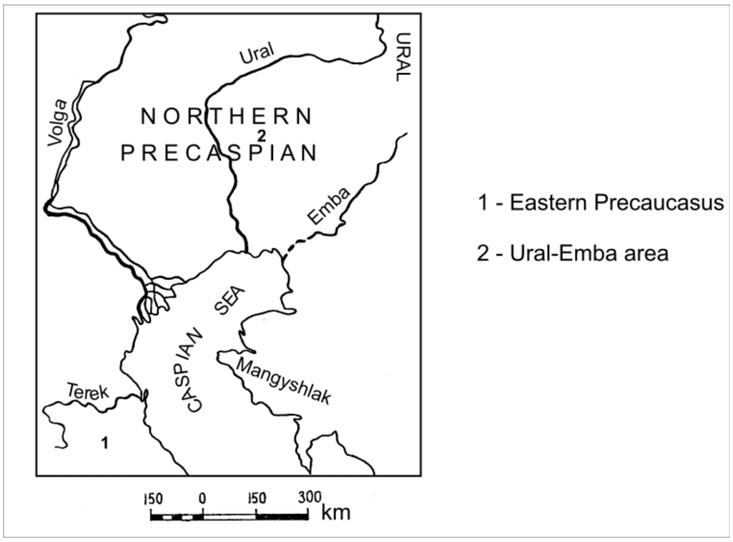

Fig. 1. The Northern Caspian Region

STRATIGRAPHY

Until now the stratigraphic status of the Akchagylian has not been properly defined.

A three-fold subdivision of the Akchagylian is the most widely used. In this work, palaeomagnetic boundaries are used to define the Upper Pliocene and the Eopleistocene, in accordance with published data (Nevesskaya et al., 1984; Pevzner, Vangengeim, 1986; Trubikhin, 1987; Nikiforova and Alekseev, 1989). The base of the Akchagylian is at the boundary between the Gilbert and Gauss paleomagnetic intervals, at around 3.6 Ma; the Akchagylian/Apsheronian boundary, is at the top of the Olduvai palaomagnetic episode in the 1.64 – 1.66 Ma intervals.

According to the new stratigraphic framework for the West Europe by Cita et al. (1999) the base of the Piacenzian of the Mediterranean is located at the base of small scale carbonate cycle 77 of Punta Piccola, Italy, which coincides with the Gilbert-Gauss boundary at 3.6 Ma and with the base of the Akchagylian of the Caspian region (Naidina, 2009).

The base of the Gelasian of the Mediterranean starts at stage 103.20 ka above the Gauss-Matuyama boundary, at 2.589 Ma and also corresponds to the mid-Akchagylian of the Caspian region. Suc et al. (1997) proposed that the Plio-Pleistocene boundary be moved back to the 2.6 Ma horizone (Gauss-Matuyama boundary).

MATERIAL AND METHODS

Cores from several boreholes drilled in the Plio-Pleistocene deposits in the Ural-Emba area from the east of the Northern Caspian Region were provided by the geological survey team from the Kargalinsk geological exploration expedition. Well material has been described and characterized faunally.

Pollen grains were separated using a cadmium solution according to the method of Grichuk, followed by acetolysis using the method of Erdtman. Identification and counting of pollen were undertaken on a “Laboval” biological microscope at a constant magnification of 400x.

Palaeogeographical analysis of fossil arboreal flora of varying composition was undertaken using the method of Grichuk (1959).

RESULTS

Pollen preservation is exellent in the upper Pliocene sediments of the Ural-Emba area. At around 3.6 Ma and prior to 2.6 Ma two main pollen assemblages are recognized: a steppe assemblage with pollen from xerophytic Chenopodiaceae, and a forest assemblage dominated by pollen from various pines and elms.

At around 2.6 Ma, pollen assemblages are distinguished by the growing influence of forest-taiga pollen species, and they correlate with the mid-Akchagylian pollen assemblages from the deposits of the Urdinsk beds in the west of the Northern Caspian Region (Kovalenko, 1971) and in the Eastern Precaucasus (Naidina, 1999) (Fig. 1).

From 2.6 Ma to 1.6 Ma pollen assemblages differ in containing more diverse pollen coniferous and broad-leaved trees. At around 1.6 Ma deposits are characterized by uniform pollen assemblages with a dominance of Chenopodiaceae pollen.

COMPOSITION AND PALEOENVIRONMENTS

Until the end of the Pliocene the Northern Caspian Region was situated between two floral regions: a European area of mixed forest and a Mediterranean area of steppe (Nevesskaya et al., 1987). During the Akchagylian there was succession of changes in the relationships between the geographical elements of the flora, and the role of thermophilic elements decreased.

The main types of pollen assemblages in the Akchagylian deposits of the Ural-Emba area reflect forest, forest-steppe and steppe landscapes. Phases of development of the vegetation have been recognized, the alternations of which reflect fluctuating climatic conditions. Periods of forest vegetation correspond to humid intervals, whereas treeless periods were arid.

At the beginning of the early Akchagylian, a treeless landscape predominated. At the end of this time interval, the Ural-Emba area had a forest-type of vegetation. Pollen from pan-holarctic geographical groups (Picea, Pinus, Abies, Alnus, Betula, Salix, Juniperus, Cornus, Myrica and Rhamnus), American-Euroasiatic groups (Corylus, Fagus, Quercus, Tilias, Ulmus, Acer and Ilex), and also areas with subtropical elements, show that the climate was moderately warm and quite humid. The early Akchagylian forests were characterized by the maximum diversity of arboreal species. Representatives of American-Mediterranean-Asiatic (Castanea, Juglans, Pterocarya, Zelkova, Celtis, Rhus and Liquidambar), American-East Asian (Tsuga, Carya, Nyssa, Liriodendron and Magnolia) and East Asian (Keteleeria and Sciadopitus) geographical groups are present.

A cooling trend is present in the mid-Akchagylian. This is demonstrated by numerous types of coniferous species, the occurrence of forest-taiga forms, and the reduced of termophilic elements.

Towards the end of the mid-Akchagylian a tendency towards a more continental, arid climate is noted. Treeless landscapes developed. The beginning of the late Akchagylian marked an increase in aridity. This is shown by the development of sparse oak-pine forests and treeless landscapes. Apparently, on the flat and gently undulating plains between rivers, there was a predominance of xerophytic grasses and undershrubs. Sparse forests grew on the slopes of river valleys.

The late Akchagylian and early Apsheronian times were characterized by an intensification of the continental climate and an increasing aridity. Xerophytic Chenopodiaceae-Artemisia steppes landscapes predominated.

IMPACT OF THE AKCHAGYLIAN TRANSGRESSION ON THE VEGETATION

In all probability, during the Late Pliocene and Eopleistocene there was a single transgression. The stages of expansion and contraction of the palaeo-Caspian were due mainly to the influence of climatic factors, which had an even more immediate influence on the vegetation. According to Sidnev (1985), the first stage of the transgression occurred as early as the Kimmerian. Later, in the middle of the early Akchagylian, the transgression spread, and the treeless landscapes of the earliest Akchagylian were replaced by forest landscapes. Broad-leaved-conifer and pine forests dominated, with elm, tsuga and relict turga flora. Arboreal flora of this type indicates a temperate-warm and humid climate. During the second stage, the Akchagylian transgression reached its maximum. It occurred in the second half of the mid-Akchagylian, extending to the north, northeast and west. A general cooling on the adjacent land led to the growth of forest-taiga spruce-pine forest with tsuga and fir. The zone of forest-taiga shifted to the south over a considerable area of the eastern part of the Northern Caspian Region.

The succeeding contraction of the marine basin occurred during the late Akchagylian. The late Akchagylian regression was related to a decrease in humidity. This led to the development of a treeless xerophytic vegetation. In the Caspian region the Akchagylian/Apsheronian boundary generally represents a regressive stage of the marine basin.

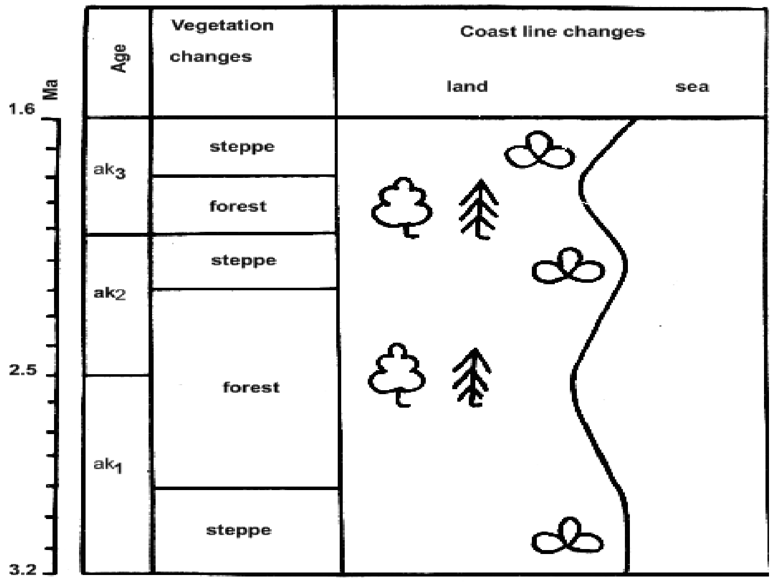

Fig. 2. Correlation of changes in vegetation with changes of the coast line

Pollen analyses shows that during transgressions the area occupied by forests increased, whereas regressions correspond with a more arid, continental climate with a steppe and semidesert environment. According to the pollen assemblages, the types of vegetation cover varied from steppe during periods of decreasing marine influence, to forest-steppe and forest during transgressive episodes. The changing vegetation cover was determined by the climatic fluctuations and variations in sea level. During the Akchagylian, the change between forest and treeless landscapes in the area of the modern Northern Caspian Region occurred no less than five times (Fig. 2). Since the Akchagylian is thought to have lasted for 1.6-1.8 Ma, the change occurred approximately every 0.2-0.3 Ma.

CONCLUSIONS

The main conclusions of this study are:

– paleogeographical analysis of the arboreal flora shows that throughout the Akchagylian, there was a successive reduction in the proportion of thermophilic elements;

– expansions of the sea led to moderately humid conditions, with the development of forest landscapes. Contractions of the sea were characterized by increased aridity and the development of treeless landscapes;

– the first cooling was at around 3.6-3.4 Ma, and corresponds with the beginning of the Akchagylian and the Gilbert/Gauss palaeomagnetic inversion. There was change in the main floral elements. The second more significant cooling, at 2.3-2.6 Ma, corresponds with the beginning of the mid-Akchagylian and the Gauss/Matuyama palaeomagnetic inversion; the maximum stage of the Akchagylian transgression occurred and coniferous forest landscapes developed.

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CYCLIC DEVELOPMENT OF THE QARA-SU RIVER DRAINAGE NETWORK IN RESPONSE TO CASPIAN SEA LEVEL FLUCTUATIONS IN LATE QUATERNARY

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Keywords: Qara-Su River; Caspian Sea Eustasy; Drainage network; Gross and normalized values; Reconstruction; late Quaternary.

INTRODUCTION

The Qara-Su River basin is located in Golestan Province, northeast Iran. Its topographic relief ranges from +3204 to –28 m and trends toward the west. The basin has a south side asymmetric drainage network along 60 km and drains more than 1779 km^2 of the Gorgan Area to Gorgan Bay, southeast corner of the Caspian Sea (Fig. 1).

In our opinion the key to the logical reconstruction of evolution of the QSRDN (and lower stream of large rivers in coastal plain especially with deltaic system such as Volga River and Gorgan –Rud River) lies in the CSL fluctuations in glacial and interglacial periods, a mysterious phenomenon that does not easily let itself to scientists.

Instrumental records of sea level change reaches back only to 1837, and age data on earlier sea levels are fragmentary and often contradictory (Kroonenberg et.al, 2003).

During the late Quaternary, the CSL has fluctuated with amplitude of tens of meters under the different combinations and synergies of Tecto- glacio eustasy. In the last 8000 years it fluctuated repeatedly with amplitudes up to at least 15 m, and it dropped from a highstand at +50 m in the Last Glacial down to possibly even -113 m in the early Holocene (Kroonenberg et.,al ,2003). In spite of serious uncertainties in dating, the frequency and magnitude of these fluctuations are well documented by raised marine terraces, coastal fixed sand dunes (Ehlers,1971; Ownegh, 1999), fluvial and eolian sediments(Ministry of power and water, 1970), and fossil shells as *cardium edule* (Yasini,1981) in the Gorgan Plain and Alborz foothills. Similar evidence has been reported from the other locatities of the Caspian Sea coast such as kara-Bogaz-Gol Gulf and Volga Delta (Gasse, 2001; Girant, 2000; Varushchenko et al., 2000) and Kura Delta (Kroonenberg et.al, 2003).These excellent environmental archives allow the reconstruction of the past conditions of the Caspian Sea coastal geomorphology.

The drastic oscillations of local base level has severely affected the geomorphological work and spatial configuration of the QSRDN which contains 9 namely sub-basins. This evolution has been very obvious and critical so that it can be mentioned as an exceptional case throughout the Caspian Basin due to the specific spatial configuration and synergistic effects of the Alborz Mountain direction, active Gorgan Fault strike, presence of long narrow tectonically controlled Gorgan Bay (Dickerson, 2000), and the continuous fluctuations of the CSL.

At present this area is known as **"Qara-Su Lowlands"** and contains several marshes while usually threatened by flooding and ponding hazards in winter and early spring.

The main purpose of this paper is to reconstruct and mapping the development stages of the QSRDN in response to CSL fluctuation in late Quaternary using available data.

ASSUMPTIONS

Due to the spatial and temporal nature of the subject, and mutual reaction of tectonic activity and Caspian Sea eustasy in the region, this research is based on the following assumptions*:*

2.1. The drainage basin morphometric adjustment to the sea level changes can be reconstructed by the chrono- stratigraphical and geomorphological methods (Bo, 2001).

2.2. The tectonic effects of the Alborz uplift and south Caspian subsidence is not meaningful to change local elevation of the tributary junction points to the mainstream, although vertical displacement of the Gorgan Fault of several meters has the potential to complicate the reconstruction of the past sea levels and their evidences in regional scale.

2.3. Current available chronological data on the entire CSL during historic and geologic times can be combined grossly for a regional scale such as Gorgan Area (south Caspian Basin).

2.4. Reconstruction of the river drainage network development for the last complete cycle or regression of the Caspian Sea from +15 to –28 m during the 45000 BP.

METHODS

Considering the morpho-chronological nature of subject, this research was accomplished by a combination of the present data and documents of the CSL fluctuations during the Wurm glacial and Holocene through the following stages:

3.1. Extraction and combination of the CSL elevation in historic and geologic time scale that were dated by the more sophisticated radiometric methods (C14, Th, O18 ,TL) or estimated (correlated) by geomorpho- sedimentological and fossil evidences.

3.2. Mapping the ancient extent of the Caspian Sea and Gorgan Bay according to current topographic map contours at +20,0,-10,-15,-20 m that are very close to critical sea level points of stream branch junctions.

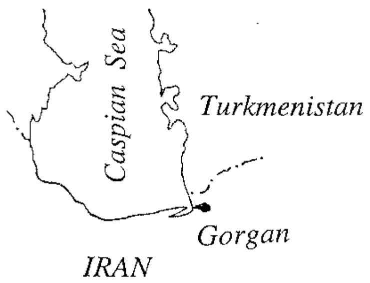

Fig.1. Location map of the study area

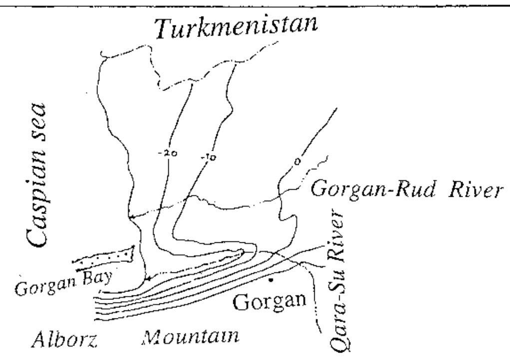

Fig.2.Topograpy of the Gorgan Plain

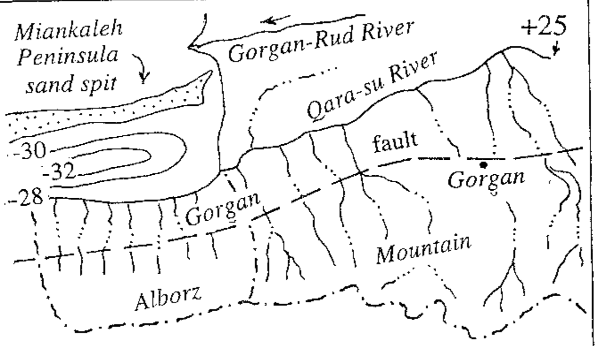

Fig.3.Gorgan Bay isobath and Gorgan Fault.

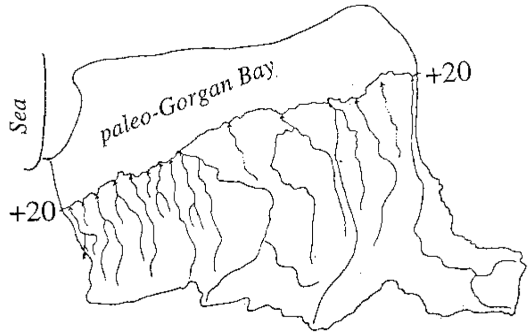

Fig.4.Drainage network at +20 m

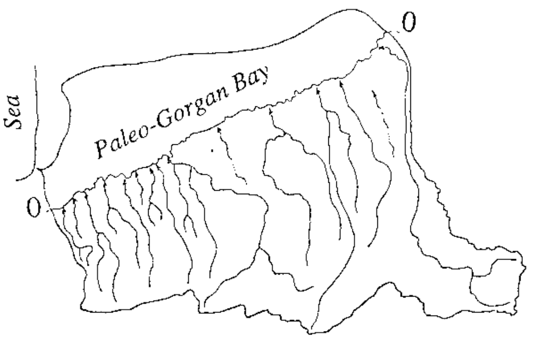

Fig.5.Drainage network at 0 m

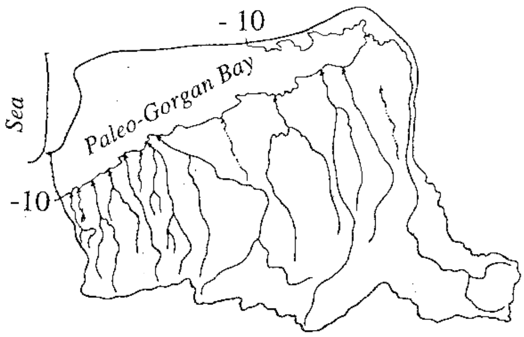

Fig.6.Drainage network at –10 m

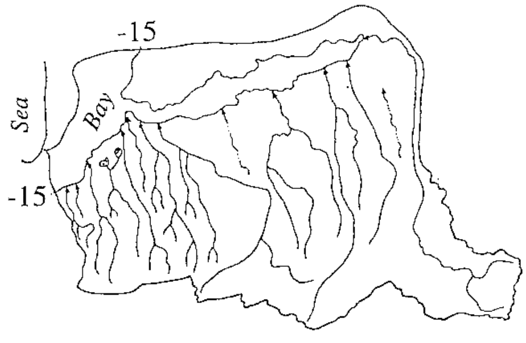

Fig.7.Drainage network at –15 m

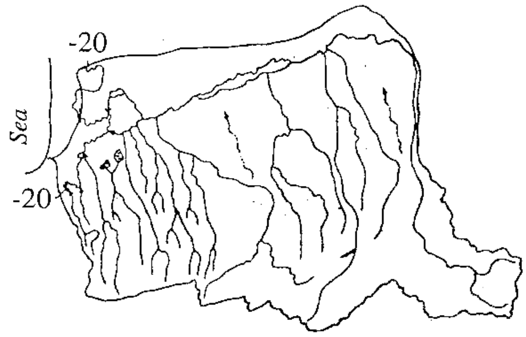

Fig.8.Drainage network at –20 m

3.3. Determining the tributary junction points elevation (I to X) to the main stream as effective and critical levels in the evolution of the basin drainage network using 1:50000 scale topographic map. For the detection of the Qara –Su mainstream bed and tributary junction points air photos (1:50000), TM (1:100000) and Cosmos (1:50000) satellite images were also used. In this scheme, every critical sea level is an indicator to a tributary junction (in sea regression) and separation (in sea transgression). Basin drainage network mapped at different critical sea level with separation of 9 sub-basins (Fig. 4-8).

3.4. Selection and calculation of 10 hydro-geomorphological additive parameters(A,P. W1, W2, W3, W4, W5, NW, L, Ls) that play key role in the reconstruction of the river paleo-drainage network under the known global and regional eustatic trends (Ownegh,1992). Outlets of sub-basins were closed at the junction points to the main stream so that in several cases lead to considerable inter-basin areas and alter somewhat the amount of the key parameters.

3.5. Determining the effect of the each tributary junction on the amount of key parameters or calculation of their variations between successive critical sea levels (A to I) in gross (percent) and normalised value (frequency difference divide by elevation difference).

3.6. Rank comparison the effect of each tributary junction between critical sea levels on the hydro-geomorphological development of basin drainage network in both gross and normalised values, and testing their statistical differences by chi-square method.

RESULTS AND DISCUSSION

This study has resulted in several key hydro- geomorpholoical concepts on the evolution of the QSRDN during late Quaternary. The most important of these are:

Sea level fluctuation trends

At present literature, there are different data and opposing (paradox) paradigm upon the time, amplitude, duration, rate, and number of regressions and transgressions and really regarding to **"Caspian Palimpsest"** in Pleistocene and historic time (Ownegh,1997).

Interpretation of a relatively comprehensive curve shows that the water level of the Caspian Sea has been experienced a typical quasi-cyclic variations in all of the possible time scales including seasonal (40 cm), annual (15 cm), decadal (150 cm), centennial, (up to 10 m) (CEP, 2002) and millennial (up to 50 m) (Derbyshire and Goudie, 1997) since the maximum last glaciation. Amplitude of fluctuations for the last 450-500 years is equivalent to 7 m (Fig.9, (CEP, 2002).

Table 1 . Variations of the Caspian sea level during Late Quaternary (Sources:Derbyshire and Goudie,1997:Golubev,1998*)

Critical sea level	Number of occurrence	The oldest YBP **	the newest YBP	A .time of occurrence
+ 25	1	45000	45000	45000
+ 15	1	44500	44500	44500
0	9	44637	14284	3373
– 10	12	44280	11250	2752
– 15	7	11540	7220	617
– 15.5	11	11500	7242	388
– 16	16	11462	6322	428
– 18	12	11422	6042	448
– 19	12	11362	5902	455
– 19.5	13	11342	2560	676
– 20	14	11322	2600	623
– 23	21	11220	320	518
– 28	26	1090	20	419
– 34	4	5272	1442	958

* +25 to -10 m from Derbyshire and -15 to -34 m from Golubev
** Year Before Present

In the last 8000 years it fluctuated repeatedly with amplitudes up to at least 15 m, and it dropped from a highstand at +50 m in the Last Glacial down to possibly even -113 m in the early Holocene and the last major highstands occurred 2600 BP and 300 BP. Both highstands coincide with worldwide periods of cool and wet climates, marking the beginning of the Subatlantic and the Little Ice Age respectively (Kroonenberg et. al, 2004, Fig.10).

According to the available data the CSL has never been stable and in last 45000 years it has experienced at least 75 fluctuation cycles with amplitude of 1.5 m and average period of 625 years. Maximum relative stability of the CSL has been documented at –25 m for almost 6000 years from 28500 to 22500 BP (Table 2 and Fig.9).

In the Gorgan Area there are several reliable morpho-sedimentological evidences to the at least 4 cycles of the CSL long-term catastrophic fluctuations in late Quaternary (Ownegh, 1991).

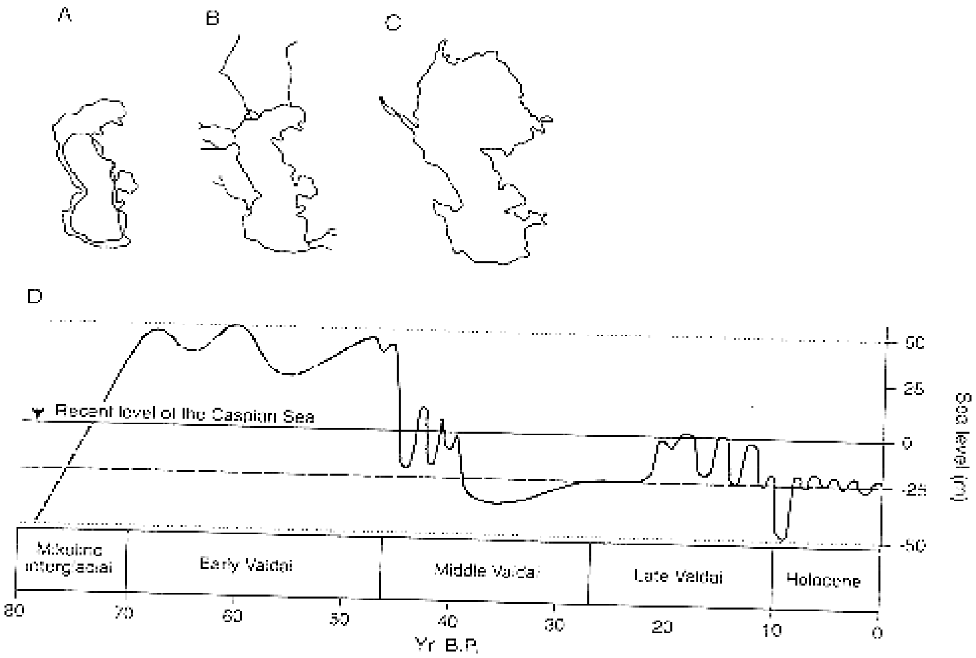

Fig.9. The changing nature of the Caspian Sea (A) The extent of the sea during the Mikulino interglacial (B) at the present day; (C) The greatly expanded sea during the Early Valday glaciations; (D) The transgression and regression of the Caspian since the last interglacial (modified from Chepalyga, 1984)

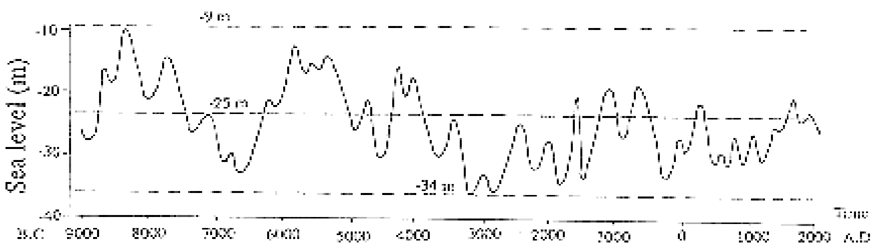

Fig. 10. Variations in the water level of the Caspian Sea during the Holocene (Klige, 1992)

Sea level changes effects

Long-term, erratic and successive changes of the CSL in the late Quaternary have had direct and indirect effects on the hydro- geomorplological evolution of the Qara -Su River basin that can be divided in two different patterns:

– Slow effects on the geomorphological work of rivers, including changes in normal and backward erosion, longitudinal and cross profile of streams, alluvial fans, deltas, flood plains, marine terraces, coastal sand dunes, and sequences of marine and continental deposits and related coastal underground water aquifers. At current sea level raised period, under the severe sea storm waves brackish water penetrates upstream up to 3 to 4 km and causes a submerged temporary condition on the river mouth and delta.

– Rapid effects on the spatial pattern of drainage network, including changes in drainage pattern, stream junction and separation, and numerical value of the hydro-geomorphological (physiographic) parameters especially between successive critical sea level or tributary junction points

. – According to available isobath maps, the present-day Gorgan Bay with maximum depth of 4 meters at –28 m sea level (Fig.3) has dried at –32 m several times, and probably the follower extent of the mainstream of Qara-Su River changed drainage patterns of the basin as an indication of **"Ancient Qara-Su River Basin"** or its last generation.

– The number of sea level repetition in the late Quaternary varies from 1 at +25 m and 26 at -28 m (Fig.3-8). Therefore the total number of branch junctions and separations were 1(Gharmabdasht at +15 m) and 21 (Zavardasht at – 23 m) .

Table 2 .Extreme rates of the Caspian sea level fluctuation during late Quaternary(last 45359 years)

Sea level (m)	Start YBP	End YBP	Duration year	H mm	Rate mm / Y	State *
+40–26.5	45359	7	45352	66500	1.466	Multi--cycles , R
+40 – 20	45359	43579	1780	60000	33.707	Mono--cycle , R
–9 – 32	8360	6680	1680	23000	13.69	Multi--cycles , R
–12– 32	6720	5820	900	20000	22.222	Multi--cycles , T
–21–32.5	3642	3522	120	11500	95.833	Mono--cycle , R
-24.5 –25	28572	22499	6073	500	0.082	Mono--cycle , T
-29.2-26.5	24	7	18	2700	150	Mono--cycle , T**

* R = Regression , T = Transgression ** The last episode of sea level rise

Drainage network development

– The evolution of the QSRDN has taken place under the very sensitive morpho-tectonical conditions and complex eustasy of the Caspian Sea in late Quaternary, so that the QSRDN connected and disconnected several times during last 45000 years.

– Following the regression of the Caspian Sea (ancient Gorgan Bay) at +25 m, the mainstream of Qara-Su River gradually developed on the graben bed of the Gorgan Bay and received new branches from the northern slope of the Alborz Mountain at critical sea level elevations. Even at +20 and 0 m almost 32.4 and 25.9% of the current surface of the basin and nearly all of its mainstream length has been occupied by the Caspian Sea or Gorgan Bay (Figures 4 and 5). The maximum extending of Gorgan Bay in a more distinct long narrow shape has occurred at -15 m in about 700 BP and it was possible to spreading at least to -10 m even without the formation of Gorgan (Miankaleh) sand Spit.

– Successive regressions and transgressions of the Caspian Sea during the late Quaternary resulted in successive junctions and Separations of the 9 tributaries to / from the mainstream

– Vertical distance of critical points vary between 30.5m (class A) and 0.5 m (class B), and their horizontal distance vary from 9.96 km (class D) to 0.42 km (class B) Table.2), that affect severely the normalized rates of parameter variation.

– In a continuos regression model of the Caspian Sea (or a complete cycle for Qara-Su Basin), the first and latest tributary (respectively at +15 and –23 m) has connected to the main stream between 44500 to

2600 BP (Table and Figure). Therefore, at least for the last complete cycle the branches junction time and development rate of QSRDN can be dated by the CSL stages.

– The erratic and rapid morphometric changes in the basin drainage network has taken place at the critical sea level or tributary junction points from +15 to –23 m. Above and below +15 m there were many sub-basin internal changes (Figure). Over the +15 m, all of the 9 tributaries (or sub-basins) of the current Qara-Su River has been independent streams and has directly entered to the ancient Gorgan Bay at same time. In this model, tributary junctions has begun at +15 m and ended at –23 m through passing –16, -18, -19,-19.5 ,-20, -22 m respectively. The effects on the drainage network above the +15 m and even above each tributary junction point can be termed **"Sub-basins internal evolution"**. The most outstanding of them are for example the junction of two mainstreams of the Ghazmahleh (at +143 m) and Zavardasht (at +19 m) sub-basins (Fig, 11).

– The high degree of youthfulness of the mainstream rather than their branches from the fluvial point of view. The maximum age of the main stream as a distinct river can be estimated almost 45000 years.

– According to actual value of the 10 morphometric key parameters, at every present critical sea level, the succession of rank or relative importance of the 9 sub-basins (with direct junction to mainstream) is different. At –23 m as the latest junction point the rank order of the sub-basins are as: 5,3,1,2,4,6,8,7 ,and 9 respectively (Table 3).

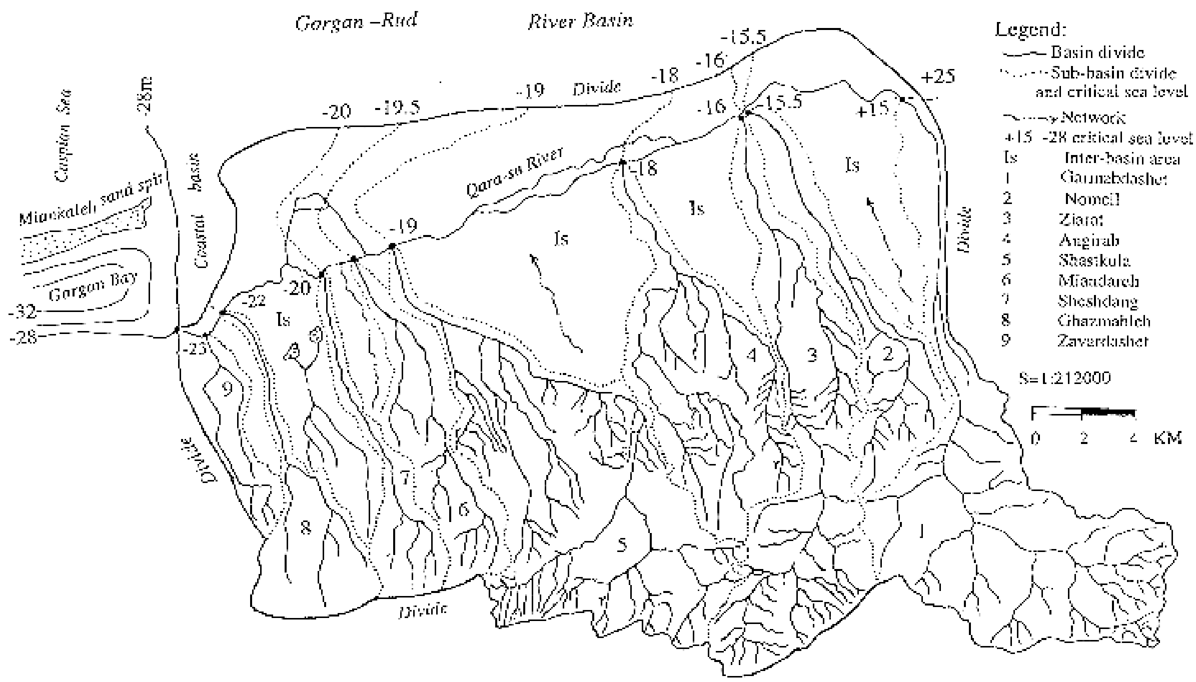

Fig.11.Qara – Su river drainage network, sub-basins and location of tributary junctions at different sea level (between +15 and –28 m) and time (historic period and Late Quaternary)

– The 9 sub-basins of the Qara-Su River can be divided to eastern and western groups according to their hydro-geomorphological properties and contribution to the related changes in drainage network in the late Quaternary. The eastern sub-basins including 1, 2, 3, 4 and 5 are much larger and effective in comparison to the western sub-basins including 6, 7, 8 and 9 (Fig.11, Table 2).

– The average rate or acceleration of the CSL fluctuation for a continuos regression or transgression (multi-cycles) between +40 to –26.5 m is 1.466 mm/y. The rate of latest sea level rise (mono-cycle in 1978-1995) is 150 mm / y (Table 2). Therefore the temporal morphometric variations of the QSRDN depend on the elevation of the junction points and the rate of the sea level changes (in preference to sea regression), but the similar spatial variations relate on the morphometric dimensions and geographical distribution of the sub-basins.

– The differences between branch junction effect in gross and normalized values indicate to differences of two successive critical sea level elevation and hydo-geomorphological dimension of branches that can be related to rate and date of sea level changes (Fig.12).

Table 3 .Measures of hydro - geomorphological parameters of the Qara-Su river watershed at different critical levels of the Caspian sea

Criti. Level / Parameter	I + 15 m	II – 15.5	III – 16	IV – 18	V – 19	VI – 19.5	VII – 20	VIII – 22	IX – 23	X – 28
A *	247	451.5	640	860.5	1339	1453	1538	1724	1777	1779
P	110	125.5	147.4	153	183	186	194	206.4	208	209.3
Cc	1.96	1.65	1.63	1.46	1.4	1.36	1.38	1.37	1.38	1.39
U1	51	69	123	156	229	240	243	247	251	251
U2	15	19	29	37	54	57	58	59	60	60
U3	5	6	9	11	16	17	17	17	17	17
U4	1	1	2	3	4	4	4	4	4	4
U5	0	0	1	1	1	1	1	1	1	1
Nu	72	95	163	207	303	318	322	327	332	332
Rb	3.8	4.26	3.24	3.55	3.9	3.95	3.96	3.97	3.98	3.98
Ls	48.5	62.5	62.9	71.3	89.1	91.2	94.1	103.5	105.9	108
L	178.6	273.4	459.2	615.7	935.4	1007.8	1048.4	1094.7	1134	1135.7
Dd	0.72	0.62	0.71	0.71	0.69	0.69	0.68	0.63	0.64	1.63
Sf	0.29	0.21	0.25	0.24	0.22	0.21	0.2	0.19	0.18	0.18

* A=Area, KM^2 ;P=Primeter. KM ; Cc= Compactness coefficient(basin shape) ;U1 to U5 = Number of stream order 1 to order 5; Nu = Total number of streams ; Rb= Bifurcation ratio ; Ls= Length of main stream, KM ; Σ L= total length of drainage network Dd= Drainage density , KM / KM^2 ; Sf = Stream frequency , Number of stream per KM^2 .

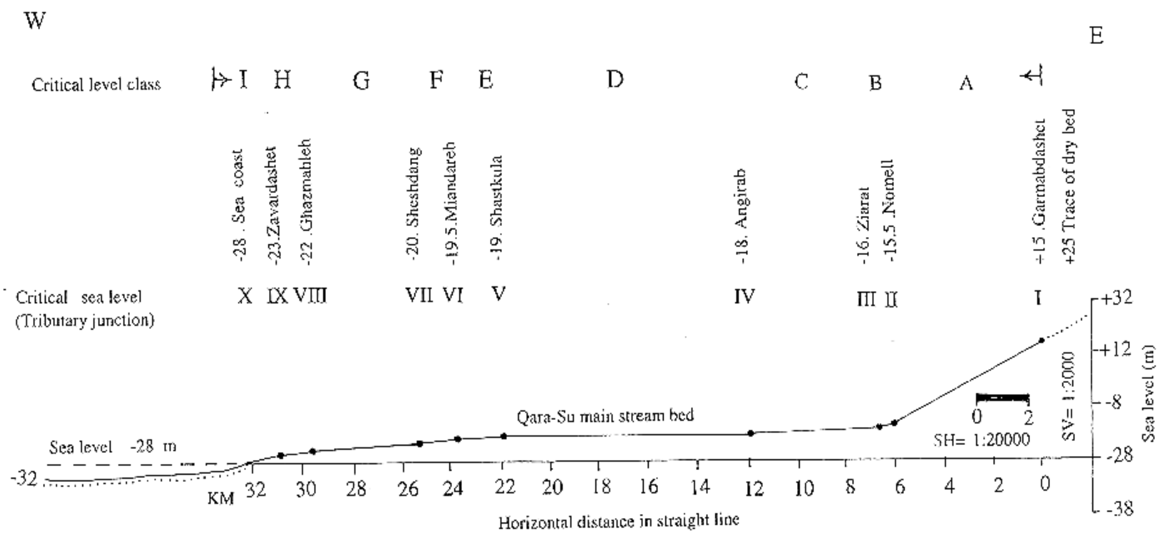

Fig.12.Qara-Su river main stream bed longitudinal profile and its tributary junction points at different critical sea level.

– The differences of successive critical sea level or branch junction elevation are meaningful at 0.01 confidence level.

– The variation in the amount of key parameters (except of Ls) between successive critical sea level were different and significant at 0.01 and 0.05 confidence level (Table.3).

– The differences of parameter average changes between critical levels are considerable at 0.01 confidence level, so that maximum and minimum of them have been in B (junction of Ziarat at level of III or -16m , D (junction of Shastkula at level IV or –19 m) and H (junction of Zavardasht at level IX or –23 m) and A (junction of Nomell at level II or -15.5m) critical level classes in both gross and normalised values respectively (Tables 2 and 3).

CONCLUSION

The complete cycle of hydro-geomorphological evolution of the QSRDN can be reconstructed by the simplification of the very complex eustatsy of the Caspian Sea in late Quaternary (in last 45000 years) between +15 and –28 m critical sea level In this proposed model, Garmabdasht river with diversion to the west at + 15 m (was not able to reach to Gorgan-Rud River mainstream) has established the first generation of the QSRDN in 45000 BP.

The initiation of the mainstream on the tectonically bed of ancient Gorgan Bay during the Caspian Sea regressive stages and cross to the southern independent streams caused to their successive capture and gradual formation of the present day QSRDN.

In comparison to southern tributaries, the mainstream of the Basin is very young (younger than almost 45000 years). In addition, the youthfulness of the establishiment of the current Qara-Su basin can be counted as an exceptional case in the entire Caspian Basin.

The sensitivity of the QSRDN and its coastal geomorphology to the quasi-cyclic fluctuations of the Caspian Sea level is very high.

Spatial and temporal variations of the hydro-geomorphological evolution of the QSRDN in relation to the morphometry of the sub-basins and the fluctuation of the CSL has different patterns throughout the late Quaternary.

In spite of serious hesitations on the long term predication of the CSL trends, in next 50 years the water level will rise to -22 m (if not controlled and stabilised at a desirable level to five coastal countries by offensive strategy) that will result to drastic changes and a retrogressive partial –cycle in the development of QSRDN (separation and independence of the last 2 tributaries , Zavadasht and Ghazmahahleh) and coastal geomorphology especially around the Gorgan Bay.

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SEDIMENT WAVES OF CASPIAN SEA AS STRATIGRAPHIC EVIDENCE OF LEVEL CHANGE

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Keywords: Seismostratigraphy, sediment waves, sea level changes, geohazards

INTRODUCTION

This paper focuses on structure of the Pleistocene and Holocene sediments of Central Caspian (depression between Mangyshlak and Apsheron Thresholds). Data used is of high-resolution single-channel seismic profiling systems with vertical resolution from 2-3m to 0.2m. In general, sedimentation processes in the Central Caspian are controlled by bottom topography, especially morphology of continental slopes, and sources of sedimentary material (rivers runoff first of all). The steep (first degrees) western slope is a pathway for sediment output from numerous mountain rivers of the Great Caucasus (Terek, Samur, Sulak and others), which are the main source of suspended matter in region. Mangyshlak Threshold had been formed under influence of Volga and Ural rivers, which have great water output but less suspended material. The main peculiarity of the Caspian Sea is its rapid level-change which results in rhythmic sedimentary formations of different scale: several generations of sediment waves on western slope, regenerative channel system on the west of Mangyshlak Threshold and repeating creep formations on its east. All these formations have several internal unconformities, which can be traced on seismic sections and are therefore regional. Such pattern correlated with deep well could help to improve our knowledge about sedimentary processes during level changes.

REGIONAL SEQUNCES

Basic data interpretation shows three regional acoustic sequences R1, R2, R3 (Fig.1), the same as in previous investigations [1]. Due to two deep drilling sites (PRV-1 and Central) it is possible to refer the acoustic sequences to lithological ones and to the regional stratigraphic scale and absolute age. Such correlation proves the horizon between R1 and R2 to be one of the largest regional stratigraphic markers. It indicates the most dramatic Caspian regression of last 1 mln years, the Turkanian one (occurred about 600-700kyr ago). The second horizon, between R2 and R3, marks the most dramatic transgression of the whole Caspian history, the Khvalinian one (occurred about 20-30kyr ago). More detailed interpretation shows several internal unconformities in each of the regional sequences. These unconformities have different shape and quality in different local settings nevertheless in whole they obviously separate different seismoacoustic units and can be referred to transgression and regression environments. The geological age of these regional units can be identified from synthetic interpretation of local units.

LOCAL FORMS AND SEQUENCES

Derbent sediment waves

The local sequence on the western slope of Central depression consists of several generations of sediment waves, interbedded by acoustically transparent layers (Fig.3). The whole sequence has a form of a wedge and is situated between the shelf break and the steep step down to abyssal plain. The relief of present bottom shows vast field of sediment waves (1km length, 30m height, field 100km x 30km). The field has been developing during last 700kyr, and occupies Regional Sequences 2 and 3. Sediment waves are of mixed origin, because the environment favors both turbidity and bottom current processes. The main regional source of sediment material are numerous Caucasus rivers on nearby shore (shelf break is only 30-40km from the coast here). The material supply is very good, thus occasional trigging from Caucasus is responsible for regular turbidity flows. On the other hand, there are bottom currents of complicated pattern. Erosive or accumulative effect of the currents depends on sea level. Nowadays (transgression) erosion is occurring. The pattern of local unconformities and wave pattern of seismic sections clearly represent transgressive-regressive cycles (Fig.2). Geological and absolute age table is taken from [2].

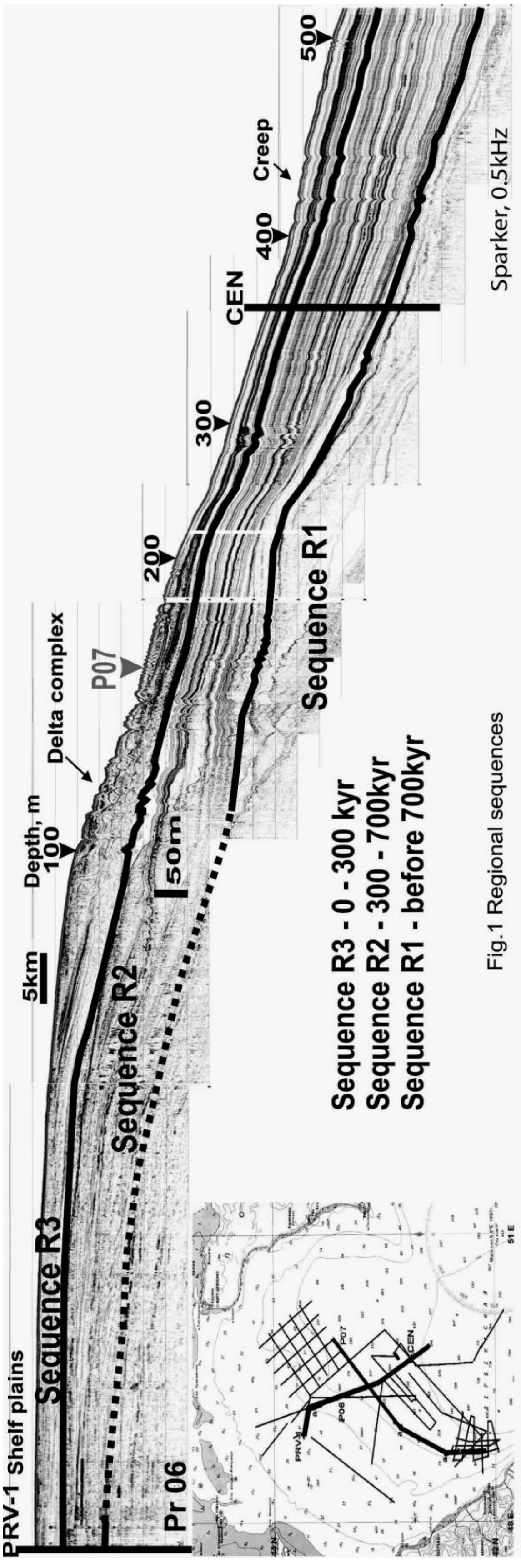

Fig.1 Regional sequences

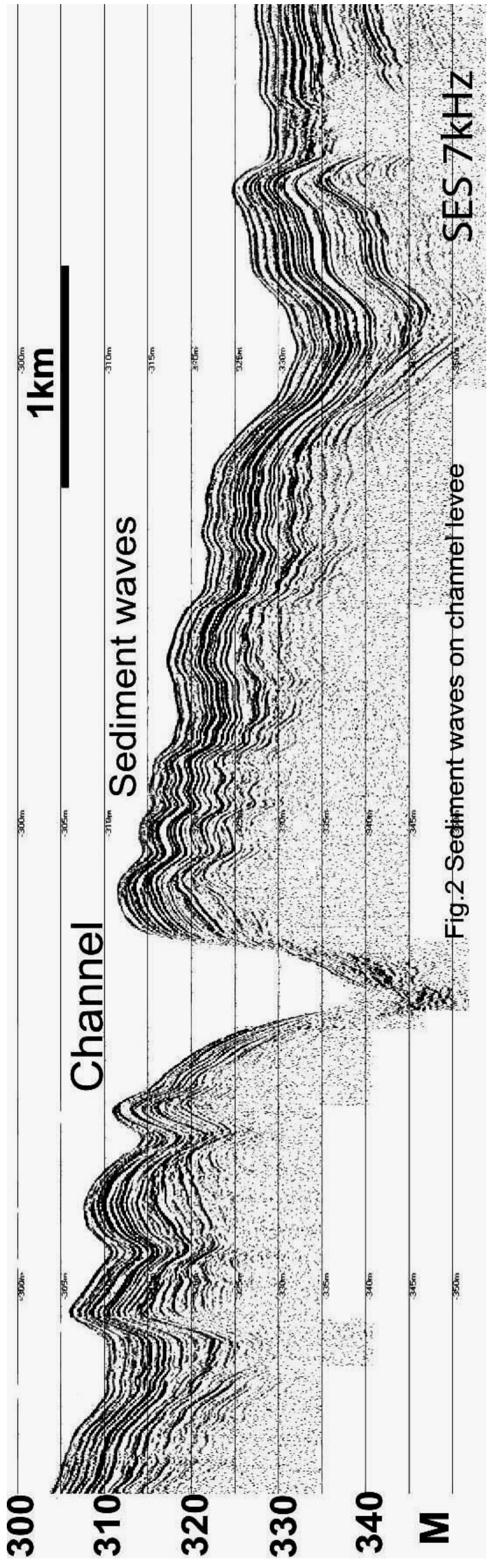

Fig.2 Sediment waves on channel levee

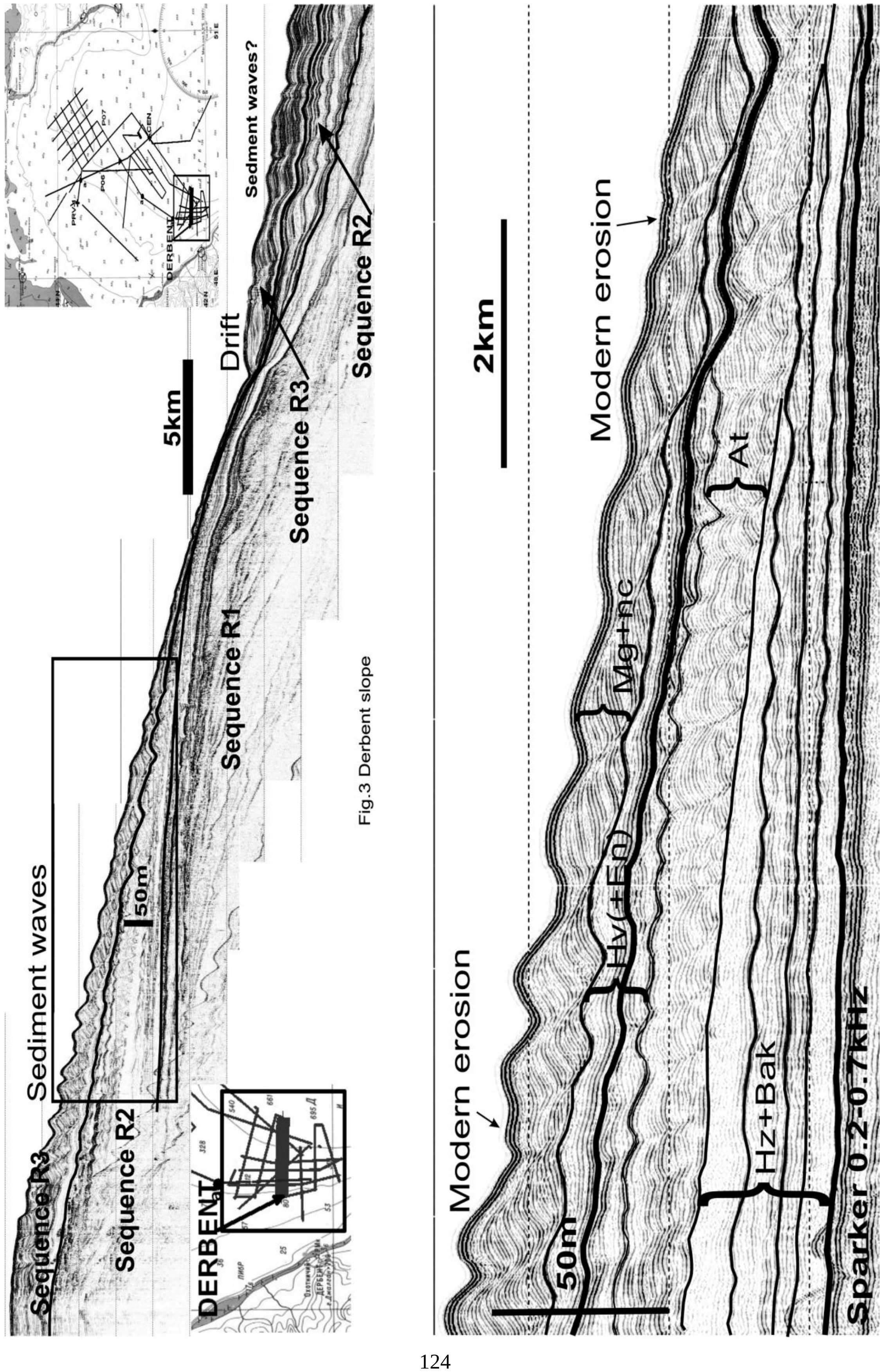

Fig.3 Derbent slope

Sediment waves of channel system

The western part of Mangyshlak Threshold is built by several great fan systems of Volga and Terek Rivers with influence of nearby smaller rivers. Each regional sequence here represents a cycle of growing and retreating of local fan system and its lobes with spectacular erosion unconformities and lobe bodies, which clearly correlate with regressions. A dramatic system of channels exists in modern bottom relief, and several paleo-channel systems of different age are visible on seismic sections. There are several fields of turbidity sediment waves on their levees (Fig.2), both modern and paleo ones (average parameters 100–500 m length, 10 m height). Sediment waves show different morphology, probably because of not precisely normal transactions, nevertheless they can be considered as indicators of meanders and active environment. Geological data inside channel in present bottom shows filling of thin modern sediments over coarse Mangyshlak sediments. Thus, the modern channel system is at least of Mangyshlak age.

Sediment waves of contour currents

Between wave field of Derbent and the channel system, there is a zone of wavery bottom relief (2-3km length, 20m height), which also represents seismic pattern of “running wave”. Due to big distance among profiles, this third type is questionable at present. Nevertheless similar waves are situated seaward from the drift on continental rise of Derbent slope, in Central depression. All these forms are supposed to be the result of anti clockwise near bottom contour current or its different branches.

Mangyshlak Creep

In eastern part of Mangyshlak Threshold several paleofan and paleodeltaic complexes of Ural River are situated. The avandelta parts show spectacular creep formation. The folds are of “classical” creep shape: flat tops, narrow valleys, irregular morphology and geometry. It is interesting to follow up several “generations” of creep folds, since there are several of them in every regional sequence, and each slightly differs from others. Geological cores show water-saturated plastic clay.

Nevertheless, in nearby deep-drilling site CEN-1 the near-bottom clays are not so wet and plastic, as they do not flow into the borehole, so no casing is needed. This can be explained by change in lithological facies, which is not represented on the seismic data. It should be noted that in most eastern parts the most upper part of the creep is eroded by channels of next fan system.

CONCLUSIONS

Level changes of Caspian Sea during last 700kyr, can be better understood from accurate interpretation of high-resolution seismoacoustic data. There are several types of sediment waves (accumulative forms) and a creep zone (plastic deformation forms), which can be used as evidences of different environments and sea levels and help to understand complicated pattern of interdependent sediment processes in the past and at the present.

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PALYNOLOGY OF PRE-HOLOCENE AND HOLOCENE SHALLOW CORES FROM THE DAMCHIK REGION OF THE VOLGA DELTA: PALYNOLOGICAL ASSEMBLAGES, ZONES, DEPOSITIONAL ENVIRONMENTS AND CASPIAN SEA LEVEL

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Keywords: Holocene, palynology, pollen, dinoflagellates, dinocysts, Lower Volga Delta, Damchik, Astrakhan Biosphere Reserve, Caspian Sea, vegetation, climate, sea level change, depositional environment, correlation, deltaic deposition.

INTRODUCTION

New palynological data are presented from the Holocene and Late Pleistocene of the Volga Delta. The data are from shallow (c.10m) cores taken from the Damchik region of the Astrakhan Biosphere Reserve, Russia, during fieldwork carried out in 2006 and 2007. Around 210 samples were analysed for palynology (by K. Richards and N. Bolikhovskaya) from seven cores. Core locations were selected based on shallow seismic surveys, giving a spread of localities from the proximal (northern) and distal (southern) parts of the study area. The results are calibrated by ^{14}C dates.

PALYNOLOGY ASSEMBLAGES AND POLLEN ZONES

Almost all of the samples selected for study contained rich recoveries of palynomorphs, including mixed associations of pollen, spores, algae and dinocysts. The pollen floras include several types of tree (arboreal) pollen including *Pinus* (pine), *Quercus* (oak), *Ulmus* (elm), *Tilia* (lime) and *Carpinus* (hornbeam). Other types include *Betula* (birch), *Alnus* (alder) and *Salix* (willow). The latter can be found frequently growing at the river margins (levees) of the present-day Volga delta. Pollen from herbaceous (non-arboreal) plants occurs frequently and includes Gramineae (grass), *Artemisia* (mainly cold and dry “steppe” plants) and Chenopodiaceae (typically from desert and / or salt-marsh localities). Another important group includes pollen from various aquatic (i.e. water dwelling) plants.

These include open water, floating, types such as *Potamogeton* (pond weed) as well as rooted forms such as *Sparganium* (bur reed) and *Typha* (reed mace). Seven palynological zones, prefixed DP (Damchik Palynology), were identified which are further sub-divided into eleven sub-zones. Most are constrained by ^{14}C dates. Furthermore, the zones can be broadly correlated to the palynological climate / vegetation scheme for the Lower Volga-Akhtuba study at Solenoye Zaimishche (Bolikhovskaya 1990; Bolikhovskaya & Kasimov 2008) and also to interpreted transgressive / regressive phases of the Caspian Sea (e.g. Varuschenko et al. 1987).

Zone DP-7

Zone DP-7 is assigned only in Damchik-9, where it occurs within a thick interval of reddish sand and clay. It is characterised palynologically by mainly poor recovery (in the upper part) and by the presence of frequent (mainly Mesozoic) reworking in the lower part. Tree pollen is rare or absent, except for pine pollen which is locally common.

Sub-zone DP-7a: frequent *Pediastrum*

Sub-zone DP-7b: frequent Mesozoic reworking.

DP-7 is thought to indicate a channel succession with significant downcutting and reworking, so is likely to be represent a period of relative lowstand, although the localised peak of freshwater algae suggests periodic water flow and perhaps overbank deposition.

Inferred age: DP-7 is not directly dated in this study, but it is likely to be mostly, if not entirely, of pre-Holocene age. It is likely to represent, possibly, the earliest phase of the Mangyshlak regression (earliest Holocene) and an older, but un-dated part of the Late Pleistocene.

Zone DP-6

The top of DP-6 is marked by a high abundance peak of fungal bodies (mainly spores) and is clearly visible in several of the studied sections. A low diversity pollen assemblage also occurs, which may contain common Chenopodiaceae, and other non-arboreal pollen. Freshwater algae (*Pediastrum*) are also locally common. DP-6 is interpreted as a broadly regressive period. Fungal bodies are frequently associated with soils, or similar sediments where there is an element of sub-aerial exposure. In addition, the presence of locally frequent Chenopodiaceae pollen and freshwater algae, suggests depositional conditions varying between sub-aerial, hyper-saline and freshwater. These would have occurred in the Baer Hills, a dune field formed during the Mangyshlak regression (see below), which, as at the present time where they are exposed to the west of the modern delta, probably also had saline and freshwater habitats between the dunes. DP-6 is assumed to indicate penetration of sediments equivalent to the Baer Hills below the modern delta. They are represented lithologically, for the most part, by reddish brown ("chocolate") sands, silts and clays.

Inferred age: The calibrated ^{14}C date of 8072 BP from the very top of DP-6 (in Damchik-18) equates approximately with the late Boreal and the latter part of the Mangyshlak (regressive) stage. There are no dates from the older part of zone DP-6 but the regional correlations suggests an earliest Holocene age.

Zone DP-5

DP-5 is a very distinct zone and is characterised by a peak abundance in Chenopodiaceae pollen (to in excess of 50% of the total palynoflora). Chenopodiaceae pollen is typically indicative of salt-marsh or similar dry or salt-prone localities. Pollen of the *Ephedra distachya* type, which has a similar ecological tolerance, is also locally common. Samples from DP-5 may also contain low to moderate numbers of brackish dinocysts, almost always *Spiniferites cruciformis*. The pollen assemblage indicates a dry climate and almost certainly minimal run-off in the river systems. Caspian sea levels are likely to have been in a brief period of relative lowstand, with salt-marsh ("salt-bush") vegetation extending over large areas of the delta (similar vegetation types do occur at the present time in the dry upper and middle parts of the delta, away from the fluvial channels and seasonally flooded regions). Even though the delta region was largely arid at the time, a small rise in sea level would have flooded over the delta front areas, bringing in the brackish dinocysts.

Inferred age: Calibrated ^{14}C dates of 8072 BP from just below DP-5 (in Damchik-18) and 7287 BP in the base of DP-4 (Damchik-22) give a reliable age range for the zone. DP-5 is likely to correspond to a short-lived, but severe, dry period during the early part of the Atlantic period.

Zone DP-4

DP-4 is characterised by significant increases in pollen from herbaceous plants, notably *Artemisia*, grasses (Gramineae) and salt-bush (Chenopodiaceae). Fungal bodies, freshwater algae (*Pediastrum*) and dinocysts (*Spiniferites cruciformis*) are also locally frequent. DP-4 is condensed in Damchik-9 and has a "channel association", with frequent reworking, in Damchik-21 (sub-zone DP-4d).

Sub-zone DP-4a: increased grass pollen and fungal bodies

Sub-zone DP-4b: increased *Artemisia* and *Pediastrum*

Sub-zone DP-4c: local increase *Spiniferites cruciformis*

Sub-zone DP-4d: poor palynomorph recovery with locally frequent Mesozoic reworking.

The overall palynofloras in DP-4, with frequent non-arboreal pollen, suggest a largely dry succession, but with intervening humid episodes. The "channel association" (sub-zone DP-4d) suggests an initial period of downcutting, presumably during a regressive regime. The increase in brackish dinocysts (sub-zone DP-4c) is indicative of a Caspian transgression, with a subsequent increase in *Pediastrum* (sub-zone DP-4b) representing a dilute, freshwater highstand period. The overlying interval (sub-zone DP-4a) suggests a subsequent regression with increased fungal bodies recorded.

Inferred age: DP-4 is well constrained by ^{14}C ages. The youngest calibrated age (at the top of the zone in Damchik-17) is 3620 BP and subsequent ages are all progressively older, and therefore probably reliable. The base of the zone is dated as 7287 BP in Damchik-22. The age ranges and correlations to other sections suggest that zone DP-4 represents most of the Atlantic period and extends into the early and mid Subboreal. It is unlikely, however, that continuous sedimentation occurred at any one locality, and gaps in the record are therefore probable.

Zone DP-3

DP-3 is present in all (except one) of the studied sections and is assigned primarily on the increased presence of warm-tolerant, broadleaved tree pollen types, such as *Quercus, Ulmus, Tilia* and *Carpinus* (the "QUTC group" described by Bolikhovskaya 1990). Freshwater algae, mainly *Pediastrum* are also common or abundant. DP-3 also coincides with the appearance (up-section) of frequent dinocysts (mainly *Impagidinium* "*caspienense"*) and also with increased pine pollen and reworking, especially of Mesozoic dinocysts.

Sub-zone DP-3a: localised increase in Chenopodiaceae (only seen in Damchik-18)

Sub-zone DP-3b: frequent pollen from broadleaved taxa and increased *Pediastrum*.

The palynological record indicates that this study interval coincided with a period of mainly warm and humid climate. Furthermore, the data suggest a time of mainly high Caspian sea levels, shown by the presence of frequent freshwater algae and / or in-situ dinocysts. Common reworked elements suggest mainly high river discharge.

Inferred age: Calibrated ^{14}C ages from Damchik-9 and Damchik-18 give ages of 3388 BP and 3451 BP from the lower part of the DP-3 zone. The upper boundary of the zone is not directly dated but, on the basis of correlation, probably equates to about 2500 BP (the end of the Subboreal). Sub-zone DP-3b is suggested as an equivalent of the transgressive Turaly local stage, with sub-zone DP-3a equating to a regional sea level fall, although this is not directly dated in the cored sections.

Zone DP-2

DP-2 is present in all of the studied sections and is characterised by reduced numbers of *Salix* pollen and an increased representation of pollen from aquatic plants such as *Potamogeton* and *Sparganium* and also from grasses (Gramineae). Dinocysts, especially *Impagidinium* "*caspienense*" (common) and *Spiniferites cruciformis* (consistent) are also present. *Pediastrum* (freshwater algae) and fungal bodies also locally common, as are reworked forms including Mesozoic dinocysts.

Sub-zone DP-2a: frequent *Potamogeton* and / or *Sparganium*

Sub-zone DP-2b: increased fungal bodies

Sub-zone DP-2c: increased *Pediastrum*.

DP-2 records at least one cycle of Caspian sea level rise and fall, although the complete range of phases is not present in all sections. In general, samples with frequent aquatic pollen (sub-zone DP-2a) and *Pediastrum* (sub-zone DP-2c) are likely to represent dilute, highstand conditions, with regressive trends picked out by samples with frequent fungal bodies (sub-zone DP-2b). Damchik-24 has an expanded DP-2 succession with frequent brackish dinocysts, which is interpreted as an embayment ("kultuk") feature.

Inferred age: More than c.1000 years BP, based on consistent ^{14}C ages (calibrated) within the range of 1540 BP (Damchik-21) to 1889 BP (Damchik-24). DP-2 most probably equates more or less with the early and middle Subatlantic periods. It is likely, but not proven, that sediments relating to the Derbent lowstand may be missing or not extensively preserved in the studied sections. An exception could be Damchik-24 where calibrated ^{14}C dates within the range of 707 BP to 1064 BP were obtained, which exactly matches the inferred age of the Derbent regression. It is possible that that brackish embayment in Damchik-24 is an infilled incised channel that was initially cut during the Derbent lowstand. If so, two "older" ^{14}C dates (1706 BP and 1889 BP) from the upper part of the succession must be influenced by sediment inversion, slumping or reworking of the dated shells.

Zone DP-1

DP-1 is marked by the common presence of *Salix* pollen and occurs in the uppermost metre or so of all of the studied cores. It is largely a depositionally-controlled zone in that the *Salix* pollen is a feature of the levee localities at which most of the cores were collected. Fungal bodies, mostly spores and hyphae, are also frequent and may be a product of modern soil-forming processes. DP-1 relates to the deposition of the modern Volga Delta which, at least at the Damchik locality, has been in a state of outbuilding through progradation during progressive Caspian sea level fall within the last 100 years or so.

Inferred age: Not directly dated but assumed to be less than c.700 years BP (post-Derbent regression).

DEPOSITIONAL MODEL, ENVIRONMENTS AND CASPIAN SEA LEVEL

As has been previously postulated (e.g. Kroonenberg et al. 2005), the Volga outflow is controlled mainly by climate patterns (humidity) in the catchment, potentially a long distance away from the delta region. Other, related, factors include Caspian sea level, which provides the "base level" for delta sedimentation, and which is largely controlled by the balance between river input and basin subsidence. Regarding the palynological data, very precise interpretations of depositional environment can be made, which often vary between individual samples. When viewed together, an estimate of overall depositional trends can be made. The key parameters are, first, the pollen record in the delta sediments, which can be interpreted as indicators of warm and humid (e.g. broadleaved trees) or cold and dry climates (e.g. *Artemisia*, Chenopodiaceae). Certain pollen types are indicative of particular habitats or environments within the delta, such as *Salix* (willow) which grows almost exclusively on the river banks (levees) in the lower delta, and the aquatic plants, such as *Potamogeton* and *Sparganium* which are indicators of open water habitats (reed beds etc.). Second, are the water-dwelling palynomorph types, including algae such as *Pediastrum* (freshwater) and *Botryococcus* (tolerant of fresh and low salinity water), and also the dinoflagellates (dinocysts). The three main types of dinocysts present are *Impagidinium* "*caspienense*", *Spiniferites cruciformis* and *Caspidinium rugosum* (see Marret et al. 2004). These are known to occur in low salinity waters close to the modern delta, and also occur in the more open waters of the Caspian Sea. Furthermore, there are suggestions (e.g. Kouli et al. 2001) that some types, including *Spiniferites cruciformis*, may be tolerant of fully freshwater conditions.

The basic depositional model inferred in this study is that increased river outflow, from all rivers but especially the Volga, will have the effect of raising Caspian sea levels and lead to predominantly *aggradational* deposition. In this case, the influx of freshwater will make the water bodies in the Caspian and in the lower delta *more dilute*. This is shown in the palynological records by increased representation of either (or both) *Pediastrum* and dinocysts. The former is in response to increasingly freshwater conditions, and the latter due to mixing of the Caspian (low salinity) and lower delta (dilute) water bodies. Both *Pediastrum* and the dinocysts are therefore broadly indicative of *highstand* conditions in the Holocene delta, be they either fully freshwater or low salinity. Both might occur at the same time in different parts of the delta complex. Significant periods of dry catchment climate will produce reduced river outflow, and allow the expansion of the dry-tolerant vegetation communities, such as steppe and salt-marsh in the delta localities. The overall effect of prolonged dry catchment climates will be a reduction in Caspian sea level, leading to predominantly *progradational* deposition, and outbuilding of the delta. It follows that the water bodies in the lower delta and nearby Caspian sea will become *increasingly saline* and have reduced overall circulation. The response in the pollen floras tends to be an increase in dry and / or salt-tolerant types such as *Artemisia* and Chenopodiaceae, and other non-arboreal types (e.g. Compositae). Fungal bodies also tend to show increased frequencies in the intervals of *relative lowstand*, most probably due to increased formation and exposure of soil horizons.

Work is ongoing to integrate all of the palynological data and inferred events into an agreed framework for Holocene Caspian sea level change.

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DERBENT BASIN QUATERNARY SEDIMENTS

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Keywords: Middle Caspian Sea, sediment, crust of cementation, authigene carbonates, diatomaceous ooze, hydrotroilite, grain-size analysis, mineralogical composition.

INTRODUCTION

Derbent basin sediments (Middle Caspian Sea) collected on the 19 stations on the two areas 5 x 5 km with the help of impact tube. Core sample length are 0.5-5.7 m. Complex of engineering-geological investigations and continuous seismoacoustic forming (CSF) with high resolution [1] was dissected.

RESULTS AND DISCUSSION

Area 1 ranged on the depths 375-510 m (see fig.1), its western part – comparatively gentle slope area (up to depth 400 m) in the area pinching out of Upper Pleistocene-Holocene sediments, its eastern – sharp bottom part of the slope. From informations of CSF, sharp bottom part carried explicid flags of slips and submarine erosion.

Area 2 ranged on the more gentle northwestern slope of the Derbent basin on the depths 375-510 m (fig.1). Problems of bottom morphology associated with breakout of large submarine valleys and fans on the base of the slope.

For area 1 ranged on the depths 380-420 m (station 1-7) characteristic brownish brown consistent, riched by Fe-oxyhydroxides crust of cementation collided by fine layer of broken shells. Bellow for section occurred soft clays gray, greenish gray, brownish gray, contained fine layers, and overburdens of fine aleurites terrigenous material (fig.2).

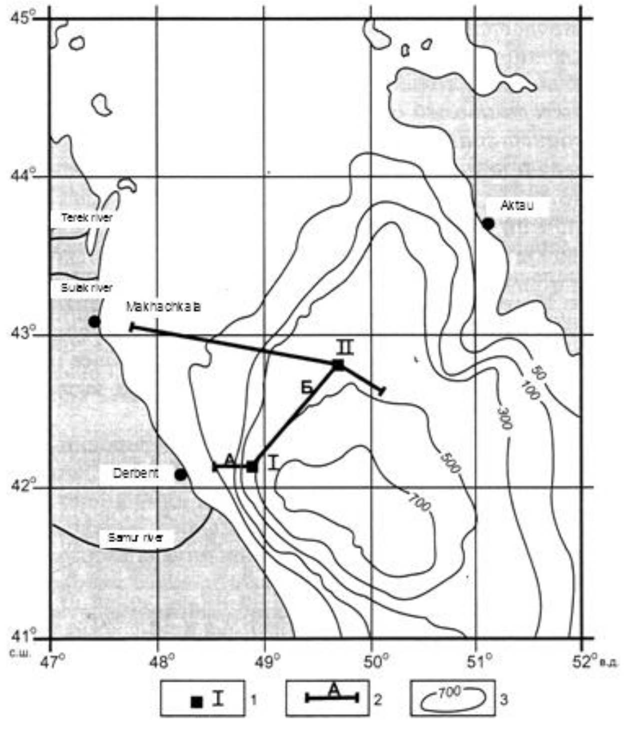

Fig. 1. Location of geological areas and seismoacoustic forms. geological area, 2 – seismoacoustic form, 3 – isobatic, m.

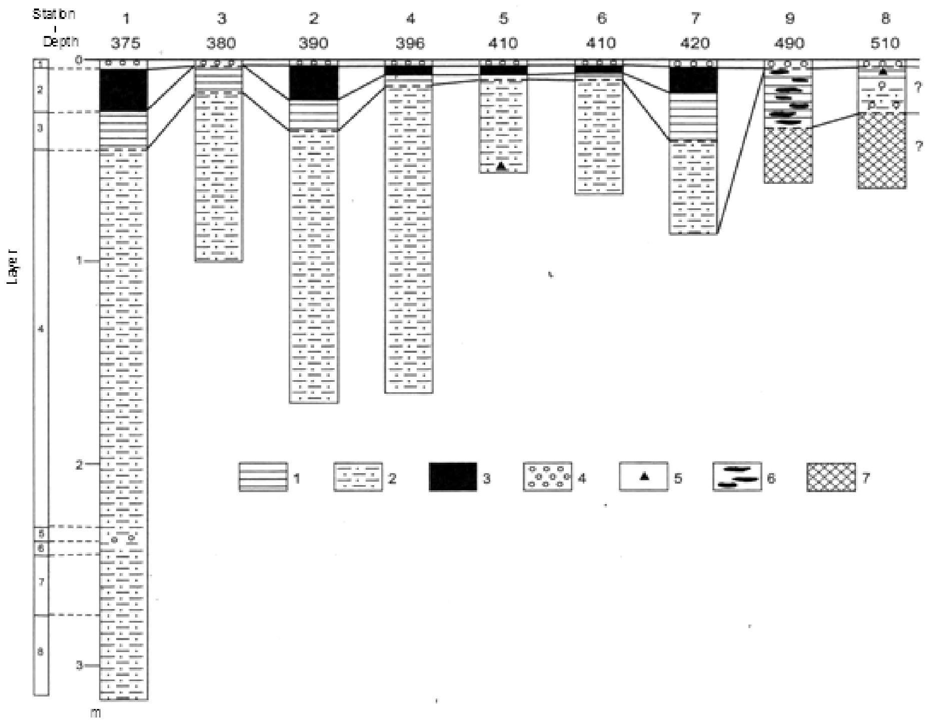

Fig. 2. Lithostratigraphy of the area 1 sediments.
1-clay soft riched by terrigenous aleurites; 2 – clay soft with lenses and layers of the terrigenous aleurites; 3 – clay condensed diagenetic tabular riched by Fe-oxyhydroxides (crust of cedementation); 4 – detritus of shells; 5- fragments of rocks; 6 – carbonate crusts;7- Pliocene dence clay.

At the base of the section on the st. 5 appeared fragment (3.0 x 1.5 x 1.2 cm) greenish brown organogenous of limestone with sandy and gravel grains of charts and quartz.

Bellow excessive slope (depth 490-510 m) in the base section 8 and 9 breaked dence clays gray, brownish brown, greenish gray, may be. Among soft clay of lower part column 8 detected brownish green carbonate crust complex fashion extent 2.0 x 1.3 x 1.0 cm.

On the station 9 fine layer of broken shell lie soft gray clay (up to brownish gray) with plane carbonate crusts extents up to 7.5 x 6.0 x 0.7 cm covered by films oxyhydroxides manganese or iron.

Content of sand fractions in the exploring examples lies on limit (%) 0.3-47.0, aleuritic – 27.5-83.4, pelitic – 15.4-71.6. Upon relationship fractions exstracted grain-size sort of sediments: pelite aleuritic, aleurite-pelite, pelite-aleurite-psammiitic, aleurite pelitic, pelite-aleurite-psammite sediment. Most coarse granular sediments time to sharp part of slope (st. 8 and 9), what probably associated with operations redeposition sedimentary material by near-bottom cources, suspension flows, rockslides. Occuring everywhere concentration of upper horizon by psammite dependent by shall detritus. In addition, on st. 9 appeared psammite-psefitic fragments of carbonate crusts.

Mineralogical composition of sediments area 1 (samples 4-90, 8-30, 8-60; data X-ray) highly regular: dominate (%) quartz – 33.5-37.9, clay minerals – 22.8-27.4. and roentgenoamorphous material (RAM) – 19.2-24.6. Next followed on dimination feldspars – 7.4-9.0, calcite – 5.1-8.6, dolomite – 0.9-2.4, pyrite – 0.2.

Scientific profit introduced carbonate educations, breakted on the area I (see. fig. 2). Up to data X-ray , organogenic-clastic limestone (samples 5-55) in base consists (%) from biogenic calcite – 52.6 and RAM – 23.7 with foreign material biogenic aragonite – 6.5. In the composition of crust complex fashion (samples 8-0) dominate (%) RAM – 65.5, and aragonite – 18.9, close to low content of calcite – 2.0 and magnesia calcite – 1.5. In plane carbonates crusts (samples 9.2-9.10) prevailed (%) calcite – 42.4-56.1; aragonite complite 2.7-3.0 and RAM – 12.0-15.1. In all samples highly shows foreign mineral quartz – 7.2-23.5%, attented feldspars and clay minerals. Part of $MgCO_3$ not top 4.0% from content of calcite.

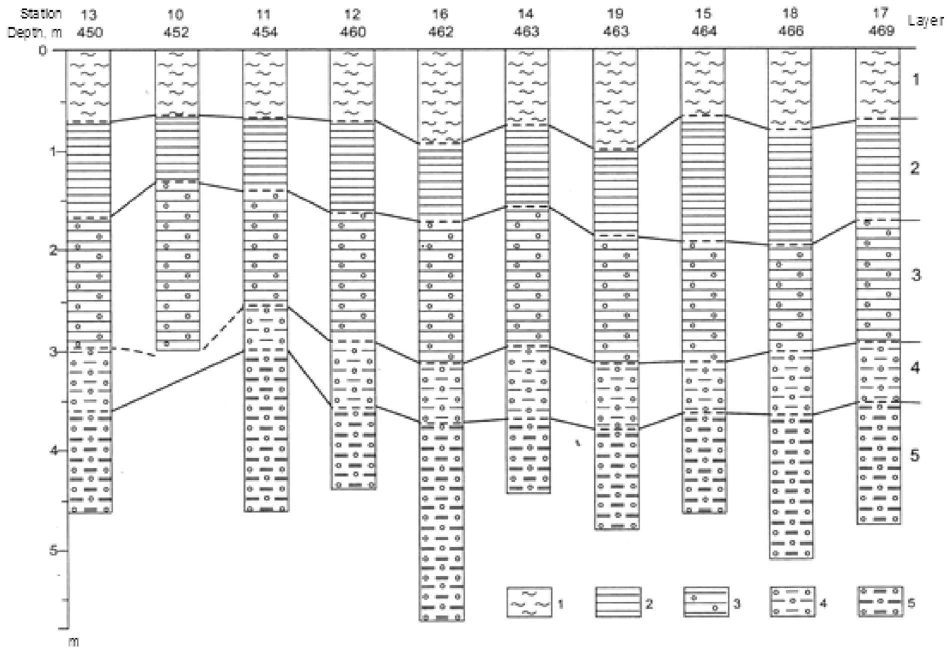

Fig. 3. Lithostratigraphy of the sediments area II.
1– diatomaceous ooze; 2-5 – clays with hydrotroilite: 2 – hydrotroilite poorly; 3 – middle; 4 – much; 5 – very much.

For the area II characteristic diatomaceous oozes greenish gray jelly-like and clotted consistency. In separated layers their painting grayly brown, greehish brown and brownish green. This cover greenish gray and light-gray solf clays, separated by hydrotroilite its amount rize down up to section (see fig.3).

Fossil diatomaceous were studied in the sediments supporting section 16. On base changing quantitative, taxonomic and environmental composition of diatomaceous in the section allocated three horizons – A, B, C [2]. As a result associated collected events diatomaceous analysis with data precursors, we may supposed, that horizons A and B answered newcaspians times and rebound different phases of the transgressive basin development: at first (horizon B) relatively poorly saline, next (horizon A) more deep-sea and more saline. Age of the horizon C not defined, but may be, that this interval of section fited concluaive phase occurrence of late hvaline basin tank.

In research samples content (%) sand fractions complite 0-5.3, aleuritic – 6.4-49.6, pelitic – 49.7-93.6. Among grain-size types of sediments dominate pelite and aleuritic pelite, at that time more coarse aleurite-pelites accurate gravitate to the base breaked sections, that may connected terrigenous clastic material.

In mineral composition of sediments area II (samples 17-155) dominate (%) RAM – 49.3, clay minerals – 18.9 and quartz – 17.3, highly constitutive forein matter calcite – 11.0, attented also forldspars, dolomite and pyrite

Supervising differences in the conclusios section of sediments two areas dependened on morphology of the bottom gravity and hydrodynamic factors. On the background of generaly engine deposition « particle by particle» on area I home material relocate on the bottom with the help of rocksides, turbidity flows, bottom currents. As a result generated beds comparatively coarse grains, poorly rejected sediments. On the sharp areas of continental slope here and there uncovered of Pliocene clays и chemical-diagenetic carbonates. More rough material in the bottom part of the layers on area II also connected, probably, with amplification delivery of terrigenous clastic material. Not expect too of positive role near-bottom currents in the generation of diatomaceous oozes on this area.

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HOLOCENE TRANSGRESSIONS OF THE CASPIAN SEA: BIOSTRATIGRAPHY, CHRONOLOGY, SEA-LEVEL OSCILLATIONS

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Keywords: Caspian Sea, transgressions, Holocene, biostratigraphy, sea-level oscillations, absolute age dating

Modern Caspian Sea is a regressive water basin. This regressive stage in its evolution started in the Early Holocene at the end of the Khvalinian transgression and considerable sea-level lowstand. Since those times periodical sea-level rises never reached positive absolute heights. These rises can be classified as low-order sea-level rhythms (stages, phases, oscillations, convulsions). The Caspian Sea Holocene is characterized by transgressive-regressive sea-level changes of different amplitude reflected in the series of facies of various age. Their stratigraphical subdivision is largely based on fossil molluscan assemblages and absolute age estimations together with geomorphological setting.

Following the biostratigraphical principles used for the subdivision of Pleistocene beds, three transgressive series might be established in the Holocene marine sediment sequence of the Caspian Sea. Hierarchically, they are regarded as Late Khvalinian, Dagestan and New Caspian stages. Late Khvalinian molluscan assemblages are distinguished from the Dagestan and New Caspian ones in composition of fossil *Didacna*. Dagestan assemblages differ from the New Caspian ones in the presence of the Black Sea immigrant species *Cerastoderma glaucum* (*Cardium edule*). Thus, the Dagestan fauna might be regarded as the evolutionary one, whereas the New Caspian fauna is migratory-evolutionary in its origin.

The <u>Upper Khvalinian deposits</u> represent the final positive regressive stage of the Khvalinian sea basin. They occur on all Caspian Sea coasts where they form the accumulative sediment cover of the low Khvalinian terraces. Lithologically they are quite uniform being represented by sands with abundant shells of Caspian molluscs dominated by *Didacna praetrigonoides* together with *D. parallela, D. subcatilus, D. vulgaris, D. cristata*, rare *D. protracta, D. delenda* and some other species.

The <u>Dagestan deposits</u> were previously considered as the lower part of the New Caspian sediment sequence, the so called Dagestan or Gousan stage. They are characterized by the New Caspian molluscan assemblage with *Didacna crassa, D. trigonoides* and other species. This assemblage is taxonomically strongly different from the Khvalinian one. However, Dagestan assemblages do not contain the index New Caspian species *Cerastoderma glaucum*. This fact was first reported by O.K. Leont'ev and P.V. Fedorov (Leont'ev, Fedorov, 1953) and later also confirmed by V.I. Artamonov (1976) and G.I. Rychagov (1997). This finding together with the clear stratigraphical position in the basal part of the New Caspian sediment sequence and geomorphological location on top of the high New Caspian terrace (~ -20 m) allow for distinguishing the single Dagestan transgression separated from other transgressions by the deep Mangyshlak and Izberbash regressions.

The <u>New Caspian deposits</u> occur on all coasts of the Caspian Sea, on its shelf and depressions. On the low coasts of Dagestan, Kalmykiya and western Kazakhstan they constitute vast coastal lowlands. On the mountainous Caucasian coast they form terraces. On the abrasion coasts of the southwestern Turkmeniya they cover narrow accumulative levels and fill deep coastal depressions. The most representative sections of the New Caspian deposits reveal their complex origin reflected by cyclic sedimentation. However, it is impossible to record cycles amounting to 6-9 transgressive peaks reported by several researchers in the history of New Caspian transgression (Varushchenko et al., 1987; Rychagov, 1997).

New Caspian sediments contain diverse molluscan fauna. Its distinguishing feature is the abundance of *Cerastoderma glaucum* and *Didacna* of the "*crassa*" group (*D. crassa crassa, D. baeri*) together with *D. trigonoides* and *Dreissena polymorpha*. Molluscs form diverse assemblages reflecting different ecological settings of the Caspian basin.

Numerous radiocarbon datings (more than 170) have been so far obtained for Holocene deposits of the Caspian Sea. Given the present Caspian Sea level of -28 m, when analyzing radiocarbon dates we assume that all datings of the coastal sediments reflect transgressive rhythms of the Caspian Sea during Post-Khvalinian regression, while the datings from shelf and basin depressions just record various sea-level lowstands.

The datings from the coastal sediments demonstrate certain clusters along the Holocene chronological axis. The dates are concentrated within the following intervals: 0.4-2.7 ka; 3-3.8 ka; 5.4-6.4 ka; 7.2-8.5 ka; 9.5-9.7 ka. These clusters, in turn, consist of smaller concentrations of datings corresponding to the lower-amplitude rhythms of the Caspian Sea level. Clusters of datings from the coastal sediments reflect transgressive positions of the Caspian Sea level. They are separated by the intervals lacking datings: 2.5-2.9 ka; 3.9-4.7 ka; 6.4-7.2 ka; 8.6-9.5 ka. These are likely the regressive periods when no marine sediments were accumulated on the coasts. There are also chronological intervals for which radiocarbon datings are completely absent. It might be assumed that these were the periods of extreme sea-level fall, when not only the shelf but also the upper continental slope became exposed. This could have happened 1.25-0.4 ka; 1-1.2 ka; 2.4-2.9 ka; 4.4.3-4.7 ka; 5-5.3 ka; 5.5-5.7 ka; 6.8-7.3 ka; 8.2-8.5 ka. However, the absence of any information about these time intervals could be also explained by other reasons.

Radiocarbon dating reveals three main periods (stages) of the Caspian Sea level rise during the Holocene: Late Khvalinian (8.5-7.2 ka), Dagestan (Gousan, Early New Caspian) (6.4-5.4 ka) and New Caspian (3.8-0.4 ka). They are separated by regressive epochs: Mangyshlak (7.2-6.4 ka) and Izberbash (5.3-3.9 ka). All positive and negative stages are complex being composed of smaller-scale phases and oscillations. The Late Khvalinian and Dagestan stages consist of 2-3 phases, whereas the New Caspian stage includes at least five phases.

From paleogeographical point of view the Late Khvalinian transgression corresponds to the transition from a cool (Boreal) climate to the warm (Atlantic) epoch. The Late Khvalinian basin was colder than the modern Caspian Sea as suggested by the impoverished molluscan assemblages of this age. Dagestan (Early New Caspian) transgression correlates with the warmest Holocene epoch. Among molluscs the most warm-water *Didacna* of the “*crassa*” group predominate. The New Caspian transgression corresponds to the second half of the Holocene. Radiocarbon dating showed that the sediments aging back to 0.4-2.7 and 3-3.8 ka contain shells of *Cerastoderma glaucum* and undoubtedly belong to the New Caspian transgression. Sediments with an age of 5.4-6.4 ka do not contain *C. glaucum*, but include *Didacna* assemblage with *Didacna crassa*, *D. baeri* and *D. trigonoides*, which is completely different from the preceding Late Khvalinian assemblage dating back to 7.2-8.5 ka.

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EVALUATION OF CASPIAN SEA LEVEL AT LATE PLEISTOCENE PERIOD (ON THE BASE OF NUMERAL SIMULATION ADJUSTED FOR SCANDINAVIAN GLACIER MELTING)

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Keywords: Last Glacial Maximum, PMIP II, paleoclimatology, numerical simulation of climate, fluctuations levels of the Caspian Sea

INTRODUCTION

In this paper, based on the results of climate model CNRM (Centre National de Recherches Meteorologie, France), within the framework of project PMIP II (Paleoclimate Modeling Intercomparison Project) [9], was calculated runoff of the Volga in the period of the Last Glacial Maximum (LGM). “Climatic” component of the Volga runoff was calculated as the difference between precipitation and evaporation in the watershed. However, according to paleoreconstructions and the results of simulation PMIP II, a significant change to the hydrological regime of the Volga River (21 kyr) could be due to the contribution of melt water. This means that to "climatic" component of runoff is necessary to add volume of the melt water of the Scandinavian ice sheet, which falls into the territory of Volga watershed. Modeling data contain information about the configuration of the ice sheet in the LGM. Thus, the first time we have taken into account the contribution of melted glacier in the river runoff. The results were used to assess the level of the Caspian Sea during this period. Also, level of the Caspian Sea was calculated after the complete degradation of Scandinavian ice sheet.

ICE SHEET IN NORTHERN EUROPEAN PART OF RUSSIA AND ITS IMPACT ON RIVER RUNOFF

It should be noted that the extent of glaciations LGM estimated by different authors in different ways [1,2,8,10]. Now the largest project for the Study of glaciations in Eurasia is a project QUEEN (Quaternary Environment of the Eurasian North) [10]. Paleoreconstructions in this project are based on the synthesis of classical morphological research with satellite information, data on the content of isotope O^{18} of biogenic sediments of the Arctic seas. Also it has been compared with the numerical simulation results of ice sheet configuration [10]. Note that the configuration and size of the glacier can really get snowmelt water in the Volga watershed. The configuration of the Scandinavian glacier according project QUEEN was used as the boundary conditions in climate models CNRN (Fig. 1).

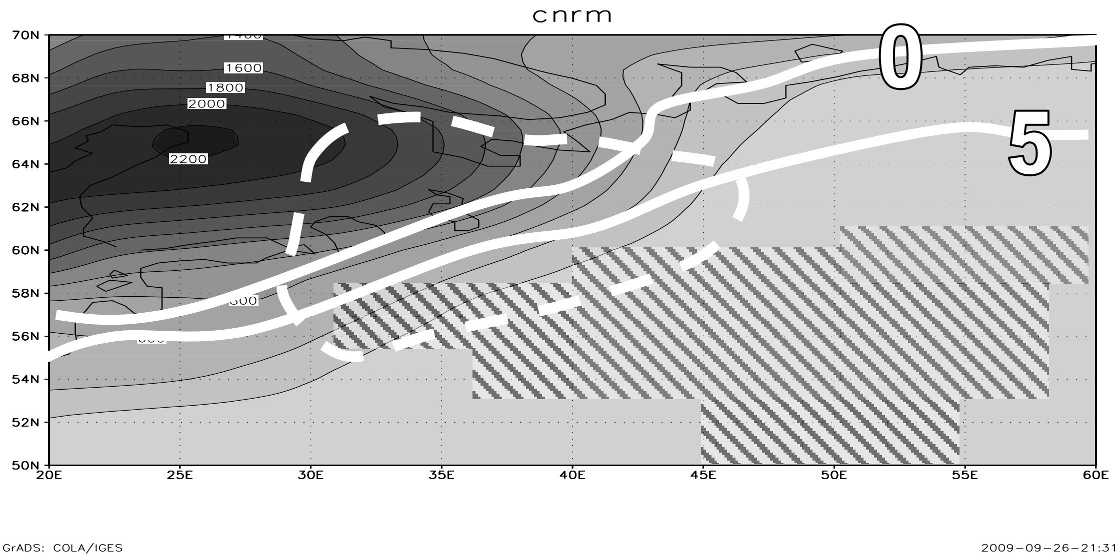

Fig.1. Scandinavian ice sheet in northern European part of Russia according to the simulation of CNRM. Dark lines – isohypses of ice surface, shading shows the region of modern watershed of the Volga, the white dotted line – part of the glacier, from which melt-water could flow into the Caspian Sea, bold white lines – isotherms of July

Based on this information, we have calculated the contribution of melted glacier water in the Volga runoff. It is expressed as follows:

$$h_c = 10W/L_c \qquad (1)$$

h_c – a layer of melt water, *mm*, L_c – heat of melting snow and ice, which is equal to 330 J/g, W – flux heat J/cm^2, which is spent on melting snow for the time interval. The coefficient 10 is required in order to express the melting layer in millimeters.

The flow of heat in the snow or ice per unit time through unit surface area is determined by the surface radiation budget of snow (ice) – B, sensible heat flux- H, latent heat flux – LE, heat flux from soils and rocks, which is the glacier – F_s and warmth that came with liquid precipitation F_{pr}:

$$dW/dt=B+H+LE+F_S+F_{pr} \qquad (2)$$

The contribution of the radiation budget B in the melting of snow and ice is about 80%, and sensible heat flux H – 10%. Results of research of mountain and ice sheets show that the last 3 terms give no more than 10% of the total heat budget [7]. Their contributions are especially small in the cold climate of Central European Russia in the LGM. Thus, the amount of heat reaching the melting of snow and ice can be calculated by the following formula:

$$dW/dt = B+H \tag{3}$$

Radiation budget was calculated on the basis of simulation results CNRM thus:

$$B = Q - R - (Ee - Ea) \tag{4}$$

Q – download flow of short-wave radiation to the surface of the glacier, R – reflected short-wave radiation from the surface, (Ee – Ea) – budget of long-wave radiation. All these values are calculated by model CNRM, which allowed us to estimate daily radiation budget of the glacier for background LGM climatic conditions. Sensible heat flux H is calculated by this formula [7]:

$$H = 162{,}2\ (0{,}18 + u_2)\ (T_2 - T_0) \tag{5}$$

u_2 – wind speed at a height of 2 m (m/s), T_2 – air temperature at a height of 2 m, T_0 – temperature of the snow surface. All values are the results of the model CNRM.

In summary, based on the results of numerical simulation of meteorological variables were obtained monthly averages value layer ablation Scandinavian ice sheet.

FLUCTUATIONS OF THE CASPIAN SEA

The connection between climate dynamics and variations of levels inland lakes means that the sea level tends to occupy equilibrium. The condition of equality of incoming and outgoing parts of hydrological budget of lake will be as follows:

$$ef = YF \tag{6}$$

Y, mm – runoff from one catchment area F, km^2; ($e = E - P$), mm – evaporation from the lake surface area f, km^2. Differentiating (6) the time, we obtain:

$$\frac{\Delta f}{f_0} = \frac{\Delta Y}{Y_0} + \frac{\Delta F}{F_0} - \frac{\Delta e}{e_0} \tag{7}$$

Here the terms with index "0" refer to the modern climatic conditions, and the values of ΔY and Δe_0 characterize the apparent deviation of runoff and evaporation from the modern values in a particular climate era. Changes Δf associated with changes in the level of special morphometric relationships, which were obtained by A.N. Varuschenko and R.V. Nikolaeva.

$$\Delta h = (\Delta h)_{p-e} + (\Delta h)_G + (\Delta h)_F + (\Delta h)_e \tag{8}$$

Consider each of the terms of the formula (8). The first term is responsible for the contribution of climatic variations to the fluctuations level, the second term is responsible for the change in lake level due to the flow of melt water from the glacier surface in the Volga. The third term describes the variation of the level arising from changes in catchment area. In [2] assumed that some Siberian rivers flowed into the Caspian Sea, but any tangible evidence of this exists. Therefore, in this paper, we take the term Δh_F equivalent zero. Consider the value $(\Delta h)_e = \Delta e/e_0$. This term characterizes the contribution to the change in the level of evaporation from the surface of the lake. It should be noted that estimates of changes in evaporation and precipitation on the basis of modeling (especially only one model, not a band) are not very reliable for this area. According to the model CNRM evaporation from the surface of the lake in the LGM declined slightly, and sea level rose by 1 meter. This quantity is essential in modern calculations of periodic fluctuations in the level. However, when assessing the possible level fluctuations 21 kyr this contribution can be neglected.

Thus, we assume that the main factors determining the dynamics of the Caspian Sea in the LGM and in the period of active degradation of Scandinavian ice sheet are the first two terms. Consider the contribution of each of them, using data of numerical simulation.

In this paper, the contribution of river flow, which is described by the term Δh_{p-e} in (8) is the average long-term "climatic" (difference between precipitation and evaporation in the catchment) runoff of the Volga, averaging over 50 years, according to the results of numerical simulation. The results of calculations, as well as calculations performed in [3, 4, 12] show that the climatic part of the Volga runoff 21 kyr decreased on average by 60% compared with the modern (according to model CNRM).

Table 1

Parameter	**Period**	**Region 1**	**Region 2**	**Region 3**
Precipitation,%	Winter	-43	-37	-41
	Summer	-50	-61	-59
	Year	-48	-47	-52
Evaporation,%	Year	-29	-44	-19
Temperature,°C	Winter	-10,5	-9,2	-5,7
	Summer	-4,5	-4,8	-3,7
	Year	-6,9	-6,2	-4,2

Note: "Region 1" – taiga and tundra, "Region 2" – mixed and broadleaf forests, "Region 3" – the steppe and forest steppe; change in precipitation and evaporation are calculated as the difference between the amounts in the LGM and modern climate, as a percentage of the amount present values, the temperature change is calculated as the difference between the temperature of 21 and modern

This is due primarily to the changing nature of moistening. Assessment of changes in the basic meteorological parameters during this period presented in table 1. The main reason for the low values of "climatic" runoff was a decrease of precipitation throughout the watershed. The decrease of evaporation was less intense, and could not compensate for the deficit of precipitation, and as a result a significant reduction of "climatic" runoff of the Volga.

Likely, the melting of glaciers in the warm season was a serious contribution to the hydrological budget of the Caspian Sea even 21 kyr. According to calculations made by formulas 4-8, based on the data of model CNRM, influx of melt water increased Volga runoff up to 462 km³/year, which exceeds the modern value more than 2-fold (table 2). These changes have increased the level of the Caspian Sea about 45-50 meters, compared with the modern.

The next experiment is calculation the level of the maximum possible rising of the Caspian Sea caused by climate change, namely the complete degradation of the ice sheet. If we consider the "model" ice only in the Volga watershed, its volume will be 44800 km ³. Using the formulas (4-8), we find that this amount enough to hide the level of the Caspian Sea to the mark of +25 m above sea level. As a "zero level" is chosen –75 m. This mark is selected, because changes only in "climatic" component of the model runoff caused changes in lake level, according to formulas (4-8), to mark -75 m. A number of studies [6, 8, 11] showed that the level of the Caspian Sea in the LGM is really much higher than modern. Numerous studies show almost complete synchronization in time glaciations of Northern Hemisphere, the Caspian Sea transgressive stage and regressions of oceans [5, 6, 13]. However, these numerical simulations do not allow us to attribute the growth level of the Caspian Sea to the particular stage of Valdaj glaciation. The results of this research should be viewed as the physical basis for possible transgressions of the Caspian Sea as a result of runoff of melted glacier water.

Table 2

Period	"climatic" component of runoff, km³/year	"glacier" component of runoff, km³/year	total runoff, km³/year	changes in the level of the lake compared with modern, m
modern climate	205	0	205	0
LGM	78	384	462	+48

CONCLUSION

In this paper, based on the results of numerical simulation of climate LGM project PMIP II were calculated amount of "climatic" and "glacial" components of runoff into the Caspian Sea. This allowed the following conclusions:

1. "Climatic" runoff of the Volga into the Caspian Sea in the Valdai glaciation was, on average, 50-60% lower than the present, because the amount of precipitation in cold climates decreased, at a relatively small change in the layer of evaporation. Similar results are obtained in [3, 4, 12]. However, the contribution of "climatic" component of runoff in total runoff of the Volga was only 17%.

2. As shown by calculations based on the results of numerical simulations, the contribution of melted glacial water in the Volga's runoff in the LGM was 83% of the total runoff. It was a main power source of the hydrological budget and the cause of the rising sea level. As a result, the level of the Caspian Sea was, on average, 45-50 m above the present.

3. The simulation results are generally consistent with the palaeogeographic ideas about the transgression of the Caspian Sea during the cold periods of glaciation.

4. A possible explanation of the reasons Late-sea transgression 15-14 ky calBP authors consider intensive melting of the part of the Scandinavian ice sheet that occupied the Volga River watershed (based on calculations, is about 45 000 km^3) in the period 16-20 kyr. It is shown that in this case, the amount of melt water collected by the sea, led to an increased level up to elevation +25 m.a.s.l.

This result should not be considered evidence of transgressions of the Caspian Sea in a period of degradation Valdai glaciation. It is only physically reasonable hypothesis, illustrating the possible mechanism of formation of Last Pleistocene transgressions. The authors do not insist on the glacial nature of the phenomenon. For example, excluding the possibility of ice supply, one can wonder about the role of permafrost.

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BIODIVERSITY OF THE CASPIAN SEA MOLLUSKS DURING THE LAST 10 KY

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INTRODUCTION

The characteristic feature of the Caspian Sea is unstable sea level. During the last 10 ky it has been fluctuating within the range of almost 50 meters, approximately from 0 m in the Late Khvalynian transgression to -50 m in the Mangyshlak regression and to -19 m in the maximal stage of the New Caspian transgression. The immediate causes of sea-level changes are believed to be: the volume of river and groundwater drainage, percipitation on the basin and evaporation, sedimentation and the degree of diagenesis, tectonic and seismic activity of the basin, coastal geomorphology etc. These factors are closely connected and determined by the nature of atmospheric circulation, solar activity, climatic cycles, the morphosrtuctural position of the region and its recent geodynamic activity. At present the role of human impact (e.g. Irretreavable extraction of river water) has increased greatly. The existing material on sea-level fluctuations allows us to conclude that the main reason for Caspian instability is the climate — large-scale hydrometeorological processes that occur not only in the Sea's basin but in its proximity as well.

The Caspian waters are brackish. The mean salinity of the Caspian Sea is 12.7–12.8‰. It varies between 1–3‰ near the Volga River mouth to 12.5-13‰ in the Middle Caspian, 12.8–13.1‰ in the Southern Caspian. The salinity of brine in the Kara-Bogaz-Gol Bay is more than 360‰. Temperature conditions in different parts of the Sea are determined by the latitude of the location. Three different water bodies are united within Caspian Sea, each of them has its own physical conditions and biological diversity. It is difficult to contemplate about general biological diversity of the Caspian Sea. The real biodiversity of the Caspian Sea is made up of that of all water bodies, including deltas and their wetlands.

The modern biodiversity of the Caspian Sea simply reflects a complicated history of paleo-Caspian transgressions and regressions, desalinisation and salinization and, recently, human activity. The Caspian history during the last 10 ky includes the end of the Late Khvalynian transgression, Mangyshlak regression and several stages of the New Caspian transgression. The Late Khvalynian basin emerged 11-9 thousand years ago under climate conditions, which were more humid and colder than the present one. The maximum level of the Late Khvalynian transgression was close to the 0 m. The Mangyshlak basin formed about 9-8 thousand years ago. It emerged in the period of postglacial warming and climate aridity. Its waters used to cover only depressions of the Middle and Southern Caspian. The level of Mangyshlak Lake was – 80 m (Mayev, 2006). The New Caspian transgression maximum emerged approximately 5-6 thousand years ago. The sea level was -19 – -20 m. In the 20^{th} century it has been fluctuating within the range of almost four meters, approximately from -25 m in the beginning of the century to -29 m in 1977. In the end of the 20^{th} century, the sea level soared, and in the beginning of the 21^{st} century began to drop again.

The influence of the Caspian Sea level change on the mollusk biodiversity we trace on two different areas: Turali (Dagestan, Middle Caspian) and Volga Delta (Northern Caspian).

TURALI AREA (DAGESTAN COAST)

The waters of the Middle Caspian can be referred to as a mesohaline ecosystem. It is inhabited by the great number of unique Caspian species, which descend from ancient inhabitants of the Thetis Ocean. This part of the Caspian has never completely dried up, independently of climate changes that occurred in Pleistocene and Holocene epochs.

The composite sediment section of the Turali area represents the whole Holocene sequence of the Caspian Sea region – from the Upper Khvalynian beds to modern marine deposits. The facially diverse Holocene sediments with abundant fossil mollusks record cyclicity in sedimentation reflecting the complicated hierarchy of the Caspian sea-level oscillations. The Upper Khvalynian deposits represent a complete cycle separated from the subsequent cycles by a long break in sedimentation. The New Caspian and modern deposits represent a system of cycles with different duration divided by periods of breaks in sedimentation and erosion caused by sea-level oscillations of different amplitude and direction.

A total of 19 species of mollusks were identified in the Turali region that belong to four families: Mytilidae, Dreissenidae, Cardiidae and Scrobiculariidae. Mollusks represent four different types of fauna: brackish-water, freshened brackish-water, freshwater, and marine. Brackish-water fauna is the most abundant and taxonomically diverse (11 species). It is represented by autochthonous endemics of the Caspian Sea belonging to Didacna Eichwald genus (10 species) and one species of Dreissena genus – *Dr. rostriformis*. Didacna species are the most abundant, and *Didacna baeri*, *D. crassa*, *D. trigonoides* are dominant species. Freshened brackish-water fauna is represented by Monodacna and Adacna. Among them *Monodacna caspia* is the most abundant. Freshwater type of fauna is characterized by *Dreissena polymorpha*, whose valves occur as admixture in all coastal sediments except the lagoonal ones. Marine fauna is represented by euryhaline Black Sea species *Cerastoderma glaucum*, *Mytilaster lineatus*, *Abra ovata*. Valves of Cerastoderma predominate in practically all studied New Caspian deposits. The two other species were reported from the modern sediments only. Diverse taxonomic and quantitative correlations between representatives of different faunas in certain coenoses are governed by environmental conditions.

Faunistic groups from different parts of the composite sediment sequence are separated by breaks of different duration. Two epochs in existence of different faunas have been established, Khvalynian and New Caspian-recent, divided by the Mangyshlak regressive epoch. *Khvalynian fauna* is taxonomically poor and mainly consists of *Didacna praetrigonoides* and *Dreissena polymorpha* with rare *D. parallella* and single *Didacna delenda*, *D. subcatillus*, *D. crassa*. It characterizes the relatively dynamic nearshore environment. Predominance of Didacna of *trigonoides* group and Dreissena suggests water salinity of about 10–11‰ with periodic (seasonal?) freshening. *New Caspian-recent fauna* is considerably more taxonomically diverse than the Khvalynian one. It includes representatives of all faunistic types. Brackish-water species of Didacna Eichw. genus (7 species), mainly of *trigonoides* and *crassa* groups, and euryhaline marine Cerastoderma are dominant. It differs from the Khvalynian fauna in composition of Didacna (in New Caspian deposits only rare *Didacna praetrigonoides* were found), and first appearance and wide distribution of species of Cerastoderma, Mytilaster, and Abra genera. The Post-Khvalynian fauna is also quantitatively richer – sediments of this age contain abundant valves and their fragments. Most valves are thick and more massive than the Khvalynian ones. Taxonomic composition of the fauna suggests salinity and temperature rise compared to the Khvalynian basins.

Post-Khvalynian fauna is comprised of the New Caspian assemblage *Didacna crassa – D. trigonoides* – Cerastoderma and the recent assemblage *Didacna baeri* – Cerastoderma – Mytilaster. Unlike the older assemblages, these complexes reflect changes in biotic conditions of the basin (invasion and wide distribution of the Black Sea species) due to anthropogenic reasons. The New Caspian assemblage combines different faunistic groups forming sub-assemblages and associations, but no distinct temporal changes in the New Caspian fauna are observed, and the recorded differences are related to facial peculiarities of sediments.

If tracing the facial-dependent variations in composition of molluskan fauna, the following conclusions could be drawn. The facies of lagoons contains taxonomically poor molluskan association dominated by one species – *Cerastoderma glaucum*. There are no evident temporal changes in faunistic composition, molluskan associations just determine the type of lagoons- salted closed lagoons, lagoons with periodic freshening, or open ones. In the “pre-lagoonal” facies, Cerastoderma and abundant *Dreissena polymorpha* are accompanied by Didacna of *trigonoides* and *crassa* groups. Facies of dynamic shallow sea contains poor molluskan fauna, primarily, fragments and single thick valves belonging to Didacna of *trigonoides* and *crassa* groups. *Dreissena polymorpha* and *Cerastoderma glaucum* are second abundant, while Adacna and Hypanis are rare. Older deposits include numerous Didacna of *trigonoides* group and relatively rare Cerastoderma. The correlation between species abundance is different in younger sediments. The facies of calm shallow sea has the most taxonomically diverse and abundant molluskan fauna. Besides numerous Didacna, Dreissena, and Cerastoderma, it often contains elements of brackish-water fauna, usually, thin-valved Monodacna, Adacna, and Hypanis, that sometimes turn to become dominant. No evident temporal differences in species composition have been recorded. In transitional shallow water facies, Didacna of *trigonoides* and *crassa* groups, Dreissena, and Cerastoderma are dominant. The richest localities correspond to this facies (10 species).

Taphocoenoses from the gravelly-pebbly and sandy sediments are probably the most ancient ones. These beds reflect the single sedimentation cycle – the early phase of the New Caspian transgression, when the accumulative body of the bay-bar was formed. The taphocoenoses have similar species composition. *Didacna crassa* and *D. trigonoides* are either abundant or dominant, *D. baeri* is slightly less abundant, *Dreissena polymorpha* and *Cerastoderma glaucum* are present, and *D. longipes, Adacna laeviuscula*, *Hypanis plicatus* are rare. Fragments are numerous. Most valves and fragments are rounded. The character of shell and sediment material allows assuming that taphocoenoses are allochthonous. However, they include valves of the New Caspian age only, and no Khvalynian forms were identified.

It is apparent that they reflect similar environments of the coastal zone of the New Caspian Sea at a short distance from the shore (near the Bakai-Kichklik Cape as judged from the structure of the spit). Later the valves were transported with alongshore drift. Fragile Adacna and Hypanis valves were preserved as big fragments suggesting that they have not experienced long-distance transportation. Taphocoenoses form an early sub-assemblage of the New Caspian assemblage *Didacna crassa-D. trigonoides – D. baeri* according to dominant species. Cerastoderma valves are rare. The sub-assemblage corresponds to highly dynamic nearshore environments with normal salinity of the Caspian Sea.

Therefore, the New Caspian faunistic assemblage consists of three sub-assemblages corresponding to separate sedimentation cycles and stages in the evolution of the sea basin. Taphocoenoses of sediments accumulated since the beginning of the XX century comprise the modern faunistic assemblage. It is subdivided into two sub-assemblages following the stages in invasion of the Black Sea species. The older *Didacna baeri* – Cerastoderma sub-assemblage is characterized by wide distribution of *Mytilaster lineatus*. According to historical records, this species was introduced into the Caspian Sea at the beginning of the century. The younger sub-assemblage is distinguished by the first appearance of *Abra ovata* that took place in the forties.

Geoecological conditions in the Turali region were considerably different during the Khvalynian, New Caspian, and modern epochs. During the Khvalynian epoch, sedimentation took place in the calm or slightly dynamic shallow nearshore zone with normally saline waters experiencing inconsiderable freshening from time to time. Species composition of mollusks was poor, probably, due to relatively cold bottom water temperatures. During the New Caspian transgression, considerable changes in coastal processes caused enhancement of the northward-directed alongshore drift. The latter produced the system of big beach barriers that formed the Turali bay-bar and the system of lagoons. Temporal changes of the geoecological situations (probably, repeated) occurred, from the open dynamic shallow sea with normal Caspian salinity to semi-closed calm bays with periodically changing salinity, and, finally, to saline lagoons. *Didacna crassa* paleocoenosis from the Turali Lake dated at 1700 yrs B.P. evidences existence of a shallow (not deeper than 5-7 m) bay of the Caspian Sea with normal or slightly high salinity, well-heated waters, and calm sedimentation conditions (Yanina et al., 2005). Geomorphological situation suggests that it had wide connection with the sea in the south. Later, due to sea-level fall, the bay became partially separated from the sea and gradually turned into lagoon. Continuous sea-level fall resulted in the loss of any connection with the sea, and, at the end, the lake was formed.

VOLGA DELTA

In spite of its geological youth the Volga delta is a territory with a complex development and very dynamic hydrological and lithodynamical processes. The dominating regime is active accumulation of diverse deltaic deposits. These processes are especially active within the avandelta and the seaward part of the delta. The seaward delta is the youngest land formation of the Volga mouth. It is represented by a low partly flooded kultuk-delta plain, split by numerous river arms and separated from the avandelta, located to the south, by a migrating marginal sea-land zone. The low plain was recently the bottom of kultuks, separated by erosion troughs. Its surface is composed with modern kultuk and deltaic sediments that overlie more ancient deltaic and avandeltaic formations. The avandelta is the most dynamic and actively re-forming river-mouth structure of the Volga. It has a southward sloping surface and is composed of deltaic deposits that facially change into shallow-water deposits of the North Caspian Sea. The shoal of the avandelta is characterized by a wide distribution of hygrophyte plants that are closely connected to the silt, silty sand and siltstone lythofacies. At the depth of 1.5–2 m the plants disappear and the sediments become more sandy and sorted.

The water salinity is not stable, it changes from 0.5 to 3–5‰ due to Volga runoffs. Many unique Caspian species rarely occur in this part of the Caspian because of low water salinity. Almost the entire waters of northern part can be regarded as an oligohaline ecosystem. Factors defining geographical distribution of mollusks include: salinity, ground and related gas regime of benthic layer; distribution and population of the major benthos consumers.

Deltaic water bodies of different size and configuration, with diverse hydrological and hydrochemical regimes, various bottom sediments are inhabited by different mollusks. Predeltaic part of the Volga is characterized by sandy grounds, relatively deep environments, current activity. The psammophilic biocoenosis inhabit it, among mollusks – rare Dreissena. Active branches, pits (“yamas”), reaches are characterized by silty sandy grounds with pelo-reophilic biocoenoses of Sphaerium, Viviparus, Dreissena, Unio. Former branches, bays, inlets, pounds with stagnant environment and muddy grounds are inhabited by pelophilic biocoenoses with Sphaerium, Viviparus, Anodonta, Unio.

Grounds covered with macrophytes are occupied by phytophilic biocoenoses. Shallow-water swamps and bogs are characterized by mixed pelophilic-phytophilic molluscan assemblages. Long and narrow ilmens between Baer knolls with muddy lifeless grounds are occupied by single Unio, Anodonta. Rushy shore fronts are inhabited by abundant terrestrial forms – Planorbis, Physa. Dreissena polymorpha, Anodonta complanata, Sphaerium corneum, Pisidium, Viviparus viviparus, Valvata piscinalis are on muddy grounds of bigger ilmenis; rare small Unio pictorum are on sandy grounds. In shallow-water rushy ilmenis with mud and plant remnants, mollusks Planorbis and Lymnea occur only in nearshore rushy areas. Poloi zone with plants hosts nearshore assemblage with Lymnea and Planorbis. Lower part of the delta branches with silty sandy grounds covered with macrophytes is habited by fresh-water mollusks: Dreisena polymorpha, Dr. bugensis, Theodoxus, Viviparus, Hydrobia, Valvata, Lithoglyphus; rare Caspian euryhaline species: Monodacna edentula, Adacna laeviuscula, Hypanis plicatus.

All Caspian species inhabiting the Volga delta are strongly euryhaline (tolerate salinities between 0.3–12‰) and oxiphilic; they prefer silty sandy grounds and weak currents. *Monodacna colorata* migrated to the Volga delta from Volga reservoirs, where it had been previously acclimatised. Kultuks with sandy silty grounds are characterized by fresh-water mollusks Unio pictorum, Anodonta complanata, Viviparus viviparus, Valvata piscinalis, Sphaerium corneum, Pisidium, Dreissena polymorpha and euryhaline Caspian mollusks Monodacna edentula, Adacna laeviuscula. Fresh-water prodeltaic area is habited by fresh-water species Unio pictorum, Anodonta complanata, Viviparus viviparus, Valvata piscinalis, Sphaerium corneum, Pisidium, Dreissena polymorpha and euryhaline Caspian mollusks. Slightly brackish-water zone with silty sandy sediments is characterized by abundant Dreissena polymorpha, far less abundant Monodacna edentula, Adacna laeviuscula. Sandy ground with detritus is characterized by the same molluskan composition but lower abundance. M. edentula and Ad. Laeviuscula predominate on the brackish-water zone.

A comprehensive research of the Damchik section (Astrakhan' Biosphere Reserve) conducted by the authors allowed to obtain interesting data on the recent history of the modern seaward part of the delta and avandelta of the river Volga. The Holocene malacofauna of the delta includes all modern species except for those, that penetrated from the Azov – Black Sea basin by anthropogenic means. The distribution of mollusks in Holocene water bodies of the Delta was similar to the modern one. This is the basis for paleoenvironmental reconstructions. The malacofaunistic analysis revealed that the fauna forms specific combinations that characterize different hydrological and ecofacial environments of sedimentation.

During the post-Late Khvalynian Mangyshlak regression the Volga River delta was located in the latitude of the Agrakhan spit. This resulted in active erosion. Two wide channels were formed in the central and eastern parts of the Volga-Akhtuba valley which served as pathways for river discharge. The sequence of deposits with different type of mollusks characterized the water basins changes during Holocene. The sequence of deposits reflects three large stages of the delta development in accordance with Caspian Sea level changes. The small-scale deposits gradation reflects the unstable sea level condition during the each stage (Yanina, 2008).

The modern Caspian ecosystem is the result of the long-term biological evolution. For a long time, all levels of biodiversity formed and interacted naturally without human influence. The development of the human civilization resulted in strong anthropogenic impact, which interferes with the natural course of events. The humankind has become a powerful external factor destabilizing the processes of the Caspian ecosystem.

ACKNOWLEDGEMENTS

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IGCP 521-INQUA 0501 PROJECT "CASPIAN-BLACK SEA-MEDITERRANEAN CORRIDOR DURING THE LAST 30 KY: SEA-LEVEL CHANGE AND HUMAN ADAPTIVE STRATEGIES": AN OVERVIEW

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Keywords: sea-level change, paleoenvironment, human cultures

The Caspian-Black Sea-Mediterranean Corridor ["Corridor"] (Fig. 1) is an integrated oceanographic system defined here as the large geographical area covering the Manych-Kerch Gateway (Manych Valley, the Sea of Azov, and the Kerch Strait) that lies to the east of the Black Sea, the Marmara Gateway (the Bosphorus Strait, the Sea of Marmara, and the Dardanelles), the Aegean Sea, the Eastern Mediterranean, and their coasts. In the Late Pleistocene, the "Corridor" was connected to the Caspian Sea via Manych Gateway.

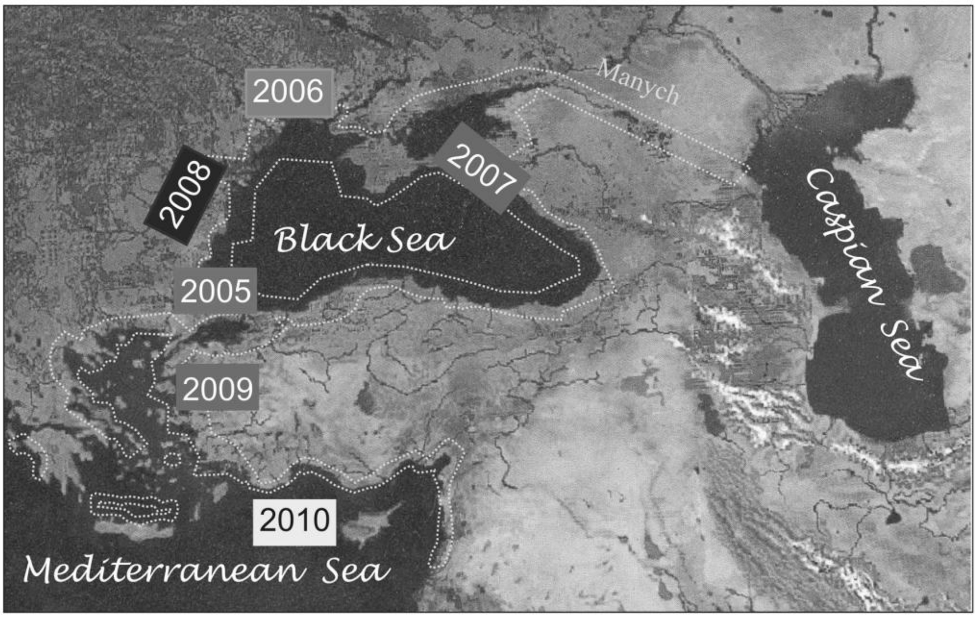

Fig. 1. Caspian-Black Sea-Mediterranean Corridor (dotted line) and locations of IGCP 521-INQUA 501 (dated rectangles) plenary meetings and field trips (2005-2010).

Today, the "Corridor" is of strategic importance not only for all coastal countries but also for at least 17 other countries sharing a drainage basin that is one-third the size of the European continent. The "Corridor" acts as a paleoenvironmental amplifier and as a sensitive recorder of climatic events where sea level variations and coastline migration are especially pronounced due to geographical location and semi-isolation from the open ocean. It also provides a linkage between the marine and continental realms.

Over the past 30 ky, the "Corridor" underwent a complicated history, which remains hotly debated. Lately, this region has spurred a tremendous international interest as a possible place where the biblical story of the Great Flood originated, encouraging a new round of controversial research on the hydrological regime in the connecting straits, the transition from a lacustrine to a marine environment, the influence of

Black Sea outflow on the deposition of Eastern Mediterranean sapropels, as well as past/present/future adaptation of humans to environmental change.

In 2005, IGCP 521 (2005-2010) – INQUA 501 (2005-2011) "Caspian-Black Sea-Mediterranean Corridor during the last 30 ka: Sea level change and adaptive strategies" (http://www.avalon-institute.org/IGCP/index.html) began with the aim of correlating scientific data obtained by diverse research projects dealing with climate change, sea-level fluctuations, coastline migration, and human adaptation within the Caspian-Black Sea-Mediterranean Corridor (Yanko-Hombach and Yılmaz, 2007; Yanko-Hombach and Smyntyna, 2008; Yanko-Hombach et al., 2010).

The common goal, collective objectives, and added value of the IGCP 521-INQUA 501 project is to bring the relevant but diverse research groups together to provide cross-disciplinary and cross-regional correlation of geological, geochemical, geophysical, paleontological, archaeological, and historical records in various settings of the "Corridor" in order to evaluate the influence of sea-level change and coastline migration on human adaptation during the last 30 ky.

The project headquarters established a multidisciplinary team of scientists that grew to almost double its initial size since 2005. Today more that 400 specialists not only from the Black Sea region but from around the world (Fig. 2) work together providing cross-disciplinary and cross-regional integration and correlation of the data obtained by multiple projects across the "Corridor." About 50% of the participants are young scientists and women. Approximately 75% of the participants are from developing countries surrounding the "Corridor."

The structure of the project is conceived as a system based upon sharing of responsibilities in order to ensure an effective and efficient control and management of the project activities: the Headquarters and twelve Regional Working Groups, headed by the Regional Coordinators, who distribute the tasks among the participants, monitor the progress of the work, and submit the data for integration to the Correlation Committee. Today, IGCP 521 – INQUA 501 activities have become a focal point where the international community of multidisciplinary scientists work together correlating their results, presenting new findings at annual plenary meetings, topical sessions, symposia, and workshops, and publishing results in various journals and books. The Field Trips carried out after the plenary sessions have allowed participants to visit many relevant sites in the "Corridor" that would have otherwise been very difficult to see, observe many relevant features under the guidance of local experts, and discuss important scientific issues about these sites with colleagues.

To reach the goal, the project incorporates four dimensions:

1. The geological dimension examines sedimentary fingerprints of vertical sea-level fluctuations and lateral coastline change caused by external (climate change, active tectonics) and internal (mainly coastal sedimentary budget) forces.

2. The paleoenvironmental dimension integrates paleontology, palynology, and sedimentology in order to add new features to the portrait of past landscapes.

3. The archaeological dimension investigates cultural remains.

4. The mathematical dimension deals with GIS-based mathematical modeling of human dynamics underlying past/future sea-level change in the "Corridor" that can be meaningfully compared with global sea-level fluctuations.

All dimensions are addressed through the integration of existing data and the testing of hypotheses.

The project has resulted in fundamental new knowledge regarding the driving mechanisms that influence human adaptation in the region that became known as the "cradle of civilization," a subject of great interest to researchers working in Quaternary, earth, marine, environmental, and social sciences. Its strong applied component will be directly relevant to coastal managers with regard to the environmental risk assessment and sustainable development of the "Corridor" under the Global Climate Change anticipated to take full effect in this century.

Besides this, the IGCP 521 – INQUA 501 project has improved east-west dialogue and integrated researchers from different countries into the international multidisciplinary R&D community. It also contributed to the preservation of cultural and religious heritage through the discussion of ancient cultures, civilizations, and their legends. In addition, it trained young researchers in new analytical techniques and state-of-the-art interpretation of data, allowing them to establish close working contacts with top scientists. For more information about project activities, please visit (http://www.avalon-institute.org/IGCP/index.html).

Fig. 2. IGCP 521–INQUA 501 participating countries (highlighted on the map): Algeria, Australia, Austria, Azerbaijan, Belgium, Bulgaria, Canada, Croatia, Egypt, Germany, Finland, France, FYR of Macedonia, Georgia, Greece, Ireland, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Romania, Russian Federation, Spain, Switzerland, The Netherlands, Turkey, Ukraine, United Kingdom, United States of America (countries with contributors to this volume are listed on the map). Note the wide geographic distribution of scientists carrying out research in the Black Sea region (from Buynevich et al. (eds), in press)

This presentation will outline some achievements and limitations of the project in assessing the relationships between environmental changes, landscape dynamics, and human adaptive strategies in semi-isolated basins.

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SESSION II.

EVOLUTION OF THE CASPIAN COASTAL ZONE

THE LAST SHARP RISE OF THE LEVEL OF THE CASPIAN SEA AND ITS CONSEQUENCE IN THE COASTAL ZONE OF AZERBAIJAN

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Keywords: Caspian Sea, sea level rise, Azerbaijan, coastal zone

At present it is fixed that more than half of the coastal territory of the Republic of Azerbaijan in lover of the condition of flooding of coastal zone of Azerbaijan during rise of the level of the Caspian Sea for 2,5 meters in period 1978 – 1996, the flooding maps of all the length (about 800 km) of coastal lines are drawn up. The schemes of maps disposition are shown on fig 1. For this purpose the aero cosmic photo, data of regular instrumental measures of Sea level and expedition works in coastal zone were used. The map of flooding of Azerbaijan coastal is drawn up by the materials of deciphering of aero cosmic photo with use of literature and fund materials, also by topographic and subject- matter plans. So about 100 maps of flooding in 1: 25.000 scales were drawn up. On the basis of the coastal zone of the Republic of Azerbaijan in two values of the sea level is drawn up : – 26,5 mBS (maximum value of the sea level for the last 70 years , observed in 1996) and in possible rise of the sea level to the mark – 25.00 mBS.

On the table 1 morph metric characteristics and square of flooding of 11 administrative regions of the Republic of Azerbaijan situated in the coastal zone of Caspian Sea are given.

Table 1

The territory of flooding of the coastal zone on administrative areas

The name of areas	Length of a coastal line, km	The area of flooding, sq. km		
		- 26,50 mBS	*- 25,00 mBS*	*THE GENERAL*
The Hachmasky	66,0	20,70	11,70	32,40
The Divichinsky	20,7	10,40	6,30	16,70
The Siazansky	39,6	6,10	4,70	10,80
The Hyzynsky	26,1	5,10	6,70	11,80
Baku – merry	289,6	38,20	21,90	60,10
The Saljansky	11,7	0,60	0,60	1,20
The Petrochalinsky	94,6	132,70	375,60	508,30
The Qizil – Aqag	102,0	239,00	369,50	608,50
The Masallinsky	31,5	26,70	19,40	46,10
The Lenkoransky	35,1	4,10	7,70	11,80
The Astarinsky	21,1	0,90	1,00	1,90
Total	738,10	484,50	825,10	1309,60

It is reported, that on flooding rote the coastal zone of the Azerbaijan Republic is deviled into 4 characteristic regions: (On fig. 1 they are shown by the Roman signs).

From river Saмur to Apsheron (I)
Apsheron peninsula (II)
From Apsheron peninsula to delta of the river Kur (III)
From the river Kur to Astara (IV)

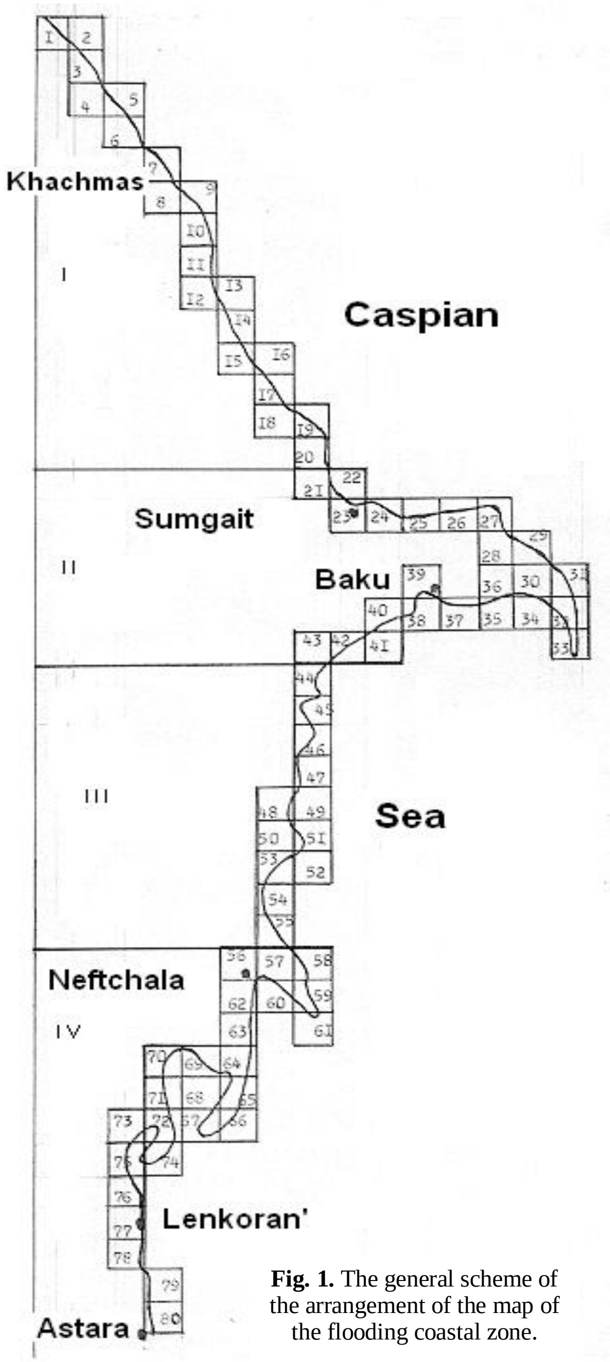

Fig. 1. The general scheme of the arrangement of the map of the flooding coastal zone.

It is revealed, that as a result of rising, of level of the Caspian Sea for the period (1978 – 1996) on all extent of the Azerbaijan coastal zone has been occurred the processes of flooding. The total area of the flooded territories is 484,5 square kilometers. If the level of the Caspian Sea has risen on 1,5 m i.e, to the mark a minus 25.00 mBS, then the flooding area in addition would increased for 825,1 square km and the flooding total area would make 1309,6 square kilometers. Thus, sea level 1.5 m at the Azerbaijan coast increases the flooding area almost three times. The greatest flooding from sea level rise the coast region threatens from delta of the Kur to Astarachay. On its share, it is necessary about 80 % of the area of possible flooding at a sea level mark – 26.50 mBS and 90 % at rising level of the Caspian Sea to a mark – 25.00 mBS . (Fig. 2.)

By the flooding Atlas the housing and economic objects located on all extent of the coastal zone which is under the threat of flooding and flooding is defined:

- 50 settlements,
- 250 industrial enterprises,
- 60 km of highways,
- 10 km of the railway,
- 30000 hectares of winter pastures,
- 10000 hectares of the irrigated earths,
- recreational objects on 200 thousand persons.

The basic ecological problems arising in connection with rise of level of the Caspian Sea.

The modern ecological condition of the Caspian Sea is defined on one side by influencing of the rising of sea level, on the other side – increase anthropogenesis load.

As a result of rise of sea level the following basic processes influencing an ecological condition of coast are occurred.

Flooding and flooding of a coastal part of territory on which settlements are located, communications, agricultural objects, landing stages, etc.

Flooding of a shallow, changes inner water with the high sea, again forming shoal, becomes the additional receiver transported pollutants from the land that will cause worsening of an ecological condition.

Flooding of oil and gas deposits with acting and preserving well and subsequent distribution of mineral oil, will lead to additional pollution.

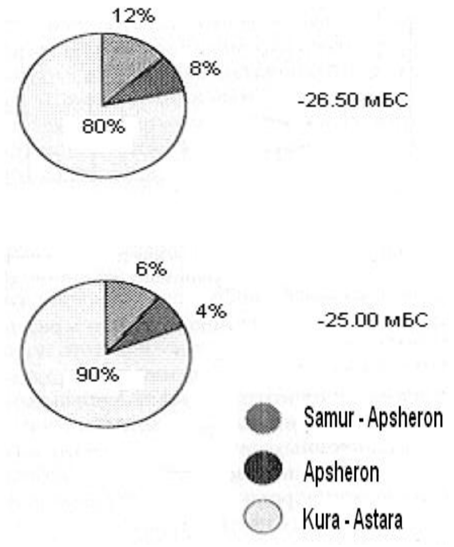

Fig. 2. Dynamics of changing flooding area on various region of the coast of the sea at two values of level

Running on the subsoil waters, promoting to sharp intensification of processes of bogging territory of deltas, and also increasing to unloading of subsoil waters evaporation, will strengthen processes of salinization and subsoil waters.

The basic sources of pollution of the Caspian Sea which are:

- Superficial drain,
- Dump of crude sewage,
- Emergencies on sea transport and in branches of sea water area,
- Superficial wash away down getting in – out of the phenomena.

The basic volume of polluting substances arrives to the Caspian Sea with a river drain, makes 90 % and more than its total volume. This parity is the traced practically all components: petrocarbons, phenols, detergent, organic substances, heavy metals. The according to the polluting substances of oil and the total amount are amounts more than 90 % dominate. The second considerable pollution Sean is phenols.

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CHANGES IN KALMYKIAN COASTAL ZONE OF THE CASPIAN SEA UNDER SEA LEVEL RISE AND ITS MODERN STABILIZATION

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Keywords: coastal zone dynamics, reed mudflat, satellite images, mapping, sea level changes

INTRODUCTION

The Caspian Sea level had risen rapidly during 1977–1995, from −29.01m ASL in 1977 to −26.66m ASL in 1995, with approximately 130mm per year (Mikhailov 1997). Afterwards, the sea level fluctuated around −27mASL, declined to −27.20mASL in 2002, and then rose to −27.0m ASL in 2005. Due to global warming, the World ocean coasts could experience rapid sea-level rise in the 21st century. Therefore, the Caspian Sea is considered as an ideal site for the study of coastal zone response to sea-level change. It is important to know this response during sea level rise and afterwards, during its lowering and stabilization.

The Laboratory of Aerospace Methods, the Department of Cartography and Geoinformatics, and the Department of Geomorphology, Faculty of Geography, Moscow State University established a research initiative aiming to investigate the response of low-lying northwestern Caspian coasts to sea-level change. The major research activities included multi-date satellite image interpretation and map compilation to illustrate the coastal ecosystem dynamics.

MATERIALS AND METHODS

Compiling of maps to illustrate the state and dynamics of the coastal and deltaic ecosystems requires the use of images with a sufficient spatial resolution. Image types we used varied over time: photos taken from orbital stations for the sea-level decline period in 1970s, photos from Resurs-F and images from Resurs-O for the sea-level rise period in late 1970s-mid 1990s, and optical and radar images from Meteor-3M, Landsat-7, SPOT-4 and Envisat for the stable sea-level period and afterwards since late 1990s to 2009.

By using visual interpretation and computer processing of multi-date satellite optical images, we compiled several maps for the low-lying Kalmykian coast to illustrate the coastal ecosystem states in 1978, 1991, 1997, 2003, 2009 (fig. 1) and maps of the transgressive changes in the coastal zone for the periods of 1978–1991 and 1991–1997, and the post-transgressive changes for 1997–2003 (fig. 2). The map scale is 1:200 000. We also used radar images to study the coastal zone post-transgressive changes with a multidate color composite and a tailored interpretation key to define the changes.

REGION OF INVESTIGATIONS – THE KALMYKIAN COASTAL ZONE

The Kalmykian coast extends by 120 km from north to south, along the northwestern Caspian Sea. It is a low-lying coast affected by wind-induced surges. An extensive mudflat belt covered with dense reeds has been formed there. The mudflats are adjacent to dry land, which comprises plains at the top of the Caspian Sea terraces covering with dry steppe in the north and semi-desert vegetation in the south. In the north, a specific relief of the Baer’s mounds exists near the Volga River delta. It is a repetitive succession of dry steppe hills and wet swamp hollows, which extends in the west-east direction. Our satellite image interpretation indicates that the sea-level transgressive changes along this coast increased with distance from the Volga River delta, suggesting that the vast and very shallow water Volga prodelta acts as a buffer zone which attenuates the effect of sea level rise (Kravtsova and Lukyanova, 1999).

CHANGES OF COASTAL ZONE IN TRANSGRESSIVE PERIOD

During 1978–1991, the sea-level rose by 1.75 m, but the northern shoreline changed very little (Fig. 1a, 1b). This weak response can be attributed to the ‘buffer effect’ due to the existence of extensive shallow-water area in front of the Volga River delta. On the other hand, the sea-level rise significantly affected the more southern coast, which is far away from the Volga River delta. From the satellite images, we can see that the mudflat’s front edge was submerged with sea waters and the shoreline retreated by 1–3 km. By constructing a coastal zone profile, we see that new beach ridges formed along the water line due to the wave activities. The development of beach ridges and lagoons behind them was quite common along the Caspian coastal zone under the sea-level rise condition (Ignatov et al. 1993, Kravtsova and Lukyanova 2000). Mudflat widened landward from 1–2 to 6–10 km. With the beginning of sea-level rise, a large lagoon was formed behind the mudflats due to the wave activities and the groundwater level rise. During the 1990s this lagoon belt with 1–2 km in width was clearly seen along the northwestern Caspian coast. The coastal plain behind the mudflats was influenced by groundwater; a waterlogged zone of several kilometers wide can be observed at the back of the lagoon.

During 1991–1997, the sea-level continued to rise till 1995 when it remained at −26.6m ASL, and then it began to decline. Shoreline in the northern Kalmykian coast and near the Volga River delta changed very little and was consistent with the preceding period (Fig. 1c). However, the coastal plain became more humid, particularly along the troughs between Baer’s mounds. In the southern Kalmykian coast, the shoreline retreated by 4–5 km in some places. As a result, the reed mudflat changed considerably with less dense vegetation cover and more open water areas, particularly along the narrow, prolonged troughs between beach ridges. A series of such parallel troughs along the shore was the main feature of mudflat zone at that time. The reed thickets became more fragmented, and the landward side of the mudflat changed significantly. The large lagoon began to disintegrate into separate segments and then disappeared from most of the coast. The mudflat continued to grow landward and reached beyond 2–4 km in width. However, the mudflat belt only shifted landward and did not change its width noticeably after 1991.

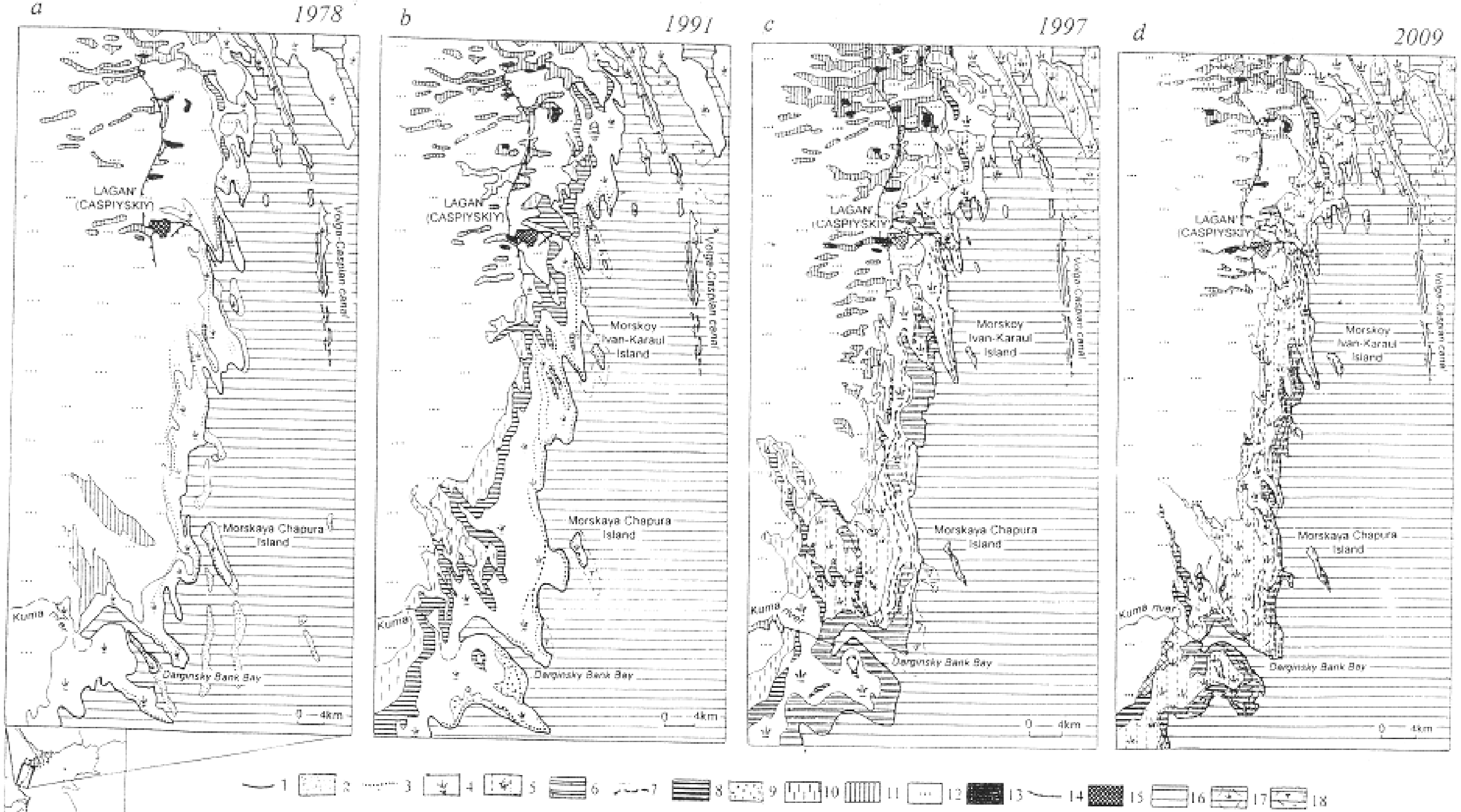

Fig. 1 Kalmykian coast of the Caspian Sea. The state of the coastal zone in 1978 (a), 1991 (b), 1997 (c),2009 (d):
1 - shoreline (outer limit of reed-covered mud flats); 2 - offshore deposition features3 - beach ridges; 4 - reed-covered mud flat; 5 - reed-covered mud flat with withered reed; 6 - mud flat oversupplied with water; 7 - narrow strips of water along beach ridges within the reed-covered flat; 8 - lagoons and their relicts behind of reed-covered mud flats, lakes of open water inside reed-covered mud flats9-sand flat; 10 - waterlogged area behind mud flat and along canals; 11 - meadow-solonchak depressions; 12 - semi-deserted plain; 13- inner water bodies (lakes, man-made reservoirs);14 - canals; 15 - urban area: 16 - sea; 17 - sea zone with water vegetation; 18 - sea zone with submerged reed vegetation

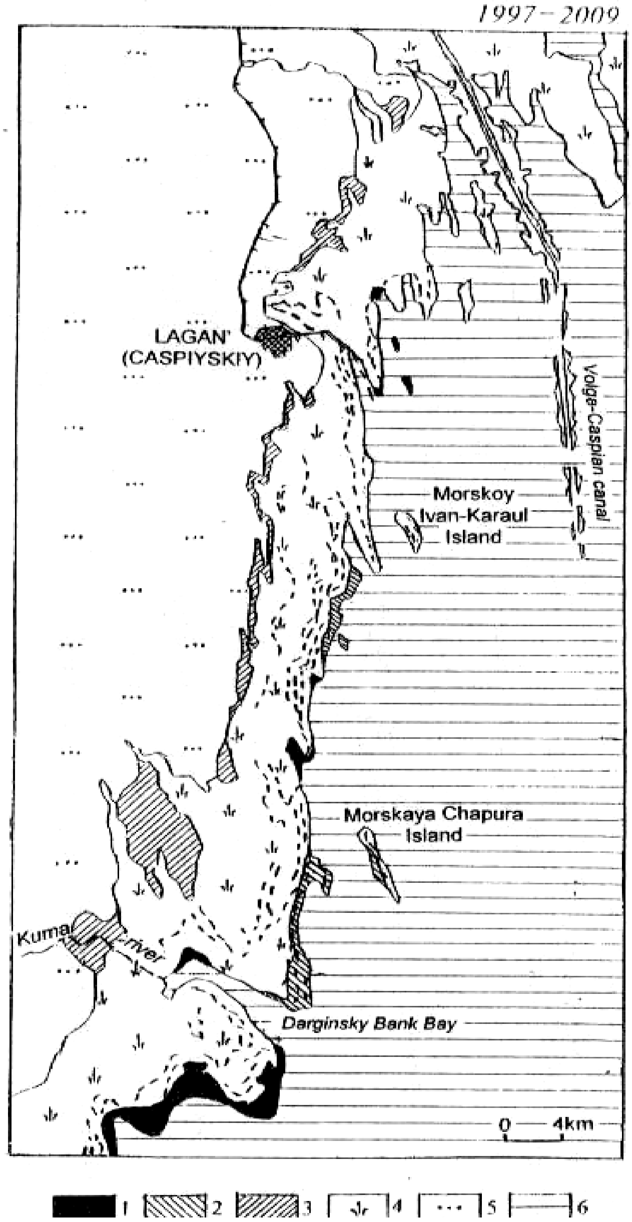

Fig. 2. Kalmykian coast of the Caspian Sea dynamics of the outer limit and back side of reed covered mudflats in 1997-2009 1-zone of shore retreat by flooding at outer limit of reed-covered mud flat; 2-zone of shore protruding by growth of reed at bottom heights; 3-zone of back mudflat boundary retreat (seaward moving); 4-reed mudflat; 5-semi-deserted plain; 6-sea

CHANGES OF COASTAL ZONE IN POST TRANSGRESSION PERIOD

After 1995 the sea-level fell to 2001 up to −27.2m ASL, representing 0.5m of decline, then was a little rose and fluctuation around −27m ASL. The shoreline change at this period was marginal. The shoreline near the Volga River delta virtually did not change and was consistent with the previous periods. But the shoreline of more than 30 km from the Volga delta, changed at two opposite directions – retrogression and progression: flooding of reed thickets and shoreline retreat at the concave parts of coast and growth of reed and formation of shore projections at bottom heights. During this period, the mudflat was remained humid, largely due to decreasing of reed thickets density. Fragmentation of reed thickets continued when water depth at mudflat zone was more than 2 m (Fig. 1d).

Such phenomena of reed belt destruction under water depth increase more than 2m was investigated also at the Ural River delta [Kravtsova and Shumatiev 2006; Kravtsova 2008]. But in back part of mudflat zone, in opposite, the lagoon behind the mudflat completely withered, with only some narrow water stripscoast and the other to the north of Chapura island) were filled with water more than in 2003, and in the last case, shoreline retreated by 2 km. But to the south of Ivan-Karaul Bay, the shore protruded by 1-2 km along district of 10 km; small island has appeared here at 1 km from the shore. This island connects with shore by reed belt at bottom height – a future peninsula is forming here. At southern part of the coast, near Darginsky Bank Bay, shore also has accreted due to reed growth at heiths of bottom, and to the north of Darginsky Bank Bay mudflat accreted seaward for 3 km. So, during period of sea level stabilization, the Kalmykian coast develops in direction to more complex shoreline with a series of bays and peninsulas. At mudflat zone, water stripes along beach ridges are seen as in 2003, some of them became more narrow.

Small relict remainders of a lagoon in back part of the mudflat are disappeared. An outer part of mudflat zone, near the shore, is too wet, with rare thickets and water windows. But within the most part of mudflat zone, the reed vegetation is withered and fragmented.

This phenomena was caused by long period of 2-m water depth, unfavorable for reed growth. Back mudflat boundary moved seaward approximately by 2 km (Fig. 2). Only the deepest depressions between Baer’s mounds are covered with green vegetation at the steppe coastal plain.

CONCLUSIONS

The response of the low-lying Kalmykian coasts to sea-level rise as examined by using of satellite imagery included the formation of a lagoon complex and the growth of the reed mudflat zone. The reed mudflat shifted landward, but when water depth exceeded 2 m, reed vegetation withered. A small sea-level decline led to the mudflat boundaries moving seaward but the reed-sea boundary changed very little, and the reed-land boundary, in opposite, was more mobile.

Based on the multi-date image mapping and the subsequent analysis of the coastal dynamics, the two important conclusions are summarized:

• Coasts with reed mudflat have two critical boundaries: one between reed thickets and the open sea and the other between reed thickets and land. We found that the first boundary tended to be less mobile, largely due to the 'buffer' effect from the reeds. The second one was more sensitive to the sea-level changes; it tended to move landwards when the sea-level rose and seawards when the sea-level declined. As the reed-land boundary is more sensitive to the sea-level fluctuations than the reed-sea boundary, it is necessary to reinforce the monitoring effort along this more mobile boundary.

• The state of reed thickets depends on the magnitude of the sea-level rise and hence on water depth. During 1978–1991, the sea-level rose by 1.75 m, the reed thickets were intact, with the increase both in area and width, indicating a good ecological condition. During 1991–1995, when the sea-level rose by 2.35m, depth growth more than 2 m, the reed thickets became more fragmented, large water windows formed, and reed thicket boundaries retreated. It is evident that reeds should have a specific ecological niche, probably around 1.9–2m in depth, where reeds were quite sensitive to the bathymetry and water-level changes.

Our research focus was on the local Caspian Sea level fluctuations rather than the global sea level change. But the reaction of the Kalmykian coastal zone to the Caspian Sea level rise can be interpreted as a benchmark to forecast the processes which can take place in the world coastal zones under global sea-level rise.

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GEOMORPHOLOGIC FEATURES OF CHELEKEN PENINSULA

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Keywords: Cheleken peninsula; Aeolian geomorphology; Mud volcanoes; Arid geomorphology

Cheleken Peninsula is a special geomorphologic region, located in the Turkmen segment of the eastern coast of the Caspian Sea. The increased interest of researchers in this small section of land does not cease since the first detailed description made by A.E. Fersman in the 1930's. Created by the great geochemist romantic image of the peninsula, "where everything is boiling", continue to surprise researcher in our days. Indeed, it is difficult to find another such a small area, where so clearly we can see geological and geomorphological processes in action: fault tectonics, diapirism, mud volcanism, deep stratification, erosion, aeolian, coastal and other processes.

Cheleken is located in dry harsh continental climate. Average annual air temperature: 15,4°; absolute maximum is 44°, the absolute minimum is -18°. The duration of the frost-free period is 260 days. The annual rainfall is less than 150 mm. Soils are dominantly sandy, but widespread are also salty soils. Ground waters occur at depths ranging from 0.6 to 50 m, the water is mainly salty, unfit for drinking and technical use. Vegetation meager: desert and semidesert. Sparse grass cover are green only during the of March-April period, in May grass are usually burned.

Geologically, the peninsula Cheleken located within the West Turkmen cavity, which is part of the large South Caspian area of subsidence. A characteristic feature of this area is the presence of large encircling faults, for which occurred an intense immersion in Neogene and Quaternary period with the uplifting of the surrounding mountain structures. These faults identified the nature of the underlying processes, the origin, morphology and relative position of individual structural elements. In the northern part of the West-Turkmen Depression, Balkhan zone there are extended chain of northwesterly directed anticlinal folds. As part of this tectonic line it is often allocated from the southeast to the northwest anticline folds of Karatepe, Mondzhokly, Boya-Dag, Burun, Barsa-Gelmez, Kotur-Depe, Komsomolsk and Cheleken that are located on land, continued in sea by Prichelekensky dome, banks Zhdanov, LAM, Gubkin, Barinov and Livanov.

Tectonically Cheleken structure represents a large elongated fold SW-NE trending with turn to the west. Size of Cheleken fold is 40x10 km. The wings of structure are asymmetrical: south-east steep (10-25°), north-west is gently sloping (5-15°). The fold is complicated by tectonic on different age and amplitude, age and length, as well as secondary fold and synclines, domes and mud breccia zones.

The structure of Cheleken in the main part is Pliocene sediments (krasnotsvet and Akchaghyl-Apsheron) and clays of Baku and Khazar. Anticline ring is surrounded by sandy deposits of Khvalin age. North and South Cheleken spits are formed by Novocaspian sands.

The central part of the peninsula is formed by Chokrak upland composed of medium- and upper Pliocene clay deposits. The south slope of upland excised by a dense network of gullies and ruts (relief of badlands), that opens their mouths in a large salt marsh. The entire western part of the peninsula is occupied by dunes, on other sites salt marshes and deflation basins are developed. Dedicated to the outputs of the upper krasnotsvet and Akchaghyl-Apsheron on Chokrak upland mud volcanism is expressed in the form of volcanic lakes (porsugels), gryphons, springs, mineralized beds (akyrs), armored by different salts surfaces (kyrs). The main part of the peninsula is a slightly sloped terrace of Khvalin age. To the north and south Cheleken are continued to sea by two low sandy spits: North and South Cheleken, that are elongated in the meridional direction.

Most of the peninsula is a plain (absolute height -26 to 92 m) occupied by sand and clay desert with salt marshes (solonchaks). Sandy ridges, dunes and hummocky landscapes are widely distributed. The sandy ridge is stretched from north to south and the north-east to south-west, height is 10-15 m, slopes from 5 to 25°. Hummocky sands are widely spread, maximum height of the mounds reaches 5-6 meters, the prevailing distance between the mounds are 10-20 m. Depressions between the ridges and dunes are often occupied by salt marshes and takyrs.

In the central part of the Cheleken structure there is a large area of Chokrak upland, composed in the main part of the clayey rocks of upper Krasnotsvet. Hills have the size of 35x22 km and represent a set of elevated anticlinal structure, with asymmetric slopes: steep SSE and gentle GCC. Within Chokrak several sloped levels of Khvalin terraces are distinguished: poorly preserved upper (at elevations 60-90 m), medium (about 50 m) and bottom (15-20 m) level.

Chokrak hills in the field of the upper terrace, and especially on the southern steep slope are heavily eroded by narrow deep ravines. The clay core of Cheleken structure are cut across due to the latest tectonic movements in the crease and torrential nature of rainfall in the region and the complete lack of vegetation here. Flushing clay material of Chokrak on the northern slope does not form the alluvial fans, mostly forming a balanced saline, which gradually transforms into Khvalyn terrace. On the southern slope, thanks to its greater steepness and proximity to the coast, torrential flows mainly reach the coast.

Standing watercourses on Cheleken are absent due to trace amounts of precipitation on the peninsula and significant evaporation. Most of the year, there are streams, fed by waters rich with iron, copper, lead, zinc and other compounds that come from underground sources. However, in the hottest periods of the year

Cheleken represents an area without a runoff, as even the streams of the major sources of almost completely dry before reaching the sea.

Fig. 1. Kertgaya cliff in 2009

Flowing down the northern slope of Chohrak akyrs do not reach the sea and deposit the material at the bottom – you can see many alluvial fans in 3-4 km from the crest of the upland. The southern akyrs drain into located to 5 km to the south large takyr, some of them often reaches South-Cheleken gulf and shape of the fans on the shore. It should be noted that both the banks themselves, and alluvial fans of akyrs unstable and represent something like a swamp. Many researchers emphasize this feature and describe accidents that occurred near akyrs and porsugels (mud volcano lakes).

Substances contained in water are deposited on the shores and bottom of lakes and temporary water streams, which contributes to cementation. Cementation on the shores of akyrs protects the valley from deflation, while the surrounding area being active influence of deflation. Such prominent valleys are usually raised to a height of one meter above the salt marsh.

The same steadiness to deflation can be observed in the fields were springs come to the surface. All Cheleken springs are not in the hollows, but on top of the small hills, raised above the surrounding surface to a height of between 0,5 and 1 meter. These mounds are usually composed of bedrock, rather than spring sediment.

Salt marshes are widely distributed on the surface of the peninsula. The Most of them are located on the west and south Cheleken. The largest, 3,5-4 km wide and 5 km in length located to the east of the Cheleken city.

Numerous takyrs on Cheleken occupy relief depressions between hillocks and sand ridges spaces. Takyrs on the peninsula are extremely diverse in size, ranging from a few square meters to several square kilometers. Their form is rounded or irregular, sometimes elongated, in the form of bands (mainly between the sand ridges).

As shown on the geomorphological map (fig. 2), Cheleken takyrs can be observed mainly in central and north-eastern part of peninsula, in small drainage areas. In their formation the main role belongs to ephemeral streams, which bring into the recesses of thin slimy material that dries cemented, protecting takyrs from deflation. Deflation begins often as a result of anthropogenic influence: overgrazing or the impact of transport.

Widespread of aeolian landforms is typical characteristic of Cheleken. This is conditioned because of the constant flow of sandy material from the continent. The primary source of material is huge Kelkor saline, located to the ENE of the peninsula. Movement of sand molds is oscillatory, as the winter winds blow from the north-west, and summer – from the south-east. Nevertheless, there is a weak dominance for a long period of the eastern winds.

On the eastern part of the peninsula aeolian relief are monotonous. Here, in terms of saturation of sand material, sand ridges formed in height from 20 to 25 m, in some cases up to 50 m, elongated in the meridional direction. Impressive size and beauty of these dunes amaze observer.

On the east of Cheleken, with movement to the west, the ridge gradually flatten and clay plain of the peninsula begins. The central part of the peninsula is dominated by small-sized sand hills that form the vast acreage of small-(height of mounds about 25 cm), medium (25-50 cm) and large hillocks (more than 0,5 m) landscapes. They cover most of the surface of Cheleken. The most interesting forms of aeolian relief formed in the coastal part of the peninsula. In this zone there are complexes of aeolian relief presented by large coastal dunes, barchan chains, small separately standing dunes, sand mounds and spits. In the Kertgaya area coastal sand ridges and dunes, located on the currently pulverized maritime plain of Khvalin time, in 15-20 meters above the water line. The height of the dunes in the central part is 17-20 m, the height of the horns is 7-8 m, and length is more than 300-350 m, width 50-70 m. The crest is stretched along the coastline, the horns are turned slightly to the shore.

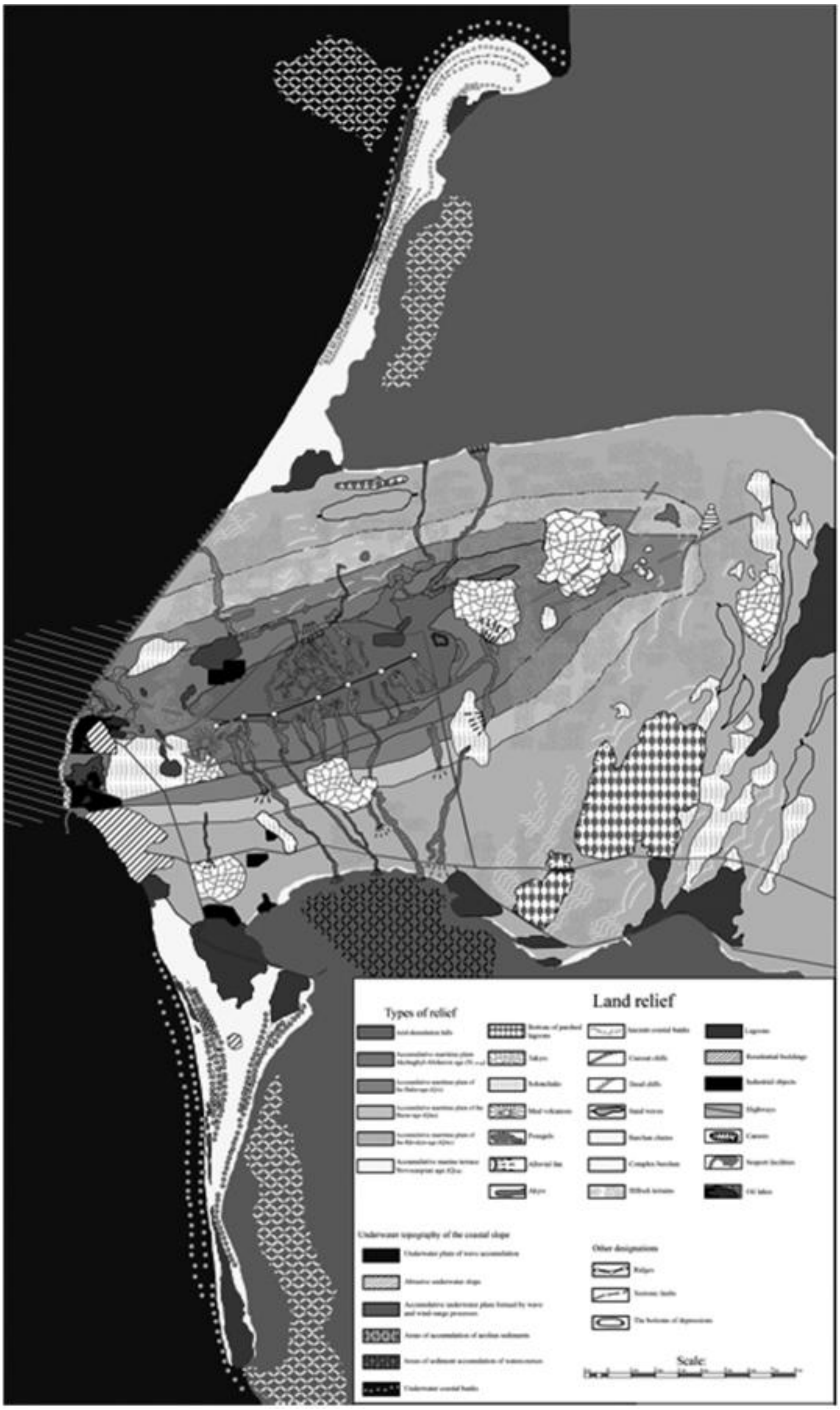

Fig. 2. Geomorphologycal map of Cheleken peninsula

West bank of Cheleken often regarded as an example of the winged cape. Peninsula is divided into three parts: Kertgaya, North and South Cheleken spits.

Kertgaya is the most elevated part of the peninsula and formed by anticlinal uphill. On the south and north, it is represented as a relatively low dead cliff with height from 1 to 5 meters. In the central part of this site cliff also was not active for some time. However, the recent rise in the level triggered activation of abrasion. It is now possible to observe the sheer cliff, the height from 10 to 20 and even 25 meters. The beach in this area is narrow, from 1 to 8 meters. Erosion is very active nowadays. Water for a few hundred meters from the shore is muddy.

Pesuliarity of Cheleken peninsula is its sandy spits. North-Cheleken spit is north-north-easterly direction and stretches nearly 20 km to its distal end, which turned to the east. On average, the height of it ranges from -20.8 m to -24 m. Spits are formed of fine-grained marine and aeolian sand.

South-Cheleken spit stretches for 17 km to south. Northern part of spit relatively narrow – about 1,5 km. To the south, it expands, forming a Dervish peninsula. At this point the width of the spit is about 5 kilometers. Then it gradually narrows and again slightly expands. In the center of the Dervish peninsula spit reaches the height of -22,2 m, and in general it is characterized by the height of -23 m to -27 m. Spits framed wide sandy beaches, which have a width of 200-400 m. Along the outer coast of the spit is the longitudinal displacement of sediment. A noticeable effect of this process was observed on South-Cheleken spit, which extend in 1960-1985, approximately 150-170 m. The surface of the spit is formed by series of ancient beach ridges, their height does not exceed 1,5 m. Aeolian landforms are widely distributed on spits, especially on the southern one.

In 1977, the sea level was at one of minimum values in the 20 century: -28.8 m abs. The area of the peninsula has increased significantly: the width of spits and Dervish peninsula doubled, Kertgaya coastline shifted south by more than 1 km. Especially the increase in area can be clearly seen on the North Cheleken spit in its distal part.

New rapid sea level rise in 1992 triggered activation of Kertgaya cliff on the west. Shoreline shifted to the east more than 350 m. The peninsula Dervish again decreased significantly, South-Cheleken spit became narrowed sand line width up to 2 km. North Spit is also strongly narrowed and lined. Large spaces were under water in the north of South Cheleken Bay. Coastline moved near the city Cheleken, flooding for more than 300 m.

In general, the level for the considered period has changed from -25.6 m to -29 m and again to -28 m. There was no significant change in the coastal zone during this time. The transgression was expressed in the decrease in area of spits and the sinking of the most depressed areas of Kertgaya cliff. Regressions led to the opposite effects: spits expanded in an easterly direction.

Cheleken Peninsula is an extremely interesting area. The central part, the Chohrak upland is anticlinal elevation with plenty of deep gullies. On the surface of this upland numerous springs poured, waters are supersaturated with various compounds of iron, zinc, copper and halogens, forming convex valleys and extensive flooding – kyr surface. Chohrak are encircled with deposits of Akchaghyl-Absheron, Baku, Khazar and Khvalin age. In some places there are areas of terraced surfaces.

The peninsula for a long time was an area of active mud volcanism. Currently, there are three active mud volcanoes: Aligul, West Porsugel and Pink Porsugel. Volcanoes morphologically expressed as lakes elevated above the surrounding plain, the area around which is covered with mud breccia.

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GEOMORPHOLOGY OF THE KRASNOVODSKY BAY

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Keywords: Kelkor; Arid geomorphology, Darja peninsula, Kubadag, Krasnovodskaya spit

Krasnovodskyi Bay – the largest semi-isolated bay of the Caspian Sea, located on the eastern part of the sea with 55 km in width and in 44-45 km length. From the sea bay cordoned by Krasnovodskaya and North-Cheleken sand spits. From the northern part bay is limited by steep slopes of Kubadag ridge, and from the east – the mountain slopes of the Great Balkhan, with Kelkor and Balkhan saline. To the south of the bay there is a sandy Darja peninsula and a Dardzhikum array, which goes south in to Cheleken peninsula.

Krasnovodsky bay, is a special geomorphologic region, located in the Turkmen segment of the eastern coast of the Caspian Sea. Krasnovodsky bays includes smaller size Balkhan and North Cheleken bays. From the north bay limited by Krasnovodsk plateau, the block area of Kubadag, crystalline arrays of Shagadam, Karadag (Ufra) and Dagada, in the west – mountain range of Great Balkhan, sand fields of Darja peninsula, Kelkor salt marsh and sandy Dardzhikum area, in the South – by Cheleken peninsula. From the east bay is surrounded with Krasnovodskaya split, oriented from north-north-west to south-south-east and North-Cheleken split SW-NE strike.

According to geological zoning of Turkmenistan Krasnovodsky bay is situated on the boundary of two districts. On the north it is part of the Usturt area. The average annual temperature is about 12-15 ^{0} C, the absolute maximum of 43 °C, the absolute minimum of -30 °C, the duration of frost-free period of 210-225 days, with precipitation about 100 mm per year.

The southern part of the bay belongs to the West Turkmenistan region with highly developed mobile barchan sands and salt marshes. Average annual air temperature is 15,4 °C, the absolute maximum of 44 °C, the absolute minimum of -18 °C. The duration of the frost-free period – 260 days, annual precipitation – about 150 mm.

Morphologycaly the coast of Krasnovodsky bay is divided into main districts: Krasnovodskaya spit, the lower slopes of Kubadag-Great Balkhan, Balkhan shore, the Darja Peninsula, Kelkor saline zone, sandy area of Dardzhikum (Maritimes Kyzylkums), the northern coast of the Cheleken peninsula and North Cheleken spit.

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	Monthly and annual air temperature, C												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Turkmenbashi	2,4	4,0	8,0	14,0	21,0	26,0	29,0	28,5	24,0	17,5	11,0	7,0	15,8
Cheleken	2,0	4,0	8,0	13,0	18,0	23,0	27,0	28,0	23,0	18,0	11,5	8,0	16,0
	Precipitation by seasons and for the year, mm												
	Winter			Spring			Summer			Fall			Year
Turkmenbashi	34			40			11			18			103
Cheleken	41			39			9			22			111

From the north over the bay rises Krasnovodsk plateau, formed with Akchagyl deposits, representing a relatively flat elevated surface, folded in the middle part of a combination of gentle rolling hills, flat-top residual mountains and closed depressions.

Fig.1. Khvalin terrace near Balkhan bay

Southern region of Krasnovodsk plateau forms the backbone of asymmetrically built Kubadag ridge, that precipice (up to 300 m) to the coast of Krasnovodsk bay. Further south there are crystalline arrays of Shagadam and Kuradag complicating the gulf coast.

Krasnovodskaya spit extends to the south-east from the northern shore of Krasnovodsk bay and has a length of about 37 km. Width of spit is 9 km at the base, in the middle it narrows to0.5 km, and in the southern re-expands to 2.5 km. Spit is sandy, with a smooth surface.

Fig. 2. Sand ridge of Dardzhikum

The root of Krasnovodskaya spit formed with 16 m terrace, relating to Sartassk stage of Hvalynian sea. Below younger (Dagestan) terrace is observed with height of 11 m.

Slopes of Kubadag and Great Balkhan ranges greatly eroded with ephemeral streams, forming a dense network of gullies and ravines, deeply embedded in proluvial plume in the middle part of which indicated the ancient shorelines of the Caspian Sea.

To the south and further to the west Khvalin abrasive-accumulative plain stretches, composed of sandy-gravelly deposits, among them spots of Khazar age are exposed. In zones where Khazar comes up to the surface, a plateau-like increase with steep slopes 3-4 m tall is formed. Reduced areas are occupied by undulating plain with widely developed pebble coats and accumulations of shifting sands.

Balkhan shore currently is a broad platform with the surface of chubby saline. Balkhan shore is difficult to access due to the liquid-plastic consistency of the salt marsh (fig.1).

Fig. 3. Barchan ridges of the Cheleken peninsula

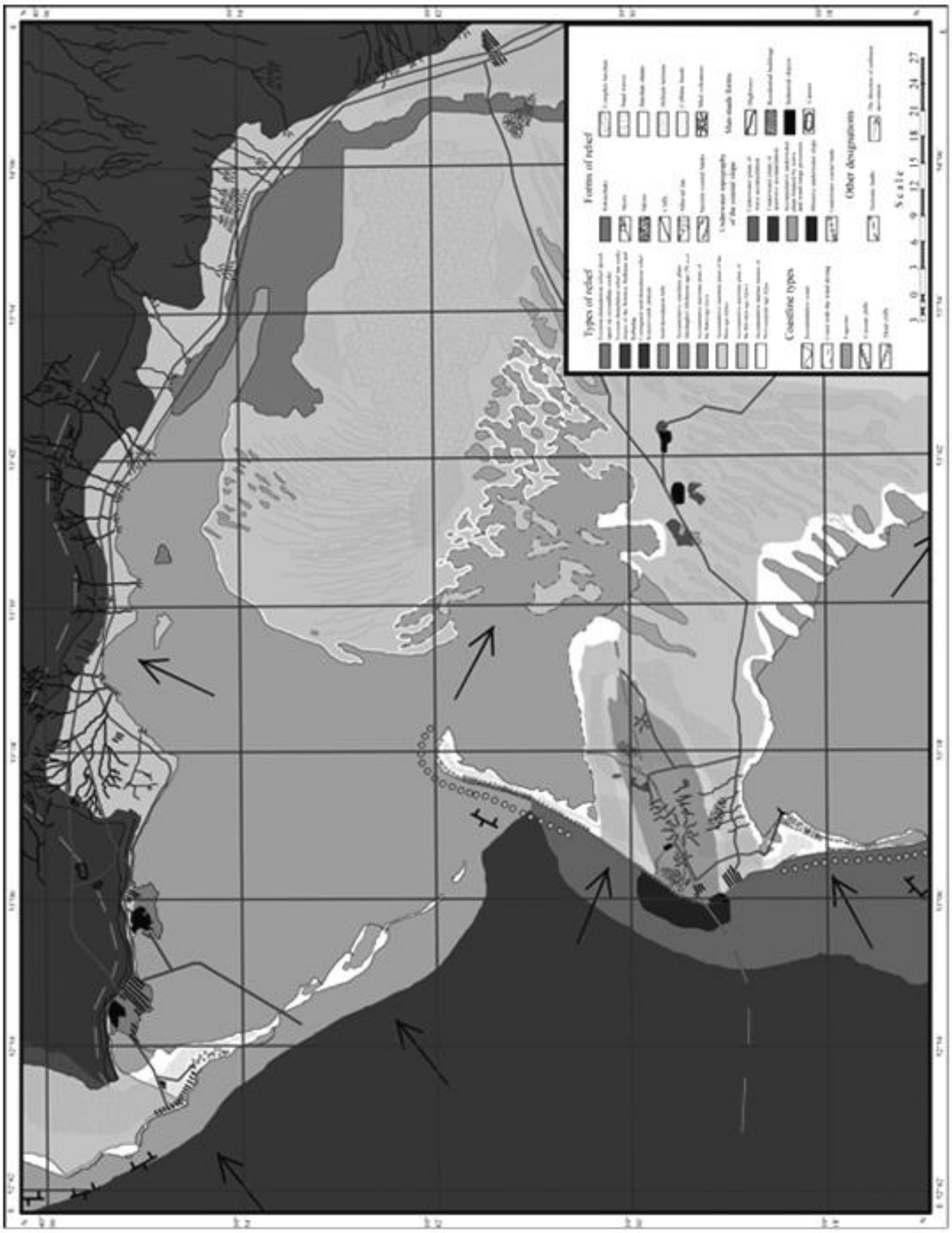

Fig. 4. Geomorfologikal map of the Krasnovodsky bay

To the southwest of the Great Balkhan array Balkhan shore, gradually changing its orientation with sub-latitudinal to south-south-east, turns into a huge Kelkor saline, in the shape of a circle with diameter of 40-42 km. Absolute mark of this salt marsh close to the -26 m. During the Novocaspian transgression Kelkor was the gulf of the Caspian Sea, later turned into a closed lagoon. Kelkor is an ancient land blowing field, filled first by the sea, and later – with fresh water lake, fed by Uzboi river. After the cessation of Uzboy flow Kelkor was recovered with waters of the Caspian Sea. Today it is a dry salt flat, where more than half a century rock salt is being produced.A specific feature of the relief of Kelkor depression are caused by tectonically uplifted clay badlands – Nebitdag (71 m), Syrtlanly (117 m), Mondzhokly (27 m) and others. The slopes of these anticline hills are cut dry gullies and complicated with steps of Khvalin terraces. From the Kelkor salt marsh two downward depart. One of them pulled at first directly to the east, gradually tapering to 2-3 km and wrapping the north-east between the Greater and Lesser Balkans. This reduction represents lower part of the former river valley of Uzboy.

Currently, the channel is a series of salt marshes and small saturated salt lakes. Other lower branch starts at the north-west part of the salt marsh and stretches to the north, gradually turning into a clearly expressed, bordered terraces ancient river valley of Aktam river.

To the west of Balkhan-Kelkor depression there are a number of arrays of sand ridges and dunes. High sand ridges of Darja peninsula are formed by Khvalin marine sediments. The peninsula is located between Balkhan and Michaylow bays. The peninsula is low-lying coast with a sandy beach width from 20 to 50 m. This waterless sandy desert with individual relief branched convergent to the south and concave curved sand. The surface of the peninsula occupied by sand, a whole system of large ridges, reaching 60 m in height and extending in length to 20 km. Ridges are in the south of the meridional stretch, passing to the north in the north-east. In inter-ridge depressions salt marshes are located.

Maritime Kyzylkum zone (Dardzhikum), characterized by development of huge barchan dunes with steep concave slope on the west and the gentle eastern slope. The relative height of this complex of sand dunes is up to 60 m (fig.2)

Dardzhikums to the west are gradually moving to the Cheleken peninsula as the isthmus with 18-20 km width, as an alternation of barchan dunes with large lagoons. The basis of the Cheleken peninsula is Chohrak upland, composed of medium-and upper Pliocene clays and sandy rocks and representing badlands relief. The maximum height of peninsula is 92 m. Morphologically upland is sharply asymmetric, is characterized by gently sloping north-western slope and steep south-south-east.

A characteristic feature of geology of the Krasnovodsky bay is slight vertical movement, contributed to a weak modification of the coast. That is why exogenous factors and especially coastal processes have a decisive relief-forming role here. The main contribution to the formation of morphological image of Krasnovodosky bay belongs to the Caspian Sea.

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ANTHROPOGENIC DEVELOPMENT OF THE CHELEKEN PENINSULA (SOUTH-EASTERN CASPIAN SEA)

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Keywords: Cheleken peninsula; Khvalinian transgression; Mud volcanoes; Arid Geomorphology.

Cheleken Peninsula is one of the most developed parts of the Caspian Sea. By the end of 1920 several thousand tons of oil was extracted on Cheleken and there were several hundred working and abandoned wells. Nowadays, there are several thousand old and new wells (depth of 1 to 3,5-4,5 km) on the peninsula. From the depths of Cheleken hundreds of millions of tons of oil, mineral brines, billion cubic meters of associated gas, significant amounts of ozokerite, iodine, bromine and various salts was extracted. Today on the peninsula, along with oil extraction, large chemical plant are working, producing iodine, bromine and various salts, Carbon Plant, mooring and cargo-handling terminal of Alagja-port, numerous industrial and pilot plants for stabilization and transportation of produced oil and gas materials on land and in the newly developed offshore fields (banks Zhdanov, LAM, Gubkin).

Fig.1. Pink Porsugel mud volcano

Over the past 130 years of industrial development of oil and gas and other resources, Cheleken became one of the major socio-economic centers of Turkmenistan with a population of 35-40 thousand. In view of such intense pressure on the relief of the peninsula at the present time, the surface of the peninsula almost completely anthropogenic revamped. Below as far as possible we will try to describe the development of the peninsula, from three key positions, each imposing specific features in the relief of Cheleken: 1. The development of topography, formed as a result of natural geological and geomorphological processes (fault tectonics, mud volcanism, deep stratification, coastal, aeolian, and other processes). 2. Anthropogenic development of relief, formed as a result of vital activity of the population of the peninsula (construction of housing, cultural, educational, municipal and transportation facilities, as well as local fisheries and distant-pasture cattle breeding). 3. Industrial development of the relief formed as a result of oil and gas, ozokerite and brines, processing and transportation of produced raw materials, and other processes associated with them.

Geomorphologicaly relief of Cheleken peninsula is a sandy-clay desert with various forms of aeolian and arid-denudation relief. The central part of the peninsula is small clay Chokrak upland largely rugged by the valleys of ephemeral streams. Upland are straddled with the system of marine depositional terraces with multiple forms of aeolian relief: fixed hummocky fields, single sand-dunes and barchan chains, sand ridges of kilometers in length and a height of 35-55 m, separated by inter-ridge takyrs and salt marshes of various sizes (from several to tens of square kilometers).

The natural development of the relief of the peninsula is now most pronounced in the west, the most elevated part, in zone of bedrock outcrops within the Cheleken oilfield. In this zone, relief is heavily dissected by erosion and looks like a hilly-ravine area with many natural remedies to the surface of oil, gas and deep mineral brines in the form of mud volcanoes, griffins and other variety of sources. As a result, the surface formed by numerous oil and salt lakes (porsugeli) and flows (akyry) with sedimentation of various minerals and metal salt series. A wonderful world of distinctive and unique landscape of mud volcanoes and numerous highly mineralized iodo-bromine, sulfide, sulfate, iron hot (70-110 C) water, hydrocarbon, hydrogen, sulfide, carbon, nitrogen and other gases coming from the depths due to high formation energy can be seen in the central zone of the western part of peninsula on the outcrop of red Akchaghyl-Absheron marine clay.

The main geomorphological elements within Cheleken structures are Chokrak upland located in the center of the fold with a maximum mark of 92.5 m, located to the east of it zone of mud volcano Pink Porsugel and hilly upland Dagadzhik. Cheleken structure is surrounded by a ring of Khvalin aged marine accumulation plain, from which two large sand spits depart: North-Cheleken SW-NE trending and elongated from north to south South-Cheleken spit.

In the central part of the peninsula, west to Chokrak upland, Aligul volcano is located. It is a slightly elevated platform folded by mud breccia. Even to the west there is a small lake with a diameter of 50-60 m, filled with pinkish-brown boiling water – Pink Porsugel mud volcano.

Chokrak is surrounded by salt marshes and unloading takyrs, formed as a result of physical and chemical weathering of moisture argillaceous rocks with high capillary rise of soil water with chloride, sulfate, sulfide and other salts. After the ring of saline marshes Khvalyn terrace continues in the form of sandy plains with an altitude ranging from -25 to 25 m. The main surface of terrace is occupied by loosely held by hillocks sands, and in the extreme west and east there are fields of barchan chains stretching from SW to NE.

In general, Khvalyn terrace with sandy-desert terrain covers an area of about 950-1000 square km; cheleken spits – 75-80 square km, and elevated Chohrak hilly-gully surface – about 300-310 sq.

INDUSTRIAL DEVELOPMENT OF THE RELIEF

The main production on Cheleken peninsula is associated with extraction of oil and gas, and their preparation for transport to consumers. A special place is occupied by production of highly iodine-bromine brines, their processing at a chemical plant, waste management in special barns, lakes, evaporators. Associated gas from the field is burned on Hazar Technical Carbon Plant, located 5 km NE from the town of Hazar. To the north of the city Aladja-port on the west of the Dervish peninsula are located that operates oil loading. Also on the peninsula there are power train, a lighthouse, industrial base of exploration drilling, 3 oil and gas fields.

Fig. 2. Depleted oil wells, East Cheleken

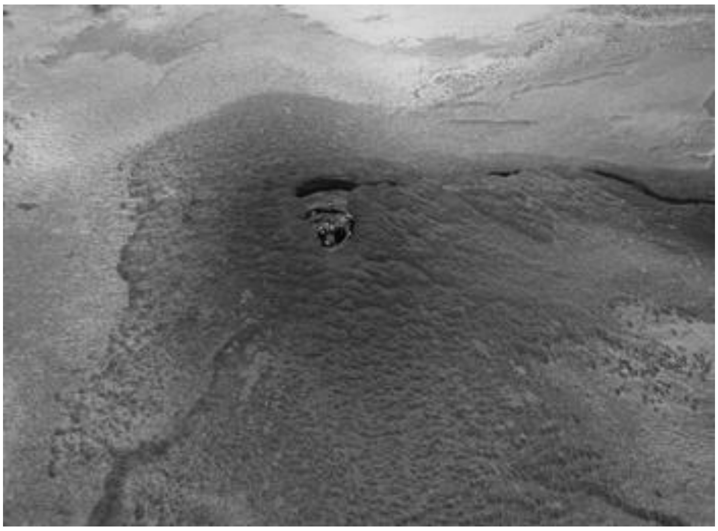

Fig. 3. Oil gryphon – depleted oil well

The main oil field is located on the west of Cheleken peninsula and represents anticlinal structure of SW-NE (210-230π) strike with length of about 23 and a width of about 6 km. At the outcrop on the eastern half of the structure exposed aquifer sediments of the upper Krasnotsvet 16x4 square kilometers, oil and gas deposits of the lower and middle Krasnotsvet. The field is divided into separate blocks. In the drilled part of the structure currently providing three oil-stations: West Cheleken-Aligulu; Dagadzhik and Eastern Cheleken. Initial reserves of Cheleken oil field was estimated at 400 million tons of oil and gas condensate. Yearly extraction of oil on Cheleken is about 1,5-2 million tons, and less than 2 million on the marine part of the oil field (Zhdanov, LAM, Gubkin banks)

On the western Cheleken oil, ozokerite and salt was mined from ancient times. Industrial development of the wealth of the peninsula began with the 70th years of the nineteenth century. Such a long and intense human pressure on the relief of Cheleken expressed in almost complete its reorganization, particularly in oil field part of the deposit. Deep horizons of the field were also changed with a substantial violation of the reservoir hydrodynamics and geological parameters.

The results of the industrial load can be observed throughout the peninsula. Out of oil field often contain areas of exploration drilling, expressed in an abandoned piles of twisted metal, spilled oil, reduced vegetation, increased aeolian processes.

In the central part of the peninsula in the Dagadzhik zone ozokerite deposits was extracted from 1950s to 1990s. Currently, the production is suspended, but to the east of the volcano Pink porsugel survived two major waste dumps height of 25-30 and m in diameter 200-250 m wide. The intensive production left entire complex of abandoned industrial buildings and infrastructure.

The greatest harm to the nature of the peninsula is caused by old and depleted oil and gas wells. These wells after shutdown and liquidation begin to appear highly mineralized brines from oil inclusions as a result of corrosion over time. The discharge of sources of this type is high (1-1,5 l/sec.) As a result there is large variety of uncontrolled mineralized water overflow. Water flowing into the adjacent takyr lowlands form large oil-water wetlands, salt marshes. It formed large salt marshes in the area of the 2nd and 3rd Cheleken oilfields. Waterlogged was also the vast territory west of Chohrak, north of the Azizbekov village where oil-brine flows widespread, creating oil-water lakes and streams. Number of emergency wells by our estimates exceeds more than hundred.

ANTHROPOGENIC DEVELOPMENT OF RELIEF

At Cheleken industrial relief as described above is mainly expressed in the form of oil and gas extraction. We identify a group of man-made landscape in a separate group because there is a clear specific effects on the morphology of the peninsula. In this category we include landforms formed as a result of direct human activity – roads, municipal, lifeline, accommodation and other facilities. They are mainly related to human settlements, the objects of life support. Some impact on the relief provided and underdeveloped agriculture, that enhance aeolian processes. There are several settlements at Cheleken. City of Hazar (Cheleken, renamed in 1998) is located in the southwestern part of the peninsula 2-3 km to the north of the base of the South-Cheleken spit. The city covers an area of about 1 sq km, is built up in the form of regular rectangular blocks, with two and four-storied houses. The current population of Hazar is about 30 thousand people. On the beach north of the town Cheleken marina and port facilities are located.

Because of the latest rise of sea level part of the town was flooded by the waters of the Caspian Sea. The stadium, several blocks of the city, beach with all the tourist and entertainment infrastructure was flooded.On the peninsula there are several small settlements numbering 2-3 thousand peopla. The largest and most ancient is Azizbekov village, located near Hazar chemical plant north of Cheleken. Most of the houses are raised on stilts. In the 3-4 km to the south-east of the city on the shore of South Cheleken Bay the village Karagel is located.

At the extreme south-east of the peninsula, at the point of junction with the mainland is a small resort town Heles, which also was partially flooded in the late 1990's, but then gradually rebuilt and now exists as a small settlement.Relief of Cheleken is currently divided into three groups of relief-forming processes that produce the most active surface modification of the peninsula: 1. Natural geological and geomorphological processes (fault tectonics, mud volcanism, deep stratification, coastal, erosion, aeolian and other processes). 2. Man-made landscape, shaped by the immediate life of the population of the peninsula (housing, cultural, educational, municipal and transportation facilities, local fisheries and distant-pasture cattle breeding). 3. Industrial landscapes – the result of oil and gas, brines and ozokerite processing and transportation, and other processes associated with them.

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INFLUENCE OF THE CASPIAN SEA COASTAL ZONE TRANSFORMATION ON HERPETOFAUNA OF DAGESTAN

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INTRODUCTION

Herpetofauna of Dagestan is rather rich because of high landscape diversity on its territory. There are 8 species of amphibians (2 – caudate and 6 – anuran) and 41 species of reptiles (3 – turtles, 17 – lizards and 21 snakes) (Mazanaeva, 2001). Herpetofauna of this region is not well investigated till now; new species can be found there.

Amphibians and reptiles as all poikilotermic organisms greatly depend on the microclimate of their habitats, constructed by the climate of the region, local soils and vegetation. Natural and anthropogenous transformation of the habitats leads to the reduction of quantity of some species and even disappearance of them.

The Caspian Sea has inconstant level. In view of the natural course of fluctuation of the Caspian Sea level, based on the tendency of direction of modern tectonic movements of pool of the Caspian Sea, on an increase in inflow of surface water, and also on problem conditions of global warming of climate (Dujsebaev et al., 2006). Many researchers explain it as the changes of climatic conditions, on which factors of anthropogenous activity are recently imposed.

Climate of the region is characterized by the deficit of humidity, intensive evaporation, strong winds and heavy rains while the high summer temperatures.

Investigation of the herpetofauna of the Caspian western coast was conducted in the plain Dagestan, at the territory between Makhachkala city and Samur River. The width of the investigated territory was 500 m from the coastline. This region is situated at the border of the temperate and subtropical belts.

PHYSICAL-GEOGRAPHICAL CHARACTERISTIC OF THE COASTAL ZONE

Area studies are entirely located within the low-lying marine plains. The climate of the region is characterized by hot dry summers with strong winds and moderate snowfall in winter. The average summer temperature does not exceed 25^0-27^0 C, average maximum temperature – 34^0 C. Average temperature in January -0,8^0 C, and the average minimum – -17^0 C. When moisture deficit (200-300 mm) and high evaporation from the land for the year (870 mm) annual rate of moisture is (0,4-0,5). This indicator is the characteristic of the semi-arid climate zones: dry steppes and temperate semi-deserts.

About 50% of annual precipitation (60-80 mm of rain falls in summer) is in the vegetation period. The volatility over this period is 450 mm. Consequently, the summer humidity ratio is 0,15-0,16. Such an acute shortage of water is the characteristic for the zone of deserts.

Vegetation and soils of this territory have clearly expressed zonal-specific, peculiar to the temperate semi-desert zone with intrazonal features of the seaside terraces. Here the grass-artemisia associations (with predomination of *Cynodon dactylon* predomination) are spread (fig. 1). The predominant soils are humus-containing sands (because of small period of soil formation) with limited humus. Solonchaks are formed in the mikrodepressions.

In present time morphological changes of the coastal zone are well seen (fig. 2). Because of the sea level emergence and its wave activity the coastline goes further to the land and the coastal zone becomes narrower. At the same time the level of the ground waters changes too. At the same time intensive recreational development led to the anthropogenous transformation of the landscapes (fig.3, 4).

Fig.1. Natural coastal ecosystems of the Caspian Sea

Fig.2. Influence of the Caspian Sea level and activity on the coastal zone.

Fig.3. Transformation of the coastal ecosystem by intensive digging

Fig.4. New villages just near the Caspian Sea coastline

HERPETOFAUNA OF THE COASTAL ZONE

19 species of amphibians and reptiles inhabit the coastal zone of the Caspians Sea. They represent 37% of the species richness of Dagestan herpetofauna. There are 5 species of anuran amphibians, 3 – turtle, 4 – lizard and 7 – snakes.

List of amphibians and reptiles.

Five species of amphibians – Iranian long-legged wood frog *Rana macrocnemis* (Boulenger, 1885), Shelkovnikov tree frog *Hyla arborea schelkownikowi* (Cernov, 1926), green toad *Bufo viridis* (Laurenti, 1768), lake frog *Rana ridibunda* (Pallas, 1771), eastern spadefoot *Pelobates syriacus* (Boettger, 1889);

Three species of tortoises and turtles – Pallas Mediterranean tortoise *Testudo graeca pallasi* (Chkhikvadze et Bakradze, 2002), Caspian turtle *Mauremys caspica* (Cmelin, 1774), swamp turtle *Emys orbicularis* (Linnaeus, 1758).

Four species of lizards – Caspian green lizard *Lacerta strigata* (Eichwald, 1831), sheltopusik, *Pseudopus apodus* (Pallas, 1774), steppe-runner *Eremias arguta* (Pallas, 1773), rapid fringe-toed lizard *Eremias velox* (Pallas, 1771).

Seven species of snakes – slender racer *Platyceps najadum* (Eichwald, 1831), red racer *Hiepophis schmidti* (Nikolsky, 1909), large whip snake *Hierophis caspius* (Gmelin, 1779), Dione snake *Elaphe dione* (Pallas, 1773), grass snake *Natrix natrix* (Linnaeus, 1758), water snake *Natrix tessellata* (Laurenti, 1768), sand boa *Eryx jaculus* (Linnaeus, 1758).

Species *Pelobates syriacus*, *Hiepophis schmidti*, *Eryx jaculus* and subspecies Pallas *Testudo graeca pallasi* does not occur anywhere else in Russian Federation.

Rare and protected species account for 21%. *Testudo graeca pallasi* and *Pelobates syriacus* are included into the IUCN Red List (www.iucnredlist.org), *Eryx jaculus* – the Red Data Book of Russian Federation (2001). These species, as well as *Hiepophis schmidti* are in the Red Data Book of Dagestan (2009).

Mauremys caspica has limited distribution on the territory of Russian Federation. These species and subspecies, the main area of which lies to the south from the borders of the Republic, are represented here by marginal populations.

SOME ECOLOGICAL FEATURES OF THE RED DANA BOOK SPECIES

Pelobates syriacus in the arid conditions of Dagestan is distributed sporadically depending on the presence of suitable waters for spawning in the lowlands and foothills up to 1100 m above sea level. This spade footed toad uses plenty watered shallows with muddy bottoms and submerged vegetation located in semi-desert and steppe landscapes. It inhabits various soils: sandy, muddy, salty, dense clay and rocky. Prefer to spawn in the warm, clean and slightly acidic water with low salinity, but multiplies in highly contaminated water with the presence of nitrates. It hibernates in the soil, buried to a depth of 70 cm, or in cavities under rocks, in deep crevices of sandstone and under tree roots. Breeding occurs in shallow, temporary and perennial overgrown ponds. Most larvae die without completing metamorphosis due to drying ponds. After metamorphosis fingerlings remain in water, buried on the shore. Rarity distribution of this species in Dagestan is explained by natural historical reasons. The most negative anthropogenic impacts are draining and pollution of spawning ponds

The tortoise *Testudo graeca pallasi* on the coastal lowlands of Dagestan inhabits riparian woodlands in floodplain forests in areas of coastal sand dunes and sagebrush semi-desert. In the foothills it lives in the dry desert steppes on small hills and hills covered with vegetation at altitudes up to 600 m. The main limiting factors for this species are economic and recreational development of the coastal lowlands. The unauthorized and intensive removal of sand from the coastal dunes leads to the degradation of the habitats preferred by the tortoises.

Hierophis schmidti in Dagestan inhabits the steppes, semi-deserts, shiblyak, river valleys and coastal hilly sands. It prefers to live not far from water on the places covered with vegetation. The snakes hide in the burrows of rodents and cavities under rocks. It is the egg-laying species. The snake hunts on the small mammals, birds, lizards and small snakes. It is rarely distributed in its area. The species can survive in the transformed landscapes (settlements, gardens, grape gardens), on the edge of fields, on eroded slopes, in gullies. Reduction of its number is the result of the direct killing and catching by the human population and dying under the wheels on the roads.

Eryx jaculus. Its habitats in Dagestan are confined to arid areas: fescue-wormwood steppe, shiblyak, hilly sands of the Caspian Sea coast, in the sagebrush saltwort semi-desert (on clay and rocky areas), on the edge of fields, on eroded sand slopes, in gullies and river valleys. The snake conducts secretive life, hiding in the burrows of rodents and birds, cavities under rocks and in crevices of the soil. Good to bury into the soil. In summer at hot period comes out to the surface mainly at dusk and at night, in spring and autumn – during the day time. It is the ovoviviparity species. The snake feeds on lizards, rodents, birds, small snakes and large insects. It is a naturally rare species. Anthropogenous transformation of the landscapes within the area leads to the reduction in the number of species. Intensive recreation development of the Caspian coast and the economic development of the lowlands and foothills can lead to extinction of the population in the region.

CONCLUSIONS

As a result of intensive recreational development of the coast in recent decades *Eremias arguta*, *Eremias velox Mauremys caspica* and *Emys orbicularis* have disappeared in the interval between the coastal cities of Makhachkala and the Caspian. Intensive destruction of the habitats of *Testudo graeca pallasi* (development of sand pits) in the lake district Turali led to a critical reduction in the number of this Mediterranean tortoises.

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COASTAL WASHOUT AND EROSION HAZARD OF THE RUSSIAN CASPIAN SEA COAST

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Keywords: wave erosion, erosion risk and hazard, coastal zone, Russian coast

INTRODUCTION

Problems of erosion and protection of sea coasts demand the accurate information on a modern condition of a coastal zone, on spatial distribution of the erosion process which on a rendered damage takes the important place in a number of other dangerous natural phenomena (Kaplin, Lukyanova, 1992). It causes occurrence of concepts of geomorphologic risk and erosion hazard (Natural hazards of Russia, 2002; Pignatelli et al., 2006; Lukyanova and Solovieva, 2009; Burova, 2009, etc.). The geomorphologic risk is understood as probability of social, economic and ecological losses under impact on coast of the various dangerous phenomena. Erosion hazard is a part of geomorphologic risk and corresponds to probability of display in a coastal zone of the dangerous phenomena of the certain intensity and during the certain period. The basic measure of coast processing hazard is intensity of the erosion process which can be full enough expressed by the mean perennial values of linear speed of a coastal line retreat. If to estimate erosion hazard on the basis of this characteristic, it is possible to approach to division of sea coasts on a hazard degree of their destruction. Available actual data on sea coast of Russia give average speed of their retreat under wave influence about 1,2 m / year. Accepting this value for an original critical threshold, it is possible to count, that excess of these speeds will testify to a dangerous situation. On this thesis, drawing up the large-scale (1:500 000) maps of erosion hazard of the Russian coasts (including Caspian ones) is based with allocation of dangerous and critical sites.

TECHNIQUE OF DRAWING UP OF EROSION HAZARD MAPS

As an information basis, maps of Russian coastal types made by authors before of the same and smaller scales were used**.** These maps evidently show distribution of the erosion coasts of different types at coasts of all seas washing the Russian territory. Besides, the small-scale chart «Hazard of coastal processing of the seas and manmade reservoirs» from the Atlas natural and technogenic hazards of the Russian Federation [Ragozin, et al., 2005] was involved also.

The legend to maps is based on a four-graded scale of hazard of the sea coast wave erosion process. This scale reflects gradual increase in risk of coastal wave destruction: from practically safe up to a dangerous and very dangerous category. The allocated gradations are accompanied by quantitative estimations of linear speed of coast processing, and also by the brief qualitative characteristic of erosion process of this or that category. The range of quantitative estimations in each case is chosen under the available factual data about intensity of processing of the Russia sea coast.

All distinguished categories of hazard of sea coast processing concern only process of wave erosion. The last, though, quite often becomes complicated by mass-wasting processes, especially development of landslides which considerably weaken stability of the coast and raise risk of its destruction. So, the critical categories of hazard, as a rule, reflect a combination of wave and landslide activity. At mapping of a different categories of hazard intensity, erosive sites of the large sea accreted forms are also attributed to the erosion coasts.

The "initial" category – practically safe – also concerns only to erosion process on low shallow coasts where wave influence is considerably weakened. However, on such coasts other hydrological processes rendering significant influence on settlements of the person can develop. First of all, these are tides and wind surges. In the non-tidal Caspian Sea, the basic danger get wind surges with which displacement of a shore line towards a land by some kilometers and flooding by sea waters of extensive coastal spaces can be connected.

The following category of erosion hazard – insignificant danger – unites coasts, which have rate of wave processing less than 1-1,2 m /year. Usually these are the erosive coasts of the half-enclosed water areas where the small local wave forms low coastal cliffs. Other version of this category is, on the contrary, the high erosion-denudation coast formed by strong, steady against wave erosion rocks: limestones, sandstones and different kinds of metamorphic rocks. Rate of wave erosion and retreat of such coasts is very small and seldom exceeds 0,1-0,5 m/year. However on such coasts various mass-wasting processes – weathering, collapses, taluses and landslides – are actively developed and can cause fast coastal retreat on the local sites.

The third category of erosion hazard – moderately dangerous – is characterized by rate of coast processing within 1-5 m/year. These are coasts of different height and different lithologic structure of composing them rocks. During storm seasons they experience periodic destruction and retreat, resulting in the essential losses of coastal territory and deformation of separate coastal constructions.

The fourth category of coast processing – dangerous and very dangerous – differs in the significant rate of coast destruction (more than 5 m/year), that is quite often aggravated with development of mass-wasting processes and negative anthropogenic influence. Basically, these are the coasts composed by friable and weak rocks: sands, sand-and-shingle, loamy. Such coasts are poorly steady against wave impact and pressure from economic activities. Under influence of storm waves there are constant, during heavy gales sharply amplifying destructions accompanied by menacing retreat of the sea cliff and destruction of the economy objects located near it, especially during activity of landslips and powerful collapses at wave undermining coast.

EROSION HAZARD OF THE CASPIAN COASTS OF RUSSIA

The Russian coast of the Caspian sea stretches between deltas of Volga and Samur rivers and has the general extent of a coastal line about 1500 km.

Now the morphology and dynamics of the Caspian coastal zone are substantially defined by modern fluctuations of its level. Recent rise of sea level has caused significant activity of coastal erosion on abrupt coastal slopes and wide development of young lagoon coasts – on low sites (Badyukova et al., 1996; Ecology …,1997). It is attracted an attention the big percent (84 %) of the continental coasts, practically not eroded by waves (tab. 1). Mainly, it is low, with wind surges coasts of Kalmykia and Northern Daghestan with flat (0,0002-0,0005) and shallow an underwater slope where the sea waves are completely extinguished. On the such coasts, it is necessary to expect danger not so much from wave erosion, how from the wind-surges phenomena which can provide displacement of a coastal line in this or that side by several tens kilometers. Transgressive changes here were expressed in significant expansion of the zone of surges mad flats for the account their moving on the low alluvial-marine plains (Kravtsova and Lukyanova, 2000). The huge on extent outer edge of Volga delta which accrues even under conditions of modern high standing of sea level (Ecology of…, 1997) is also attributed the same category of coasts. This is promoted by presence before delta of extensive shallowness (slopes 0,0001-0,0002) which reduces the influence of modern sea level rise.

Large marine accreted features of this area – Bryanskaya and Suiutkina spits – were formed due to alongshore sediment transport from the wave eroded coasts located to the south. Feeding erosion sites (with cliff height of 1-3 м) became more active (erosion rate of 3-4 m/year) as a result of modern rise of sea level and are concerned to moderate-dangerous category of erosion hazard. The largest Holocene accreted feature – Agrakhanskaya Spit – has been bordered along sea side by sandy beaches which were transformed during the transgressive period in lagoon coasts with the tendency to displacement towards a land. Only the proximal part of the spit is eroded by waves as a result of engineering transformations in the Sulak valley which have favoured development of deposit deficiency at this site. The cliff height is 4-5 m whith erosion rate of about 10 m/year. The similar situation characterizes the Karamansky coastal segment located to the south, erosion bluffs of which developed in New-Caspian (Holocene) sandy-gravel sediments, are stretched almost up to Makhachkala. Both of these sites concern a dangerous category of wave erosion.

Table 1

Affection of the Russian coast of the Caspian sea by wave erosion (in %)

Category of erosion hazard	The Russian coast of the Caspian Sea
1. Practically safe	84
2. Insignificant dangerous	2
3. Moderate – dangerous	8
4. Dangerous and rather dangerous	6

The coastal territory of the Middle and Southern Daghestan (from Makhachkala up to Samur delta), adjoining the Tertiary foothills of the Big Caucasus, is defined by complexity of the structural-geological plan and neotectonic mobility of territory. The consecutive alternation of mainly eroded capes, caused by outcrops of the Upper Sarmatian limestones, and sites of accumulative filling of bays is characteristic for a coastal zone. Blocking of the coast by limestones steady against wave erosion and forming of the ridges or steps of wave-cut bench which represents itself as natural coastal protection, creates preconditions for rather moderate rates of wave erosion. However, their combination with prompt sea level rise has caused the negative ecological consequences at some sites. Especially heavy position has developed in Derbent City where the inhabited quarters and industrial constructions located on low regressive terraces have got to a zone of storm wave influence.

The dangerous situation has developed also around of. Kaspyisk Town (Lukyanova, 2010). For the first decade of the modern sea transgression, wave erosion rate has been here of 20-25 m/year that has led to the catastrophic destructive consequences. Intensive erosion at this site is provoked also by technogenic intervention in the coastal processes, expressed in construction and further lengthening of the port piers, which have intercepted southern alongshore drift of deposits.

The most southern site of modern coastal erosion is Samursky one. The strip of an accretive land of 300м wide has been washed off here by the end of 1980-s years. The eroded bluff with height of 1м is fixed by the tumbled down wood and bush vegetation of the Samur delta.

CONCLUSION

Thus, analysis of the degree of erosion hazard of the Russian Caspian sea coasts has shown, that in this coastal region only 16% from the general length of its shoreline are subjected to wave erosion. Processes of modern coastal erosion are shown, basically, only in a southern half of the regional coast where the south-east spurs of the Big Caucasus come nearer to the sea, and gradients of a coastal zone accordingly grow. The greatest wave erosion hazard characterizes the separate sites connected to strengthened economic pressure upon a coastal zone. As a whole, among the eroded sites, the sea coasts with a moderate category of erosion hazard prevail in the Russian sector of the Caspian Sea coast.

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COMPARISON OF THE NORTHWEST BLACK SEA COAST (UKRAINE) DYNAMICS AND THE CASPIAN SEA COASTS (RUSSIA) ON THE BASIS OF MULTI-YEAR OBSERVATIONS

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Keywords: costal zone, sea-level change, the Black Sea, the Caspian Sea, abrasion risk

INTRODUCTION

Activation of abrasion processes along the Russian Caspian Sea coasts has been increasing during last decades as a result of sea level rise. Similar processes are characteristic of the Black sea. In this connection it is expedient to touch a problem of the connection of abrasion processes intensity on the Russian coast of the Caspian Sea and the Northwest part of the Black Sea (Ukraine).

The total length of the Northwest Black Sea shoreline (between the Danube delta and Crimean peninsula) is approximately 1000 km, 30% of which are represented by active eroding cliffs, 40% – by retreating accumulative forms amd 30% -with stable shores (fig. 1).

This study focused on the spatial-temporal analysis of the Northwest Black Sea shoreline migration, and also on comparison with the dynamics of the Russian Caspian Sea coasts during last decades.

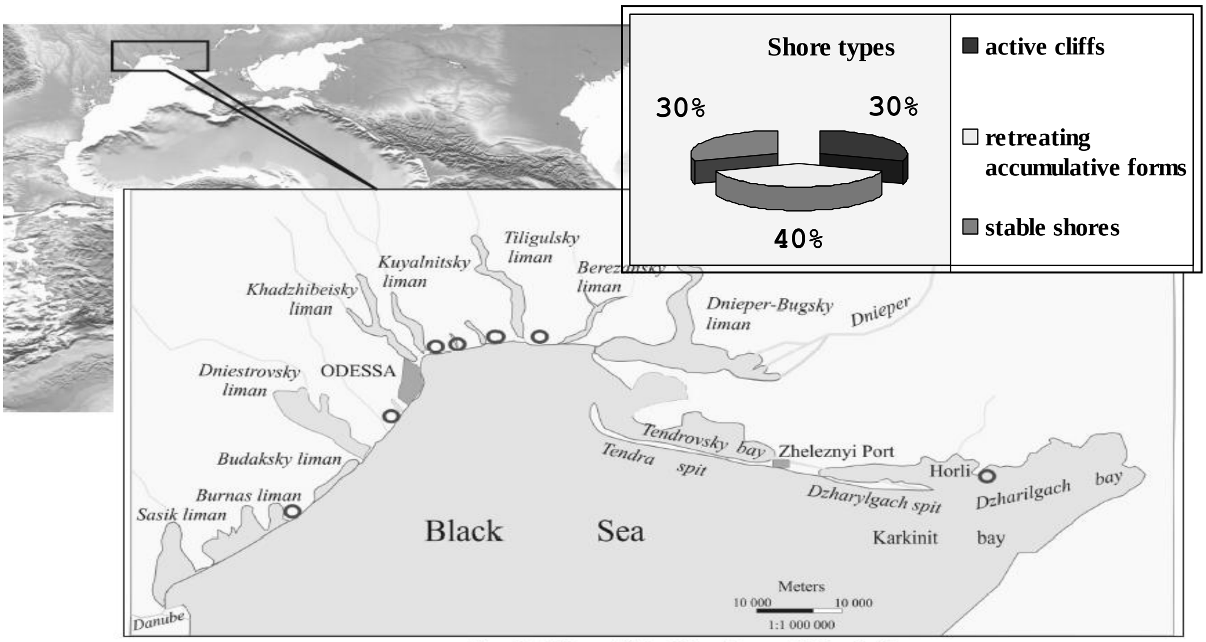

Fig.1. Map of the Northwest Black Sea

O - sites of long-term field observations (1976-2000 years)

MATERIAL AND METHODS

The following research methods and techniques were used: 1) quantitative processing of aerial photographs for last 50 years; 2) the analysis of long-term field observations at a number of sites during 1976-2000 years (data base of the Odessa National University, geological organisation "PrichernomorSRGO", Odessa, Ukraine).

As indicators of abrasion activity were used: linear retreat of edge and slope soles (m); volume of sea-worn breeds (Q_1, m^3 per 1 linear meter a year).

RESULTS

The process of abrasion is controlled by many factors: geological conditions, hydrodynamic factors: wind waves, currents, the sea level. Geological structure is one of the main factors of abrasion development. Within the landslide slopes there are four main kinds of rocks: quaternary loess, Pontic limestones, Maeothian clay and landslide accumulation. They have various durability and deformation properties. Gradual immersion under the sea level of more and more young deposits takes place to the southwest and the northeast (fig. 2).

Relative distribution of coast types in space is not uniform. The accumulative coasts are spread in the southwest. They are representes with typical coastal bars (baymouth barrier). They were generated during eustatic lifting of the sea level during Late Holocene. Their modern development takes place in conditions of sand and shell dificiency. They are retreating accumulative forms. The typical abrasion-landslide coast is located in the north of the investigated territory. The typical abrasion – debriss coasts are located in the east of the inventigated territory. Abrasion coastal ledges represent the raised sites of post-Pontic platau. Their height varies from several to 40 m.

Comparison of aerial photographs and the analysis of long-term field observations on a number of experimental sites allowed us to calculate the exact parameters of shoreline migration rate.

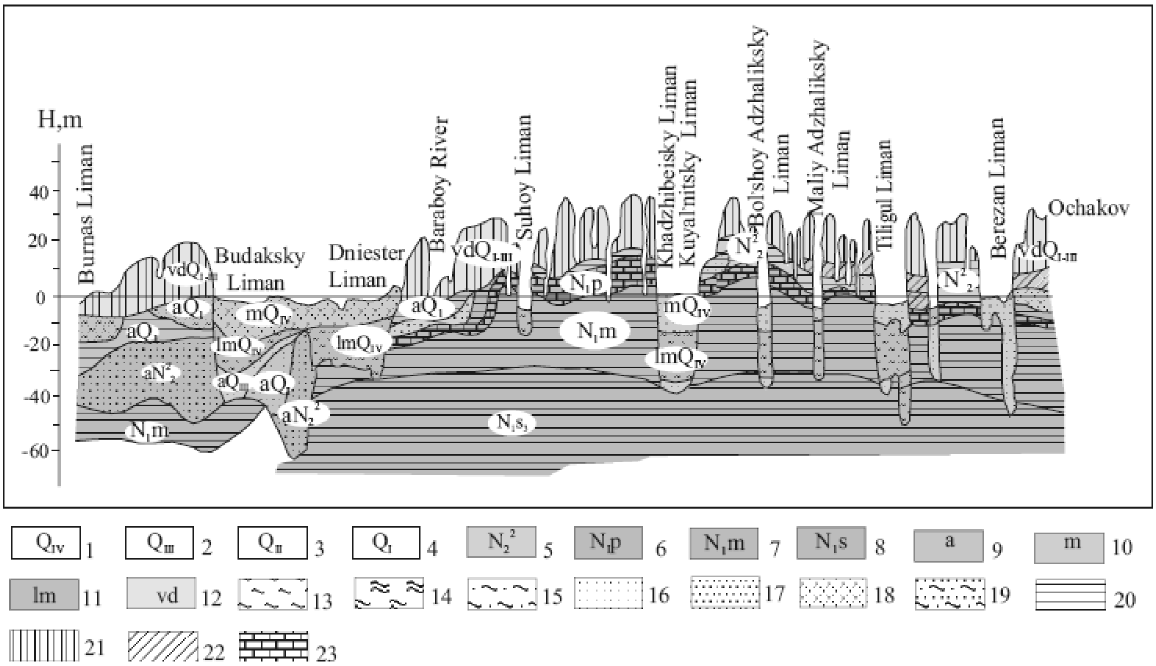

Fig.2. Geological section across the Northwest Black Sea coasts
Stratigraphy: 1 – Holocene, 2-4 – Upper, Middle, and Lower Pleictocene; 5-8 – Upper and Lower Pliocene, respectively: 6 – Pont, 7 – Meotian, 8 – Sarmatian. Genetic types of sediments: 9 – alluvial, 10 – marine, 11 –liman, 12 – colian-deluvial. Litology: 13–15 – loamy, clayey, and sandy silts, 16-17 – fine-grained and coarse-grained sands, 18 – mollusc shalls, 19 – muddy sand, 20 – clay, 21 – loess, 22 – loam, 23 – limestoune.

Clayey cliff between Burnas and Budak Capes, Tendra and Dzarilgach Spits has been retreating at the rate of 0.1 to 3.0 m/y (average multi-year data). Rate of destruction of shelly limestone cliffs between Sanzheisky cape and Tiligul Spit are from 0,1 to 0,5 m/y. Accumulative forms have been retreating at the rate up to 0.5 m/y.

Average rate of cliff retreat on stationary sites is shown on the figure and varies from 0 to 3 m. The volume of seaworn rocks makes 0-38 cubic meters per year (fig. 3).

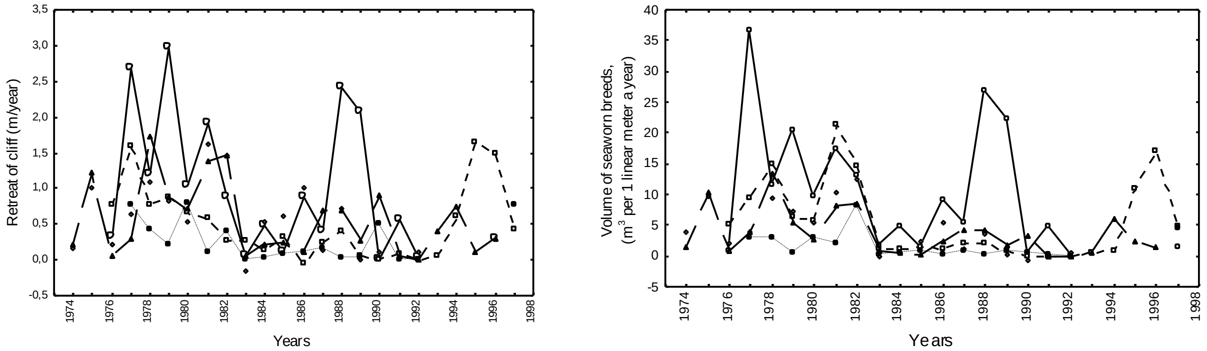

Fig.3. Cliff dynamics in the experimental sites

Thus, in the northwest part of the Black Sea annually hundred thousands cubic metres of valuable coastal territory disappear.

Lukyanova's technique (2009) has been used for calculation of the risk categories of the sea coast abrasion. This indicator has been calculated for a piece of coast of a certain category of abrasion danger from the total length of the coastal line in percent. Abrasion-landslide, abrasion-rockslide coasts and retreating accumulative forms were considered (table 1).

Table 1.

Affection of sea coast of the Caspian sea (within Russia) and the northwesr part of the Black sea with abrasion process of various intensity, %

Sea	Categories of the abrasion risk for sea coasts, m/yr							Total abrasion
	Safe, 0	Inessential			Moderateя, 1-5	Dangerous, 5-10	Very dangerous > 10	
		<0,1	0,1-0,5	0,5-1,0				
Caspian	84	2			8	3	3	16
Black	30	25	31	7	7	-	-	70

Thus, the length of abrasion Russian Caspian coasts is three times less, than the abrasion of Ukrainian Black Sea coasts. But the dangerous and very dangerous categories of the risk are 6%. Such speeds of abrasion are seldom observed on the Black sea coasts – only in certain years.

And the average rate of the Caspian Sea level rise is 12 cm/year (Ignatov 2004). Curve of average annual values of the Black Sea level change by data of hydrometeorologic station "Odessa-Port" during the period of 1870-2000 is well seen in the diagram on Fig. 4. The average rate of the sea level increase was 3 mm/year during the period of 1922-2000.

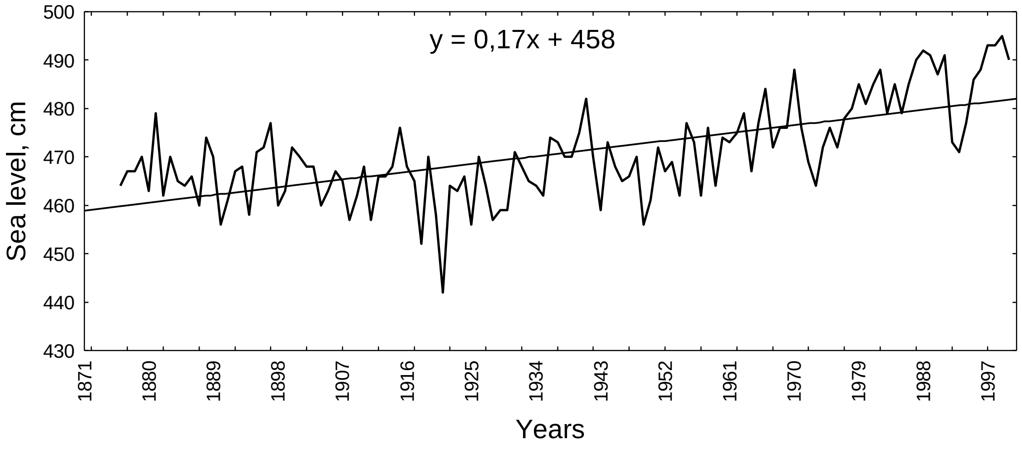

Fig. 4. Curve of average annual values of the sea level during period 1874-2000

CONCLUSIONS

Length of abrasive coasts and retreating accumulative forms of the northwest Black sea (Ukraine) is 70 %, the Caspian Sea – 16 %. Thus higher speeds of abrasion are observed on the Caspian Sea coasts, rise of the sea level being a primary factor. The geological structure, sediment volume, cliff height, amount of wave energy, the sea level are the factors of abrasion development on the Black Sea coasts.

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KARST PROCESSES OF THE MANGYSTAU PENINSULA AND THEIR ZONING

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Keywords: Kazakhstan, Mangystau, karst processes

The increasing pace of industrial, linear-transport, agricultural development of vast Kazakhstan territories generates a need for study and forecast of natural processes and phenomena which under specific conditions may jeopardize man's life and economic activity. One of such processes is karst. This phenomenon has numerous definitions, we hold to this one, given by N.A.Gvozdetsky: "Karst is phenomena, originating in rocks soluble by water and a combination of processes of these phenomena development, where chemical process of solution is the main one resulted in geological process of rock leaching". Karst activity depends on climate, tectonics, solubility of rock, solvent action of surface and underground water, quantity of infiltrating water, determined by composition and thickness of substrate, relief structure.

In Kazakhstan, despite its sharply continental climate and small amount of precipitation, karst phenomena are widespread. Area of karsting rocks constitutes 31,5 % of the total territory. So it is necessary to investigate karst, its dynamics to suggest recommendations aimed at strengthening stability of karsted territories and to forecast ill effects caused by karst in order to manage them.

Karst originates under the influence of a number of factors and closely interacts with other denudation processes, suppressing some of them (erosion, landslide) and intensifying the others (downfall, suffusion, physical weathering), adding them new features. At the same time intensity and effect of karst may be changed under the influence of some exogenic processes.

One of the main factors, determining intensity of karst processes, is generating power of karsting rocks to transmit water. For karst development especially for deep seated one, availability of fractures, porosity and caverns is essential. In this case fractures serve as main water conductive canals. Rocks, made of even such easily soluble minerals as silvinite, halite, carnallite, in the absence of fractures can be karsted only on the surface.

Jointing of salt is the main factor, governing further development of karst processes. Manifestations of karst are diverse: funnel sinks, swallow holes, hollows, caves, tubular springs, karst cavities, stripped by wells and mine workings. Micro- and meso-forms such as corries, cells, niches, karsted cracks, caverns, swallow holes exist independently and superimpose larger karst cavities. Many of them occur on the plateau chinks, slopes of uplifts, walls of large basins. Prevalence of these or those micro- and meso-forms depends on solubility degree of rocks, spatial location (horizontal, inclined, vertical). Studying and mapping of karst processes were carried out using recent data, obtained by remote sensing (Fig.1).

One of the interesting regions with widespread karst processes is the Mangystau Peninsula, investigations there were carried out in 1967-1971 and 2008-2010, the results obtained were taken as a basis for this article [3].

Within the boundaries of the region according to the peculiar features of karst processes development under the influence of natural and anthropogenic factors, extent of danger for men and economic activity on the territory under investigation caused by their progression, was estimated and the findings were taken as a basis for division into districts (Fig.2). Within the given territory only one karst area is specified, that is the Turan Plate, incorporating 3 regions: Mountain Mangystau, Plain Mangystau and Ustirt.

Mountain Mangystau consists of the ridges of Karatau, North and South Aktau, divided by the Prikaratau valleys. The Karatau Ridge top is a plateau with absolute marks up to 400 m, tops of the Aktau Ridges do not exceed 550 m, relative uplifts 220 m. Mountain Mangystau is a meganticline of north-west strike with Permian-Triassic dislocated metamorphosed rocks in the core (sandstones, shale) overlapped by Jurassic, Cretaceous, Paleogene less dislocated rocks on the structure flanks. Carbonate soluble rocks are in the Upper Cretaceous and Eocene deposits. They have a common horizon of fissure-karst water. Flow of springs do not exceed portion of a liter per second. Chalk, marls, limestones predominate in the Upper Cretaceous rocks. Middle Eocene is composed of marls and limestones. In the Cretaceous deposits karst is represented by fractures, benches, niches, caves, rare by swallow holes filled with sand and rock debris. For the Eocene limestones caverns and jointing are typical. In the arid climate conditions in Mountain Mangystau karst processes occur to a lesser degree, they can be referred to as a less dangerous type.

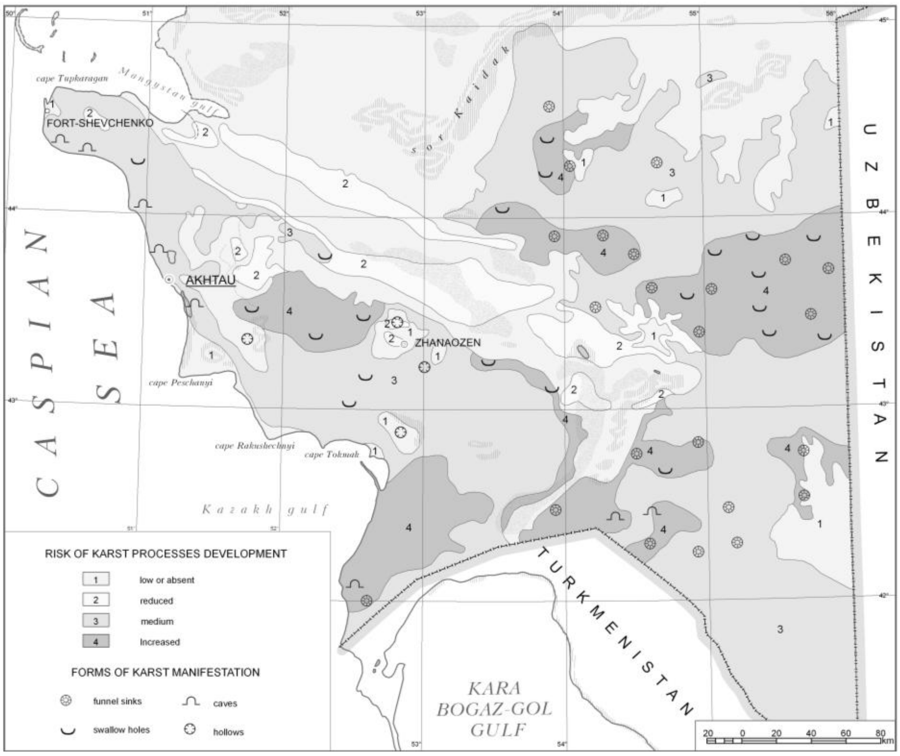

Fig.1. Karst processes of the Mangystau Peninsula.

Plain Mangystau is situated on the eastern shore of the Caspian Sea southwards of Mountain Mangystau, it is a plateau adjacent to the South Mangystau trough with absolute marks becoming less from the north-east to south-west from 270 up to 50 m. The oldest thicknesses are Permian, Triassic and Jurassic deposits and also those of Cretaceous lower division and lower part of upper division. They are composed of non-karsting rocks, patches of limestones are among them, this does not preclude the presence of ancient karst. Section of the overlying Cretaceous, Paleogene and Neogene deposits is characterized by considerable distribution of carbonate rocks, which are the most widespread in the Neogene deposits. In the local outcrops of the Upper Cretaceous and Eocene carbonate rocks there are only separate surface and underground karst forms.

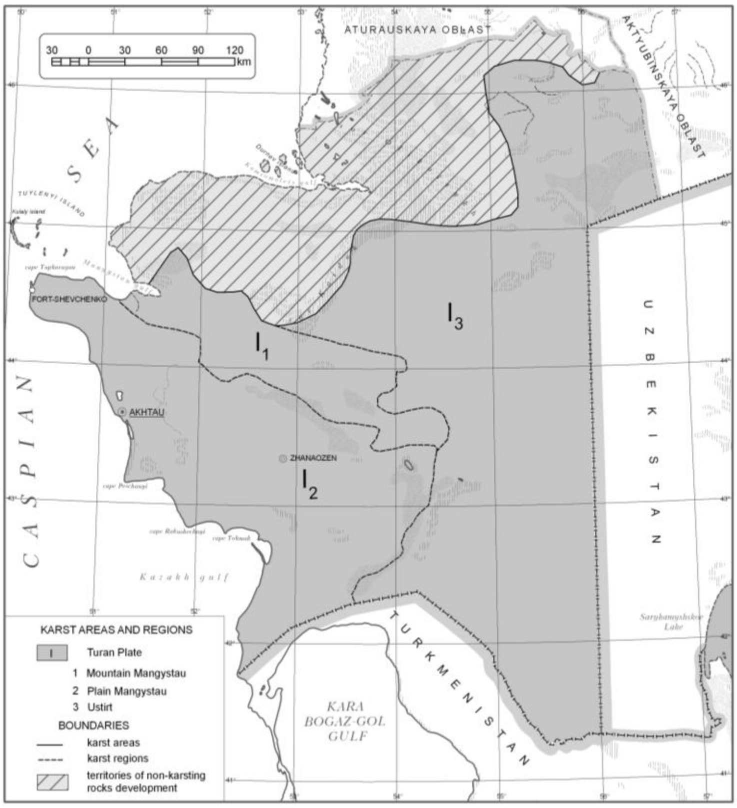

Fig.2. Zoning of karst of the Mangystau Peninsula**.**

Karst phenomena are mainly associated with limestones, shelly limestones, detritus, oolitic limestones and Miocene marls of the Sarmatian, Pontian stages and Lower Pliocene which are highly pure (insoluble matter content 0,5-4 %), rare with gypsums of Tortonian substage of Miocene, most of them are chemically pure (insoluble residue 0,5-2%). Total thickness of the Neogene deposits is 30-150 m. Among karsting rocks carbonate, mainly limestones, to a lesser degree marls, chalk and calcareous sandstones predominate.

On a Major part of Plain Mangystau karsting rocks are overlapped by eluvium thickness ranges from 0,5 up to 3,0 m, subeluvian karst prevails. In the plateau cliff walls, sometimes on the floor of large basins karsting rocks are exposed, denuded (open) karst can be found here. In the coastal part of the plateau, on the surface of limestones there are unconsolidated permeable marine deposits: sands, loams, sandy loams 2-20 m thick, here corrosion-subsidence funnels, swallow holes can be observed. It is an overlapped type of karst. Karst forms in carbonate rocks are rather diverse, micro- and meso-forms (caverns, corries, cells, niches, etc.) can be separate or superimposed on larger karst forms. Frequently occurred karst forms are funnel sinks (corrosion, corrosion-subsidence), swallow holes are widespread, rare karst hollows, which are formed when funnel sinks and swallow holes expand and unite [4].

Karst-deflation hollows are formed when funnel sinks become deeper, clayey deposits crop out on the floor and marked deflation occurs. The largest hollows are from some tens to 400 m deep, their area is 30-500 m^2, they have steep, abrupt walls and a flat floor, its lowest parts are occupied by sors. Such hollows are confined to the arches of local positive structures, their formation was initiated by karst. In subsequent development of these hollows eolian, erosion, suffusion and salt deflation played a leading role [5]. Karst micro- and mezo-forms, caused by limestones leaching, are active at present and expand hollow slopes. Large hollows are indicative of presence of recent local structures (brachy-anticlines) promising for oil and gas search. Rarely on the plateau, especially near the hollows karst-erosional ravines are found. In the plateau flanks numerous karst-abrasion caves and niches were formed, sometimes on the floor of funnel sinks there are karst caves. On the territory of the Sauyr settlement in the Sarmatian limestones there are two small karst lakes evolved from funnel sinks.

Subsurface karst formation shows itself in origination of secondary porosity (35-40%), caverns and tectonic fissuring. Downfall of drilling tools, take up of mud while drilling are indicative of underground cavities. There is little information about subsurface karst of Plain Mangystau. On the larger part of the territory, where carbonate rocks are karsting, karst processes are not well pronounced. Low and moderately hazard types of karst processes predominate here. Apart from carbonate type of karst, in the south and south-east part of the plateau there is sulphate and carbonate-sulphate karst. Sulphate karst is found in the southern part of the Karynzharyk basin in the Miocene gypsums of the Tortonian stage. Around the Shagalasor hollow there are alternating areas of denuded and subeluvial karst: in the south and far south-east of the Karynzharak basin gypsums of the Tortonian stage are covered by eluvium, here sulphate subeluvial karst is widespread. To the east and north-east from the Shagalasor hollow carbonate-sulphate rocks (gypsums and limestones) can be found, for the most part covered by eluvium. In the southern part of the Karynzharyk basin there are gypsums, overlapped by Quaternary eolian sands (mantled type of karst). Here corrosion-subsidence, rare corrosion-suffosion funnel sinks are widespread. Karst forms in sulphate and carbonate-sulphate rocks are characterized by "fresh" subsidence funnel sinks, rare subsidence-collapse shallow karst channels (40-50 m), which due to ready solubility of gypsum quickly turn to funnel sinks. Active dolines, aggravating funnel sinks are widespread; caves in gypsum karst are not numerous, corries are rare. In the southern part of the Karynzharyk basin and especially around the Shagal hollow an area of dangerous type of karst has been specified.

Ustirt is a structural armoured plateau with absolute marks 350 m in the south-east and 40 m in south-west, confined to the South-Ustirt trough. The most submerged part is the Assake-Audan basin with steep northern and inclined southern flanks. Except for its south-eastern part the plateau is bounded by steep abrupt chinks 15-300 m high.

Karst phenomena are related to the Neogene deposits, occurring on the Paleogene clayey rocks. Lower Sarmatian deposits are widespread on Ustirt, where shelly and oolite, highly porous and cavernous limestones predominate. Middle Sarmatian limestones take up less territory and the Upper Sarmatian ones can be found on small areas in the south-western part of Ustirt. Total thickness of the Sarmatian limestones amounts to 30-100 m. In the western part of North Ustirt vast areas are occupied by Pontian limestones (shelly and oolite limestones with interlayers of marls and clays, thickness is 8-15 m. Pontian deposits are preserved as remnants remained unwashed. The Neogene karsted deposits are mantled by eluvium, made of loams and sandy loams with debris partially of gypsum, 2-6 m thick that is subeluvial karst. In the southern part of Ustirt in Assake-Audan basin in a section of Neogen deposits gypsums are present. The most intensive karst formation can be seen here. Rate of modern karst denudation in Ustirt is 0,8 m/year km^2 (A.G.Chikishev, 1971). On the Ustirt plateau there are diverse karst forms: funnel sinks, swallow holes, dolines, corries, karst holes, caves, hollows, valley-like depressions, karst-erosion ravins. The largest karst forms generated during Lower Pliocene. Many recent karst holes on the plateau surface appeared due to collapse of cavities being formed before. Numerous caves are opened by karst holes. Source-like swallow holes, inclined basins with flat floor, sink holes, deepening at present, different microforms of karst are referred to modern forms. Open dolines are formed in gypsums, underground cavities, stripped by subsidence funnel sinks at a depth of 5-60 m are observed. To the south-east from the Karynzharyk basin degree of karst processes manifestation is increasing, on the rest of the territory it is moderate. Dangerous type of karst processes is specified in the southern part of Ustirt in the Assake-Audan basin, where sulphate (gypsum) karst is widespread together with carbonate one. On the rest of the territory moderately dangerous type of karst processes prevails. So studying of karst processes, growing stronger and becoming more dangerous within the boundaries of the intensely developing regions of the Mangystau Peninsula suggested that their modern and forecasted state should be taken into account in any way of nature use.

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SESSION III.

EVOLUTION
OF THE CASPIAN RIVERS DELTAS

GRAIN-SIZE PARAMETERS OF RECENT SEDIMENTS IN THE VOLGA RIVER DELTA AND NORTHERN CASPIAN SEA

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Keywords: sediment, grain-size compositions characteristics, mechanical differentiation

INTRODUCTION

Grain-size (wet sieving) analysis is an important tool in the cognition of sedimentary processes in seas and oceans. In the Northern Caspian Sea sediments were sampled in the Volga River delta at depths shallower than 6 m in areas 4 and 5 between Chistoi Banki Island and the Volga–Caspian channel and in area 6 west of Malyi Zhemchuzhnyi Island approximately 130 km away from the Volga delta (Fig. 1).

RESULTS AND DISCUSSION

After processing of the primary materials the following grain-size parameters were accepted to characterize the bottom sediments [Sval'nov V.N., 2005]: the percentage of fractions <1 mm after converting their sum to 100%; the median (*Md*); the sorting coefficient (S_0); the shape of the histograms, cyclograms, triangle diagrams, cumulative curves CC, and the empirical distribution fields (EDF) compiled in the coordinates of the decimal logarithms of the fraction boundary sizes versus the fraction percentage. The coefficients of the pelitic material differentiation *Kd* (the ratio between the subcolloidal particles and the coarse pelite) and Kd_1 (the ratio between the subcolloidal particles and the medium pelite) [Sval'nov V.N., 2006] were also calculated. By their compositional–genetic properties the recent sediments in areas 4–6 and in the Volga River delta are represented by terrigenous sands, aleurites, clays and coquina changeable safely [Alekseeva T. N., 2006].

Sediments of the Volga River delta (Table) are characterized by the average prevalence of aleurite–pelitic particles (Fig. 2, sample 3). The empirical distribution fields demonstrate maximums in the aleurite area, while the content of pelitic particles gradually increases toward the colloidal fraction. The cumulative curve indicates the prevalence of coarse aleurite and a gradual increase in the proportions of the clayey particles with decrease in their size. The triangle diagram of the sum fractions reflects the grain-size heterogeneity of the sediments from sample 3, while the proportions of the pelitic fractions in them show insignificant changes (colloidal material always dominates).

The median ranges from 6.7 to 327.6μm averaging 146.1μm. On the average the sorting of the sediments from the Volga River delta is poor (S_0=3.8 varying from 1.5 to 6.7). The average *Kd* and Kd_1 values are 3.7 and 1.8 respectively.

The sediments of areas 4 and 5 (sample 1) are largely dominated by sandy–alevritic material. The empirical distribution field demonstrates a maximum in the area of the fine-grained sand; in the area of the pelitic fractions there is gradual increase in the contents in the succession from the coarse pelite to the subcolloidal fraction. In its shape the cumulative curve is similar to that of sample 3, differing from the latter by the greater steepness due to the elevated concentration of coarse aleurite.

The sorting of the sediments from sample 1 is usuall good (S_0 = 2.0). The average median is 227.6µm.The *Kd* and Kd_1 values amount to 16.0 and 2.6 respectively. The triangle diagram of the sum fractions shows a changeable grain-size composition of the sediments with relatively stable proportions of different-size pelitic particles. The subcolloidal fraction usually prevails among pelitic material.

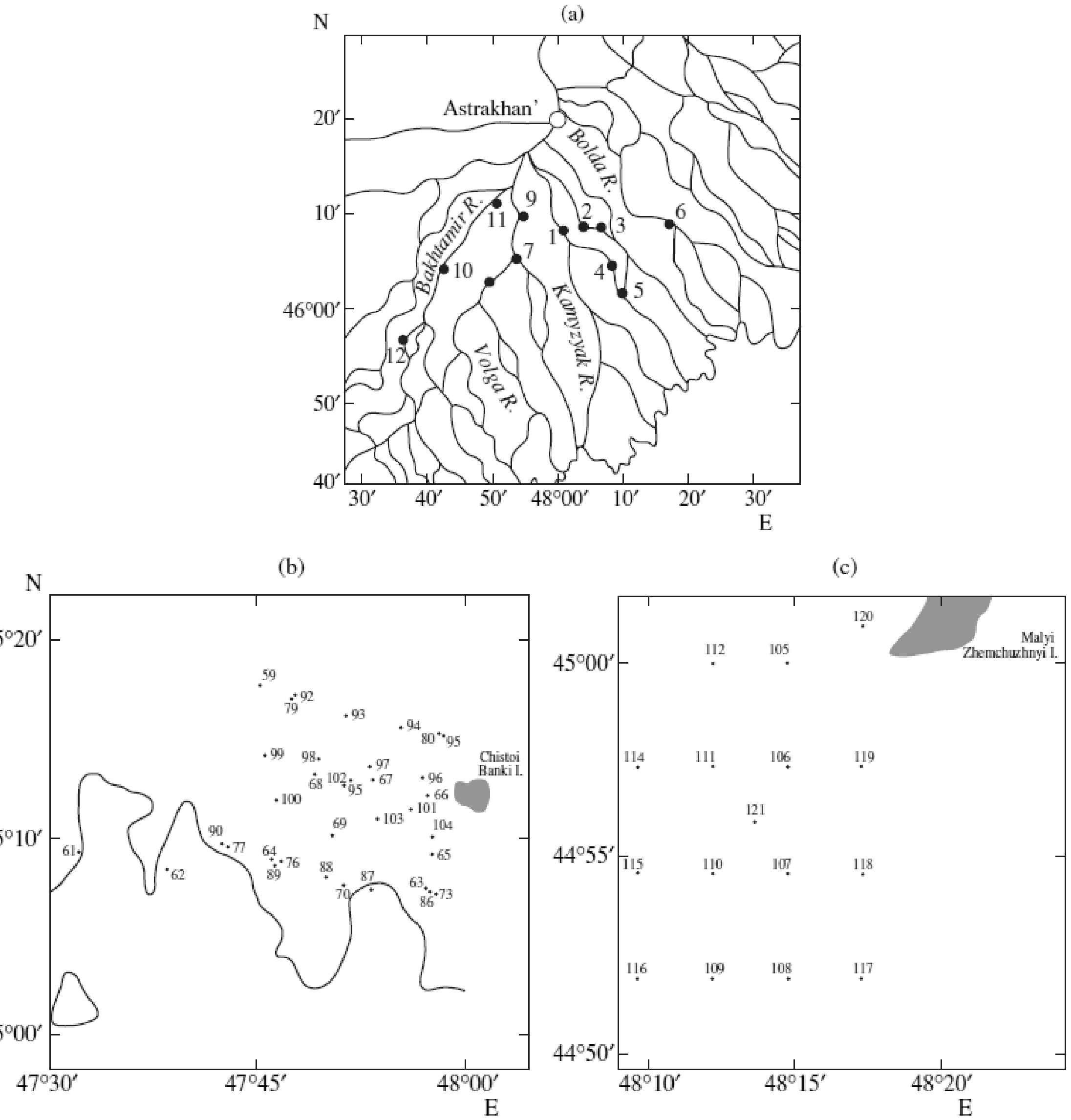

Fig. 1. Location of stations in the Northern Caspian Sea and Volga River delta: (a) Volga River delta; (b) areas 4 and 5; (c) area 6.

The sediments of area 6 (sample 2) are the coarsest in their grain-size composition. The empirical distribution field exhibits a maximum in the area of the fine-grained sand, while the concentrations of the pelitic fractions gradually increase toward the subcolloidal fraction. The cumulative curve points to the prevalence of coarse aleurite and to the gradual increase in the contents through the succession of the coarse pelitic fraction to the subcolloidal fraction. The triangle diagram of the sum fractions shows a relatively uniform grain-size composition of sediments samples 2 with stable proportions of the pelitic particles (the subcolloidal fraction persistently prevails).

The average median value is as high as 425.4µm. The sediment sorting is mainly good (S_0 = 2.1). The average *Kd* and Kd_1 values are 32.5 and 3.9 respectively.

Table

Average grain-size characteristics of recent sediments in the Northern Caspian Sea and Volga River delta

Number of samples	Content of fractions, %											Md	S_o	K_d	K_{d1}
	fraction, mm								Sand	Silt	Aleurite				
	1-0,5	0,5- 0,25	0,25-0,1	0,1-0,05	0,05-0,01	0,01-0,005	0,005-0,001	<0,001							
Volga River delta															
14	0.46	2.10	26.23	32.20	5.76	5.21	9.84	18.19	28.79	37.96	33.25	146.08	3.8	3.7	1.8
areas 4 and 5															
42	0.74	1.96	45.63	35.61	1.77	2.08	4.08	8.62	48.33	37.38	14.73	227.55	2.0	16.0	2.6
area 6															
15	9.85	20.20	47.67	13.05	0.38	0.71	2.81	5.33	77.71	13.43	8.85	425.40	2.1	32.5	3,9

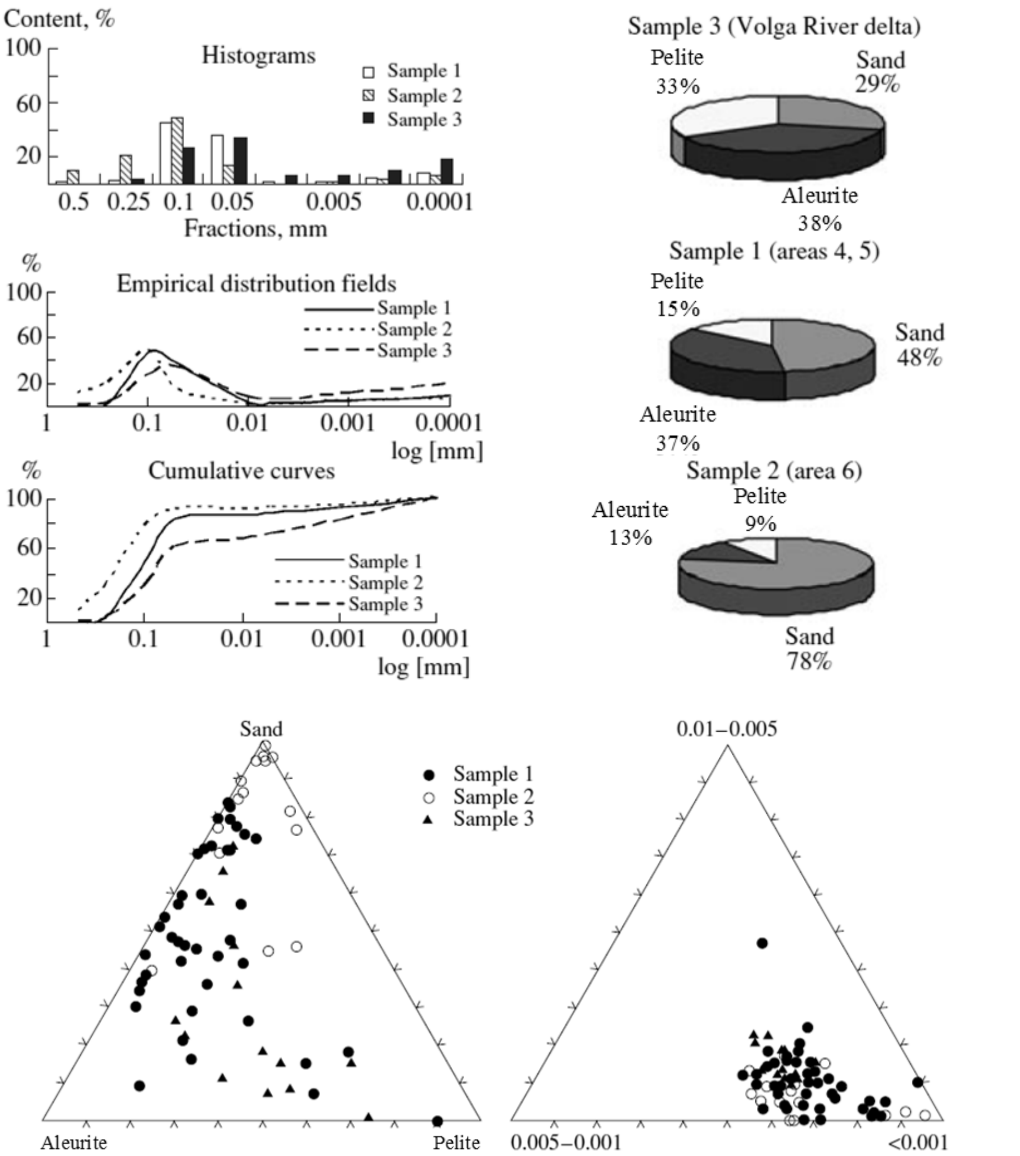

Fig. 2. Grain-size parameters of the sediments in the northern Caspian Sea and Volga River delta.

CONCLUSIONS

Thus, the shallow Northern Caspian Sea demonstrates an incomplete cycle of mechanical differentiation of the material (inversion of the grain-size composition) along the profile from the Volga River delta seaward for 130 km. While the contents of sand, aleurite, and pelite in the sediments of the Volga River delta are relatively similar (29–38%), the proportions of the sandy fractions become gradually dominant in areas 4, 5, and the southern (area 6). The median size of the particles increases, their sorting becomes better, the Kd and Kd_1 values increase in the same direction. All these features suggest a regular removal of aleuritic and pelitic material from the study area, where the grain-size differentiation of the material is only partial.

The observed inversion in the grain-size composition of the sediments examined (the increase in the share of the sandy fractions away from the shore) is probably explained by the fact that the fractionation of the sedimentary material in the Volga River delta is far from being accomplished because of the high terrigenous material influx that exceeds the energy potential of the river. Seaward (areas 4–6) relatively better sorting of the sediments is provided by additional factors: bottom currents and storms. The mechanical differentiation of the terrigenous material begins precisely in these areas, but a gradual decrease in the contents of both the sandy and aleuritic material should be expected farther southward. This is indirectly proved by the steady growth of the subcolloidal fraction share among the pelitic particles away from the shore: the average Kd value increases from 3.7 to 32.5.

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RESEARCH AND MAPPING AT VOLGA DELTA REGION BASED ON REMOTE SENSING ANG GIS-METHODS

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Keywords: remote sensing, mapping, the Volga delta, ecosystems changes

INTRODUCTION

Researches on application of remote sensing and GIS-methods for studying of natural complexes of Volga delta are conducted beginning with 1993: firstly, in cooperation with Dutch scientists (NWO – Dutch Organization for Scientific Research, ITC –International Institute for Geo-Information Science and Earth Observation), later as a part of different International and Russian projects, sponsored by UNDP/GEF (United Nations Development Program/Global Environment Facility), Caspian Environmental Program, Russian Foundation for Basic Research, and also as unsolicited projects. All the researches are implemented in close cooperation with Astrakhanskiy Biosphere Reserve and departments of Faculty of Geography of Moscow State University.

Due the fact that the Volga delta is subject to substantial fluctuations in the water level of the Caspian Sea, these researches are mainly focused on revealing and studies of changes, and elaboration of remote sensing and mapping techniques for that purpose. Investigations were implemented and proceed now at two levels of spatial coverage and detail: local and subregional. Damchik site of the Astrakhanskiy reserve represents the local level, and subregional one covers all Russian part of Volga delta, including western Ilmenno-Bugroviy area. Some of the most prominent projects of recent time are represented here.

MAPPING OF THE ASTRAKHANSKIY RESERVE ECOSYSTEMS

The starting point of this research was the development of a geographic information system for Damchik site of the Astrakhanskiy reserve as an advanced form of a regional complex atlas, which not only included digital thematic maps, aerial, and satellite images of the area, but also provided facilities for the integrated analysis of data and representation of results [Kasimov et al 1995]. The maps of the area which were compiled basing upon aerial photographs, satellite images and field observation accumulated by the Astrakhanskiy reserve staff, fixed the status of natural complexes at definite moments. Later on this data has formed a basis for mapping of changes in vegetation cover as response to fluctuations of Caspian Sea level.

In particular it has been revealed that during 1951-81 in a response to prevalent conditions of sea level dropping and subsequent lowering of underground water level, there was a change of specific structure of meadow vegetation: monodominant marshy reed meadows at vast areas were changed by reed meadows with domination of grass and forbs along with reed. There was extensive growth of reed and reed-mace swamp thickets in shallow bays at an edge of surface delta and in intra island lakes.

The Sea level rise, begun from 1978, and increasing of Volga River discharge during floods caused the rising of underground water level which in turn entailed the return change of forbs-reed meadows by wet swampy reed meadows. The increase in depths on near mouth seashore did not prevent the process of new marshy reed thickets formation along delta edge. Also some human induced changes appeared, i.e. due to shutdown of diked area cultivation halophytic herb and shrub associations formed.

Influence of rising sea level became more appreciable in 1996–2000. First of all it was expressed in transformation of reed meadows to swampy reed thicket at the lowest sites of islands, and offshore – thinning of dense reed thickets has begun in some places. It should be mentioned that during all the period of the sea level rise a process of new islets and pits formation at near mouth sites suspended, so as a result the gain of forests vegetation area has stopped.

Last years on the basis of satellite images and field works a map series for Damchik site water area was created. The map series includes: map of bottom topography, degree of flowage, types of bottom sediments, water vegetation and aquatic landscapes for 2000-02. All the maps, except a map of vegetation were created for the first time. They represent distribution of water ecosystems at the site, relationship between their components. This way the relationship between vegetation and bottom sediments was established. It is necessary to notice that avandelta as a whole it is laid up by sands, spatial distinctions in type of sediments can be observed only in the top layer with thick of about 20-25 centimeters. Silty sediments always form at sites where lotus grows, because this plant produces large biomass. On the contrary communities of *vallisneria spiralis* are confined to sites with running water and sandy types of bottom sediments. Granulometric structure of sediments depends on flowage degree, that is the less is the flowage, the more silt is in sediments, so at sites with low flowage silty sediments are generated even in case of vegetation absence. One more conclusion is that at small depths (no more 1,6 m in low water period) and prevailing flatness of the delta surface the bottom relief practically does not make an impact on formation of aquatic complexes.

LOTUS (*NELUMBO NUCIFERA*) DISTRIBUTION IN THE VOLGA DELTA

The special attention has been given to mapping of features of spatial distribution of a lotus, registered in the Red book of Russia. In particular, the applicability of satellite imagery for quantitative determination of lotus area, which is concerned as ecological indicator of the Ramsar wetland territory state and conditions, was assessed. Two image processing methods for lotus area revealing were compared: the first is a supervised classification of images and the second is a map compilation basing on on-screen interpretation of images and products of theirs processing. Both of them show close results, but the first gives an advantage for quick counting of lotus area at a definite moment, fixed by an image, but the second is more useful on studies of changes in peculiarities of lotus distribution over the territory.

Research and mapping of lotus distribution for a long period for both Damchik site with its buffer zone and marine edge of the Volga delta as a whole was implemented basin upon satellite images for the period of 1977 – 2009, which were acquired by KFA-1000/Resource-“F”, the MSU-E/Resource -“O”, MSS, TM and ETM+/Landsat, HRV/SPOT 4, ASTER/Terra, LISS/IRS. These researches revealed a trend at the Damchik site of some old lotus spots destruction together with formation of new ones and enlargement of existing lotus stands. Comparative computer analysis of several TM/Landsat-5 images for Damchik site allowed to disclose significant fluctuations in lotus stands area and coverage both during a season, and from year to year.

Mapping of lotus spreading at the whole marine fringe of the Volga delta for 1987 and 2009 allowed to reveal a long term trends: it was established that total area of lotus communities increased by 17.8 thousand ha. At the same time along with increasing of total area a destruction of lotus stands at an area of 10.7 thousand ha took place. Appearance of new lotus spots and enlargement of existing ones are inclined to northern part of the region but destruction of lotus stands takes place mainly at a southern part of it. Results of these researches have shown possibility of monitoring of lotus stands distribution basing on remote sensing data. This monitoring system includes three levels of coverage for space and time and defines preferred satellite imagery for each level (Labutina, Baldina, 2009).

THE DYNAMICS OF A MARINE EDGE OF VOLGA DELTA

Studying of changes in marine edge of Volga delta from the middle of XIX century up to the present is based on use of archival maps and satellite images. Topographic maps of the delta which were made in 1868, 1914 and 1927 years fixed the position of marine edge of the delta in the end of the long period of the Caspian sea level stabilization. Satellite images of 1975-81, 1989-91, 1998-2000 and 2007-09 have allowed to observe changes in state of the marine edge of Volga delta at the end of the sea level dropping period up to-29,0 m, and then during the period of its rising up to-26,6 m and at the beginning of the sea level relative stabilization period.

These researches allow concluding the following.

Forming of the Volga delta nowadays goes due to two main factors: sedimentation activity of delta streams and accumulation of biomass and silt due to intensive reed growing at shallow bays. Intensity of these factors action varies depending on the sea level fluctuations. During the period of stable sea level position both these factors act equally, that is, spits and island are forming in mouths of active and large streams, but at the shallow waters of marine edge thickets of reed grow up. Dropping of the sea level causes both these processes stirring up together with active overgrowing of new formed shoals with reed and formation of mud flat islands. During the period of the sea level rising the forming and growth of accumulative objects doesn’t occur, and overgrowing of vegetation becomes a predominant factor of the delta forming. There is a different rate of the Volga delta response to the changes in the sea level: the sea level dropping causes very quick protruding of delta fringe, but on the sea level raising a tendency to smoothing of outward contour becomes apparent only after some years.

LAND USE CHANGE AT VOLGA DELTA

The Volga’s delta region land use system has undergone significant changes in last decades. Fast transition of economy to market system has made unprofitable irrigated agriculture, based on engineering constructions implemented in 1960-s: irrigation systems were abandoned and partly destroyed. It has caused considerable consequences, as after irrigation suspension the most part of the arable lands protected from high waters by embankment (leveed lands), appeared to be subjected to degradation processes (shrub invasion, desertification and salting of soil).

Satellite images of TM/Landsat-5 of 1986-89 and 2006-2007 were used for land use mapping at the Volga delta. Research revealed that main changes are connected with considerable decreasing of arable lands from 120 thousand ha in 1989 to about 40 thousand ha in 2006 and corresponding increasing of degrading land area. Studies of land use changes are in progress with emphasis to use images acquired in spring, which show territories covered by flooding.

AEROSPACE IMAGE-BASE FOR THE DELTA VOLGA'S REGION

Projects on studies of the Volga delta changes are still in progress. Total amount of images suitable for territory mapping and changes detection steadily increases. We began to organize the territorially-focused image-base for Volga delta, as a uniform ordered storage of images, suitable for collective researches by Faculty of Geography scientists. Set of images characteristics (ex. satellite, sensor, spatial resolution and coverage, spectral resolution, polarization, date – time, image's code, coordinate system, geographical reference, file's name, data's format, radiometric resolution, storage data, quicklook) serve as main fields in an images-catalog that facilitates searching of image according to its parameters. Image-base should help in solving maximum number of the Volga's delta monitoring problems, that's why it includes images with spatial resolution varying from 2,5 m (QuickBird) which provide the highest level of spatial detail, to 250-

260 m of MODIS or MERIS, providing the greatest time detail. On complex studying of the territory remotely sensed data of different spectral ranges have special value. Besides multitemporal images, i.e. aero photographs as old as 1951, 1981, 1989, and images of current year, showing a present situation – give possibility to judge both about seasonal, and about long-term changes of natural complexes.

Nowadays there are many different possibilities to get satellite images via Internet for free, that's why the database is permanently renovated.

CONCLUSION

These investigations have allowed to formulate a set of the points, concerning methodical aspects of research and mapping of Volga delta on the basis of remote sensing materials.

1. This study is a further development of multiplicity principle offered by Yu. Knizhnikov (Knizhnikov, 1997), concerning the application of multitemporal images. High seasonal and long-term variability of the territory induces to use significant amount of images displaying its state for detection study and mapping of changes.

Two basic conditions can provide the reliable data about changes of studied territory by satellite images. First of all, the state of the delta systems, especially at the marine fringe, changes significantly during the whole vegetation period. Differences in vegetation aspect and area throughout a growing season make it necessary to use images fixing the same seasonal aspect of vegetation that is the most suitable for studied item, at revealing of long-term changes. For example, changes in position of the delta front can be revealed only at images acquired in early spring, when there is no floating vegetation. On the contrary, study of lotus spreading demand use of late summer images, showing the maximal area of this species for a year. Secondly, ecosystems in delta are very much changeable and vary considerably in appearance and borders from year to year, so for reliable revealing of long-term dynamics it is necessary to fix a typical condition of territory in each of considered periods. Use of images for 2-3 adjacent years allows to avoid nontypical situation in these studies.

2. Reliable results on studying of a territory state and its dynamics from satellite images are possible only with a support of detailed studies of typical key sites in the field and/or from images with the high spatial resolution with the subsequent extrapolation of data over the vast territory using images with relatively low spatial resolution. In this case we are also guided by multiplicity principle, but with respect to images with different spatial resolution, i.e. images with high spatial resolution are need for attachment of field observation and for correct transition to study the same territory but at the higher scope level.

3. It is important to notice that at geographical studying of such extended and dynamic object as Volga delta, high spatial coverage and single-stage snapshot of all the territory at chosen moment of time is more preferable than high spatial resolution and details of images with small part of the territory. Our longstanding researches have shown that at studying processes occurring at the scale of the entire delta, Landsat images use is the most effective, especially taking into account that nowadays Landsat archive images from 1975 placed in free Internet access. All this doesn't cancel high importance of high-resolution images on studies of key sites and field woks.

4. Concerning the techniques applied on changes detection and studies it is necessary to emphasize two main approaches: first is direct comparison of multidate images by computer techniques of image processing, and the second is the compilation of maps for definite dates with their subsequent comparison and the analysis. The first one is more effective on studying definite objects using images, acquired by the same sensor. The second approach is more multi-purpose, as it allows to use different sources: aero photographs, images with different spatial resolution, maps. Experience shows that combination of geoinformation methods of image processing and visual interpretation is the most expedient. Of special importance is the maps compilation process based on images and results of their processing where the important role belongs to generalisation.

5. Longstanding research and mapping of the Volga delta based on multitemporal images of different spatial resolution with a support of field observation have made this territory good key site for testing of image processing techniques and studying of objects using images in thermal or radio bands, which are not so widely used now as images in visible and near infrared bands.

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THE ESTIMATION OF THE VOLGA DELTA BIOTIC COMPLEX VARIATION IN THE RESULT OF CLIMATE CHANGE

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Leading climatologists' researches of surface air temperature long-term changes demonstrates that there is a certain sufficient tendency to its gradual increase traced during 400 years [1].

Many researches (M.I.Budyko, E.P.Borisenkov) consider that modern land surface warming is anthropogenic and they connect it with the increase of greenhouse gases content in the atmosphere. Modern warming arises due to winter air temperature growth. It says for anthropogenic warming as greenhouse effect usually affects at night.

Under the forecast of leading world climatologists, observed warming, that is noticeably shown in winter months, will be prolonged with the same speed up to 2040-2045. Climate condition researches in last decades allow to approve that global anthropogenic warming is accelerated.

In the Astrakhan region significant positive air temperature and precipitation deviations from long-term values are connected with abnormal development of the western form of atmospheric circulation at which in last 30 years humid and warm Atlantic air masses influence the Lower Volga weather. For the observation period, from 1922 to 2006, there was an appreciable increasing in annual precipitation across Astrakhan from 180 mm (1946-1955) up to 230 mm (1983-1992) and 250 mm (1997-2006), that is more than climatic norm on 47 mm [2].

For the last 30 years the average annual temperature has increased for 0,6ºC. This growth has basically occurred due to winter temperatures (tab. 1).

Precipitation increase has affected the Volga river water content. In the result of analysis of the Volga river flow long-term fluctuations it is fixed that from the mid – 70th virtually in all discharge sites the unidirectional and significant changes in annual distribution of river flow that were not marked earlier are observed. It is connected with the water content increase in low flow periods, decrease in spring tide flow and increase in the annual flow of the Volga basin and its basic tributaries. For the period 1978-2006, the increase in low flow reaches 20–40% from the norm.

Average long-term flow of the Volga is 250-300 km^3. For the instrumental observation period from 1881 its maximum value has reached 390 km^3 (1926), and its minimum value – 161 km^3 (1937). For nominally natural period (1946-1959) the river flow volume averaged 260 km^3 for a year. During the first period of the regulated flow (1960-1973) it has decreased up to 228 km^3, and during the following period (1974-1987) the annual flow has increased and its volume in the second quarter has still greater decreased. Since 1990th (1988-2007), the volume of river flow has increased up to 265 km^3. The increased flow of the Volga has caused the rise of the Caspian Sea level by more than 2 m (table 2).

The rise height of high water after the flow regulation has sharply decreased, but during the last periods, it has considerably increased – up to 333 cm (1988-2007) on the tide pole of the Astrakhan flood measuring post.

Climate change and water flow increasing has led to dynamic changes of biocenosis in the Volga delta and first of all to dynamics of the soil-vegetative cover.

Data about the results of monitoring carrying out in the Volga delta on the steady profile since 1979 are given below. Last years data of these researches are published in the following works [3, 4, 5, 6, 7].

Table 1

Climatic indexes according to the Astrakhan hydrometeorological station data

Years	Average sum of precipitation for the period with t > 10ºC, mm	Average sum of temperatures for the period with t > 10ºC, mm	G.T.Selyaninov hydrometeo-rological index	Average annual sum of precipi-tation, mm	Average an-nual tempera-ture
1946-1955	89,5	3626	0,25	179	9,5
1956-1972	99,5	3584	0,28	189	9,7
1973-1982	118,6	3606	0,33	208	9,9
1983-1992	143,9	3736	0,39	235	10,2
1993-2006	155,3	3698	0,42	250	10,5

Comparison of ionic structure of water extracts from soil samples for the observable period has shown, that from the beginning of observations in 1979 and after 1981 there was a sharp reduction of the maintenance of water-soluble salts by 30 %, especially Cl and Na toxic ions. Since 1990^{th} until today, the total number of salts fluctuated in the rather narrow limits. First of all it is caused by the volume of spring-and-summer high water (table 3).

As a whole by the results of analyses from 1979 to 2006 on 126 soil samples the attitude Cl/SO4 has decreased in 2 times, from 0,6 up to 0,3. If to go by the total effect of toxic ions in chlorine-ion equivalents average toxicity of the soil solution on a profile from 1979 to 2006 2 times decreased, especially this process is expressed on platforms presented on low-level meadows (1,2 m and below above low-water) and high-level meadows (2,5 and more) in 2,4 times.

Table 2

The Volga river hydrological conditions characteristic

Years	Flow volume in the site of the Volgograd hydroelectric power station, km3 per year	Flow volume in the site of the Volgograd hydroelectric power station, km3 per the 2nd quarter	Spring tide part, %	Maximum water level on the tide pole of the Astrakhan flood measuring post, (cm)
1946–1959	260	141	54	240
1960–1973	228	102	45	251
1974–1987	248	96	39	252
1988–2007	265	116	44	333

On the low-level meadows the total number of salts decreased constantly from 1979 to 2002, and then in 2006 there was a small increase, which is connected with the fact that the high water in 2006 was much less in comparison with the last years (76 km^3). In this connection, many areas of low-level meadows have been flooded for the short period and toxic salts have not been washed up. Toxicity of the soil solution has increased in 2 times in comparison with 2002, but in comparison with the beginning of observations it has decreased in 2,5 times.

On the middle-level meadows in height interval (1,3-1,8 m and 1,9-2,4 m) the total number of salts fluctuated, raising and decreasing, but thus both relation of Cl/SO_4 and toxicity of the soil solution were 1,4 times less in comparison with the beginning of observations.

At 2,5 m height and more (high-level meadows) the maintenance of salts fluctuated, but in 2006 it reached the least values, as well as relation of Cl/SO_4, toxicity of a soil solution has remained at a former level.

On the low-level meadows, the reduction of total number of salts can be attributed to washing effect of spring-and-summer high water. It is possible to explain the reduction of salts on the high-level meadows by precipitation amount increasing which are fixed recently (2006 – for the period of meadow grass growing the amount of precipitation has exceeded the norm in 10 times).

Table 3

The maintenance of water-soluble salts ions in a 0-15 cm soil layer in various intervals of profile heights above low-water, mg-equivalent on 100 g of soil (126 points)

Years	HCO^{-}_{3}	Cl^{-}	SO^{2-}_{4}	Ca^{2+}	Mg^{2+}	Na^{+}	T	Sum
1979	0,20	4,82	7,49	4,75	3,35	4,41	5,41	25,02
1980	0.22	5.06	7.36	5.13	3.07	4.44	5,55	25,28
1981	0.26	3.60	5.51	3.46	3.14	2.77	4,06	18,74
1990	0.29	1.38	6.75	3.31	2.85	2.26	2,13	16,84
1991	0.32	1.27	6.26	3.45	2.26	2.14	1,90	15,70
1995	0.16	1.46	4.85	3.16	1.95	1.36	1,83	12,94
1996	0.15	0.70	7.10	4.80	2.50	0.65	1,19	15,90
2002	0.39	0.61	4.04	2.41	0.96	1.67	1,01	10,08
2006	0,37	1,58	6,78	3,88	2,28	2,57	2,23	17,46
1.3-1.8 m –54 platforms								
1979	0.26	8.53	14.20	7.30	7.02	8.68	9,96	46.00
1980	0.31	7.90	13.88	7.12	6.43	8.54	9,31	44.18
1981	0.32	6.00	11.84	5.94	6.08	6.14	7,24	36.32
1990	0.35	2.55	11.70	5.29	4.70	4.61	3,90	29.20
1991	0.27	2.30	10.82	6.16	4.10	3.13	3,29	26.78
1995	0.24	3.72	11.02	5.22	5.26	4.50	4,93	29.96
1996	0.14	2.60	17.75	7.70	8.70	4.09	4,64	40.98
2002	0.40	3.99	12.15	7.68	3.28	5.59	4,90	33.12
2006	0,44	4,9	14,78	7,98	5,75	6,28	6,35	40,13
1.9-2.4 m –34 platforms								
1979	0.33	2.90	11.90	6.36	5.06	3.73	4,07	30.28
1980	0.36	5.48	12.06	6.29	5.23	6.39	6,71	35.82
1981	0.34	2.59	9.81	5.87	4.12	2.75	3,45	25.48
1990	0.23	3.05	11.20	6.04	4.68	3.76	4,11	28.96
1991	0.29	2.99	11.10	6.43	4.24	3.70	3,98	28.75
1995	0.23	3.58	10.82	5.30	5.41	3.92	4,73	29.26
1996	0.15	2.90	15.60	7.30	8.00	3.35	4,59	37.30
2002	0.32	3.08	9.54	5.51	2.54	4.89	3,95	25.91
2006	0,41	1,80	11,54	6,30	3,60	3,90	2,93	27,53
2.5 m and more – 11 platforms								
1979	0.39	6.49	7.98	5.75	3.64	5.47	7,01	29.42
1980	0.50	5.10	7.98	4.38	3.38	5.82	5,92	27.16
1981	0.42	5.24	6.44	4.26	3.52	4.32	5,76	24.20
1990	0.35	4.24	7.81	4.60	3.11	4.69	4,95	24.80
1991	0.30	6.96	10.25	5.57	5.00	6.94	7,95	35.02
1995	0.24	4.91	7.63	3.80	4.23	4.75	5,72	25.56
1996	0.16	3.30	10.60	5.13	5.31	3.62	4,43	28.12
2002	0.47	2.00	7.18	3.95	2.15	3.55	2,74	19.30
2006	0,38	2,4	6,61	3,45	2,11	3,74	3,11	18,70

Increasing of humidification in the Volga delta has affected the phytocenosis productivity.

In comparison with 1982, the general top in 2006 has increased at all high-altitude marks (table 4).

Table 4

Size of average general top of herbage, g/m²

Height intervals	1982	1991	1996	2001	2006
1,2 m and below	720,9	1014,5	964,2	1491,9	1779,4
1,3 – 1,8 m	351,3	368,7	236,3	1147,2	688,4
1,8-2,4 m	255,5	343,9	223,2	757,2	885,0
2,5 m and above	232,6	480,0	272,4	625,2	472,4

Especially big increase in productivity is noted at 1,2 m height and below them (low-level meadows) in 2,5 times. These areas became flooded for longer periods, and there was general reduction of the maintenance of salts on that areas that induces *Crypsis schoenoides* reduced its general mass from 1982 to 2006 in 11 times, and it has caused glycophyte migration on earlier salted ecotopes.

At 1,3-1,8 m height above low-water there is an increase in a biomass, for investigated years except 1996 and 2006 which were the least on high water volume (64 and 72 km^3), it has affected reduction of vegetation productivity.

At 1,9 m and 2,5 height and above (high-level meadows), which are flooded once per 9-10 years, 2006 in comparison with 1982 increased in productivity in 2-2,5 times, but due to increase in precipitation quantity.

From 17 plant species that were allocated while sorting of hay crops by 2006 in comparison with 1982, the top weight of 11 species has increased and 6 species has decreased (table 5).

Table 5

Average weight of the top, at 126 points of the profile, g/m²

№	Namatophilous	1982	1991	1996	2001	*2006*
1	*Typha angustifolia*	3,1	36,7	39,6	41,4	*23,4*
2	*Bolboschoenus maritimus*	2,7	16,6	9,4	15,8	*9,7*
3	*Eleocharis palustris*	3,4	6,6	3,5	14,0	*8,2*
4	*Petrosimonia oppositififolia*	0,7	6,1	0,6	3,1	*1,1*
5	*Litrum virgatum*	0,2	1,4	0,5	2,7	*0,8*
6	*Aeluropus pungens*	10,1	5,7	5,2	9,3	*6,0*
7	*Phalaroides arundinacea*	10,0	2,9	1,8	7,5	*25,1*
8	*Crypsis schoenoides*	5,5	1,3	0,3	0,2	*0,3*
9	*Elytrigia repens*	3,6	0,2	1,6	3,1	*15,3*
10	*Inula britannica*	2,2	0,1	0,3	0,1	*0,2*
11	*Althaca officinalis*	1,7	1,2	2,9	3,4	*0,2*
12	*Suaeda confuse*	0,1	0,4	2,2	0,3	*0,1*
13	*Rubia tatarica*	1,8	1,5	0,5	0,4	*4,8*
14	*Pragmites australis*	1,4	1,1	3,7	15,6	*68,6*
15	*Hierochloe repens*	5,4	3,8	3,4	6,5	*4,6*
16	*Glycyrriza glabra*	0,6	2,9	4,1	20,0	*49,5*
17	*Atriplex prostrata*	1,5	2,6	2,2	0,6	*0,1*
18	*General mass*	*394,3*	*510,1*	*368,1*	*945,0*	*947,7*

Especially directed increase in weight has occurred at well-grown plants, that negatively react on grazing and haying, such as *Typha angustifolia*, *Pragmites australis*, *Glycyrriza glabra*, in 8, 49 and 83 times accordingly.

After sharp reduction of cereals *Phalaroides arundinacea* and *Elytrigia repens* representation in 1991-1996, there was a restoration of representation up to values of 1982 in 2001 and increase in 2,5 times in 2006 that has improved quality of haymakings in the delta.

Climate change at last decades have led to the increase in average annual temperatures, growth of annual precipitation and increase in rivers water content, including the Volga. It has led to seral changes in soil-vegetative cover of the Volga lower reaches. On low-level meadows were a reduction of toxicity of a soil solution and change of much toxic chloride salinization to sulphide, that has led to formation of mono-dominant communities with *Typha angustifolia* and to growth of top weight from 5 up to 8 times.

On middle-level meadows were salts an general maintenance increase with the reduction of soil solution toxicity in the soil, that has also led to increase in a biomass, especially in high water level years.

On high-level meadows the increase in a biomass in connection with increase in precipitation during vegetation period is observed.

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PRIMARY PRODUCTION OF PHYTOPLANKTON UNDER THE EFFECT OF CLIMATE CHANGES AND ANTHROPOGENIC FACTORS IN THE VOLGA DELTA OF THE CASPIAN SEA

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Keywords: primary production of phytoplankton, hydrological regime, Volga delta

INTRODUCTION

The Volga River flows into the Caspian Sea and forms one of the largest deltas in the world. Biological resources of the Volga delta are unique and are characterized by great richness and diversity of flora and fauna. There are the Astrakhan Reserve that included in the UNESCO's Man and the Biosphere Programme and the Ramsar Site in the Volga delta.

Primary production of phytoplankton and allochthonic organic matter are material and energy basis for the functioning of the aquatic ecosystem of the Volga delta and its biological productivity. Hydrology conditions and river runoff are important factors that determine the primary production of phytoplankton of the Volga delta (Gorbunova and Gorbunova, 2006).

During the second half of the 20th century there has been a significant change in hydrological conditions in the Volga River and its delta under the effect of climate changes and anthropogenic factors. One of the most important impacts was the construction of the Volga-Kama cascade reservoirs and hydroelectric dams. In the 21st century climate change is one of the great environmental factors. Surface temperatures are expected to continue to increase globally and major changes are likely to occur in the global hydrological and energy cycles (IPCC 2001). Great Volga River drainage basin, which occupies about one third of the European territory of Russia, is potential vulnerable to the effect of global climate processes.

MATERIAL AND METHODS

The researches ware carried out in the Lower part of the Volga Delta and fore-delta on the base of the Astrakhan Biosphere Reserve during the period of 1996-2007.

The concentration of chlorophyll *a* was determined by standard spectrophotometric method (SCOR-UNESCO, 1966; Lorenzen, Jeffrey, 1980). The calculation of chlorophyll *a* concentration was done according the Jeffrey and Humphrey formulas (Jeffrey, Humphrey, 1975).

The photosynthesis intensity was measured applying the oxygen modification of the bottle method with 24 hours exposition of samples (Winberg, 1960) throw which the phytoplankton primary production and mineralization of organic matter were estimated.

The assessment of water trophic status of the Volga Delta was carried out due to trophic classification (Winberg, 1960). According to this classification (on the basis of chlorophyll *a* and phytoplankton primary production) 4 types of trophic state are allocated: oligotrophic, mesotrophic, eutrophic and hypertrophic.

Hydrological data are according the Astrakhan Centre for Hydrometeorology and Environmental Monitoring.

RESULTS AND DISCUSSION

The annual variability of phytoplankton primary production is related to hydrological seasons in the Volga delta. In channels of the lower zone of the delta seasonal dynamics of phytoplankton productivity indicators (photosynthesis intensity, chlorophyll *a* concentration and phytoplankton biomass) is characterized by an increase in the period of spring-summer flooding and summer-autumn mean water period. In the fore-delta area – in spring before the spring-summer flooding and during the summer-autumn mean water period in local costal zones. In the spatial characteristic of these indicators the most even distribution is in spring-summer flooding and the greatest differentiation is in the summer-autumn mean water period.

During the period of research integral phytoplankton primary production for vegetation season ranged from 106 to 199 $gO_2 \cdot m^{-2}$ in channels of the lower zone of the delta. Observed over the year photosynthesis intensity ranged from 0.1 to 3.5 $gO_2 \cdot m^{-3} \cdot day^{-1}$, content of chlorophyll *a* – 0.2-65.5 $mg \cdot m^{-3}$. In the fore-delta the observed photosynthesis intensity of phytoplankton ranged from 0.2 to 7.3 $gO_2 \cdot m^{-3} \cdot day^{-1}$, chlorophyll *a* – 0.2-113.2 $mg \cdot m^{-3}$.

At present the trophic status of channels of the lower zone of the Volga delta assessed as mesotrophic. Some of the fore-delta coastal areas are of some eutrophic character.

Primary production of phytoplankton is a function of many variable factors such as phytoplankton abundance, its qualitative composition and physiological state which depends on many environmental parameters. The major limiting factors are: availability of nutrients, temperature, lighting conditions and flow velocity. The most of these factors depend on the river runoff and the parameters of the hydrological regime in the Volga delta (Moskalenko, 1965; Hydrometeorology ..., 1996). Spring-summer flooding is very important for nutrient loud (Gorbunov, 1976; The Volga River Mouth Area..., 1998).

Comparison of average annual concentrations of chlorophyll *a* and the volume of runoff of spring-summer flooding showed similar trends in their interannual dynamics (Fig. 1). In general, years with a larger spring-summer runoff volume are more productive. However, the characteristics of phytoplankton productivity are influenced not only the parameters of the hydrological regime of the current year, but previous years as well. So, in 1997 the high value of mean annual chlorophyll *a* concentration is caused by the outbreak of phytoplankton abundance during the summer-autumn mean water period. This can be explained by the fact that in the previous year the volume of spring-summer flooding was small. Many areas of the floodplain and delta were not flooded in 1996. This provided the Volga delta with additional nutrients in 1997.

Our studies of primary production of phytoplankton completed the long-term time series data (1960-1990) for the channel of the lower zone of the Volga delta.

The methodology was consistent. Analysis of long-term data for second half of the twentieth century showed that under the regulated flow conditions from the beginning of the 1960's to early 1990's there was a rise of average quantity of phytoplankton primary production (fig. 2). The process of eutrophication was observed. At the end of last century and the beginning of present there was a decrease of primary productivity in comparison with the previous period. On the average the level of primary production reduced to the values of the 1960 – 1970th. It allows to ascertain the fact of de-eutrophication process in the beginning of the 21st century.

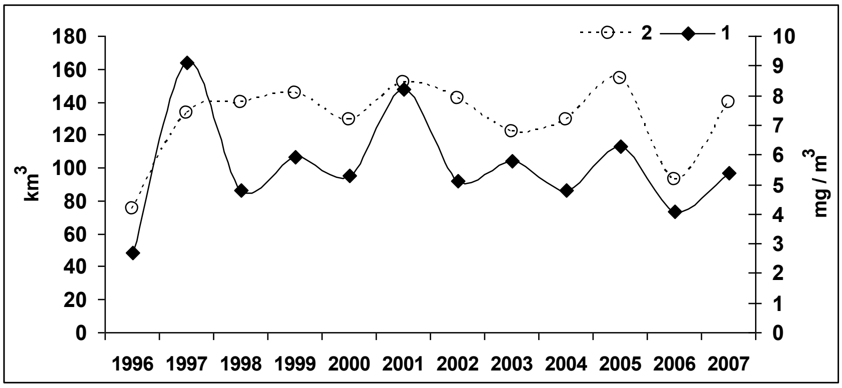

Fig. 1. Mean annual chlorophyll *a* concentration (1) and volume of runoff during spring-summer flooding (2)

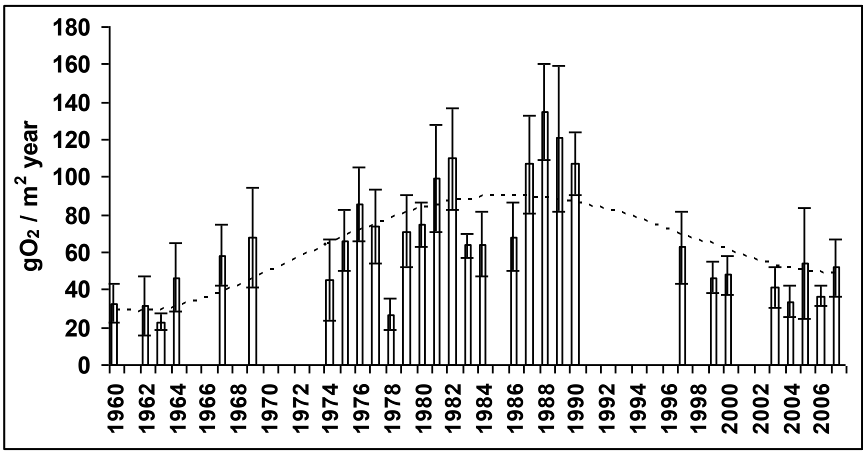

Fig. 2. Variability of integral phytoplankton primary production for a vegetation season in the channel of the lower zone of the Volga delta under the conditions of regulated river flow regime (1960-1990 – data of K.Gorbunov (1976, 1991); 1997 – 2007- our data)

During the analyzed period there were significant changes of environmental conditions in the Volga delta. One of the most important impacts on the hydrological regime of the Volga River and it mouth area was the construction of the Volga-Kama cascade reservoirs. Since 1961 the Volga River flow is under regulation. During this period there were several stages of hydrological, hydrochemical and hydrobiological state. The variability of the rive runoff allows to rank characteristic phases: 1) 1961-1970 – a phase of medium river runoff 2) 1971-1977 – a phase of small river runoff; 3) 1978-1993 – a phase of large river runoff (The Volga River Mouth Area …, 1998). The modern period mainly is characterized by a large river runoff. During 1970 – 1980th the intensive fertilizers application in the agriculture caused their significant draining into the Volga River. Since 1990th the use of fertilizers and their drainage into the water bodies reduced greatly as a result of economic depression.

These changes to a great extent explain a long-term trend of phytoplankton primary production. The main causes of eutrophication of the Volga delta during the period of 1978-1993 that was characterized by a large river runoff are the increase of fertilizers application in agriculture and extra load of nutrients from the areas of floodplain and delta that were not flooded for a long time during the previous years of a small river runoff. There was the de-eutrophication despite of rather large river runoff in 1997-2007. The reasons are both the reduction of a drain of fertilizers due to an economic crisis and lack of extra load of nutrients from the flooded areas because of effect of "wash-out" during the previous period with large river runoff.

The further de-eutrophication or eutrophication of the Volga delta will greatly depend on the scenario of hydrological changes under the influence of climate. At the same time under the conditions of regulated Volga River flow the factor of direct antropogenic impact is significant.

CONCLUSIONS

The primary production of phytoplankton varied greatly during the second half of the 20^{th} century and the beginning of the 21^{st} century in the Volga delta. Hydrology conditions and the Volga river runoff are important factors that determine the phytoplankton primary production in the delta.

There was the eutrophication of the Volga delta in 1980^{th}. On the one hand the reason is the increase of fertilizers application in agriculture that caused their significant draining into water bodies, on the other hand extra load of nutrients from the areas of floodplain and delta that were not flooded for a long time during the previous years of a small river runoff. At modern period the process of de-eutrophication of the Volga delta is caused both the reduction of a drain of fertilizers due to an economic depression and because of effect of "wash-out" of nutrient during the previous phase of large river runoff.

At present the trophic status of channels of the lower zone of the Volga delta assessed as mesotrophic. Some of the fore-delta coastal areas are of some eutrophic character. Usually the larger spring-summer runoff volume makes condition for higher annual phytoplankton primary production. At that the alternation of years of different spring-summer runoff volume is important.

The future trend of phytoplankton primary production of the Volga delta will greatly depend on the scenario of hydrological changes and river runoff.

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RESULTS OF GEOPHISYCAL INVESTIGATIONS OF BED TOPOGRAPHY AND SEDIMENTS IN CHANNELS OF THE VOLGA DELTA ARMS

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Keywords: relief of bottom, channel bed sediments, alluvium, grain size of sediments, thickness of deposits, side-scan sonar survey, seismo-acoustic profile

INTRODUCTION

Until recently, river channel studies were based on well-established traditional methodic which involved bathymetric mapping using echo-sounding device, analysis of hydrological information and comparison of maps created at different times. Elements of the channel bed topography distinguished on bathymetric maps can give only general impression of the hierarchic structure of bedforms, allowing localization of pools and riffles. Recent progress in geophysical and navigational equipment makes it possible to substantially widen the existing knowledge of structure of fluvial topography and bed sediments.

The present knowledge of bed topography and sediments of the Volga River delta arms is incomplete and insufficient. More detailed information exists on sedimentation processes on the deltaic floodplain surface and the avandelta bottom. It is known that formation of channel bed sediment is mainly associated with transit and deposition of bedload fraction of river sediment transported in drag, rolling and saltation modes, with limited input of settling part of suspended fraction of river sediment. Main source of bedload sediment is erosion of channel banks composed by alluvium or bedrock.

According to information obtained by channel surveys carried out by authors, bed sediment composition of the main arms of the Volga River delta (Buzan, Bakhtemir, Bushma, Kizan) is characterized by domination of medium (mean diameter – 0.25-0.35 mm) and fine (0.15-0.20 mm) sands. Bed sediments of smaller branches and navigable canals (Nikitinskiy, Bushminskiy, Volgo-Caspian) are composed mainly of very fine sands (0.11-0.15 mm), silts and clays (<0.05 mm).

Sandy bed sediment form different types of dune bedforms in channels of the deltaic arms and branches. Their morphometric parameters depend on flow hydraulics, bed sediment granulometric composition and thickness. Analyses of the echo-sounding transects and sonar mapping of channel beds allowed us to distinguish 5 main types of dune bedforms and 3 hierarchic levels of the associated channel bed topography. These include microtopographic (ripple marks, ripples), mesotopographic (mega-ripples, dunes) and macrotopographic (sand waves) features. Microtopographic features are represented by the smallest bedforms with length <10 m and relative elevation <0.1 m. Mesotopographic features are the most widespread and characterized by fast migration over relatively static surface of largest bedforms. Their length varies from 20-50 m to 100-150 m, relative elevation – 0.2-1.5 m. Largest bedforms (sand waves) have length from 0.2 to 6.0 km and relative elevation 2-15 m.

RESEARGH METHODS

Geophysical methods used in our studies included sonar surveys of the channel bed surface and seismoacoustic profiling of the channel bed sediments. Procedures for interpretation of natural and artificial objects on sonar survey maps and seismoacoustic profiles were developed during test runs of the equipment at the specially selected key sites. After a preliminary evaluation of available geological, hydrological and hydrographic information for the study area from published and unpublished sources, a number of key sites were selected within the area of the Volga-Akhtuba valley and Volga delta. For each of such test sites the following information was already available: 1) bathymetric maps at 1:5000 or 1:10000 scale; 2) geological survey core descriptions; 3) channel bed sediment maps at 1:25000 or 1:10000 scale; 4) hydrological and morphological characteristics of a watercourse. Detailed sonar surveys, seismoacoustic profiling, high-precision depth sounding and bedload sediment sampling was carried out at 7 key sites, including Tsagan-Amanskiy, Kopanovskiy, Durnovskiy, Astrachanskiy, Kharbaiskiy, Belinskiy (canal) and Volga-Caspian (canal). Comparison of data acquired by the above techniques with the previously available information made it possible to develop reliable and unambiguous indicators for interpreting the main types of bedload sediments and channel bedforms. The main reflecting layer depth in seismoacoustic profiles was used for determination of the channel bed sediment thickness. In the Lower Volga River valley this layer is in most cases represented by the eroded top of bedrock marine clays deposited during the Caspian Sea transgressions of the Khazar and Khvalyn ages [1].

Side-scan sonar devices (SSD) are at present the most widespread of hydroacoustic equipment used for surveying bottoms of water bodies. Technique for the SSD application for a river channel bed morphology mapping and qualitative evaluation of bedform parameters was cooperatively developed by research groups from the Oceanology Institute of the Russian Academy of Sciences (OI RAS) and Faculty of Geography of the Moscow State University (FG MSU) in 1995–1999.

The “Microsound” hydroacoustic system designed and created in the Laboratory of the Bottom Hydrolocation (OI RAS) was employed in our investigations of bed morphology and sediment in the main Volga River channel and branches on the Volga River floodplain and delta (Fig. 1). The system includes the side-scan sonar device (SSD), the acoustic profiler (AP), the satellite geographical positioning system receiver and data-logging device (personal computer) with specially designed software for collecting and processing the acquired data.

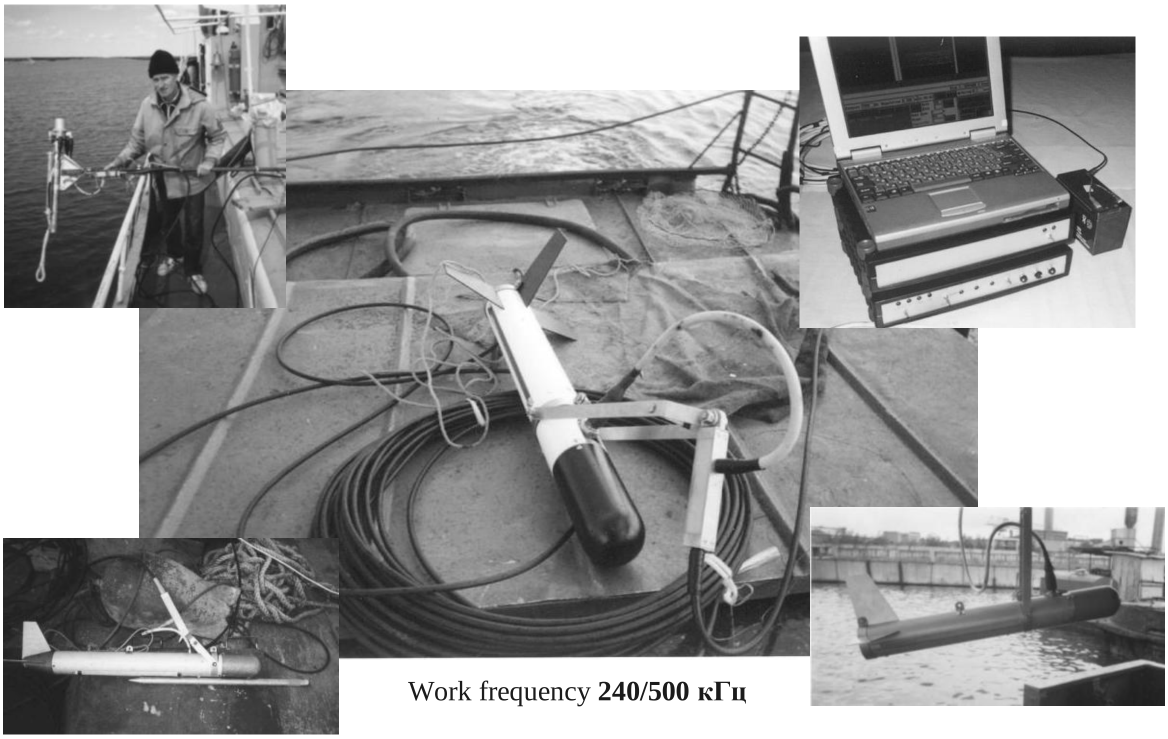

Fig. 1. Hydroacoustic system “MICROSOUND”.

RESULTS

The channel bed sediment grain size gradually decreases within the Volga River delta from its apex to the distal seaward edge. From the Astrakhan water divider down to the Bahtemir deltaic arm inlet the main channel bed sediment is dominated by medium-grained (Md = 0,25–0,35 mm) and fine-grained (Md = 0,15–0,20 mm) sands.

Sandy ripples developed in a thin layer of fine sandy sediment covering outcrops of marine clays are observed along the right bedrock bank of the Volga River channel right arm at the river reach where it erodes the so-called Baer mounds. There are some channel sections without any bedload sediment near the Kolpakovskiy, Durnovskiy and Jirgak yars and along the main channel rightbank from the Streletskaya landing to the Solyanka settlement. At zones where the main Volga River channel is separated into arms by the Gorodskoy and Ilinskiy islands, thalwegs of active channel arms (the Trusovskoy arm) have medium- to fine-grained sands bedload sediment. At the same time, gradually infilled inactive branches are characterized by pure fine sands (mean particle diameter 0,11–0,15 mm). Specific feature of the Astrakhan reach of the Volga River is a large percentage of shell fragments in the channel-forming sediment volume (up to 10–30%).

In the deltaic branches themselves, bedload sediment grain size and channel bed topography are largely controlled by hydrological and morphological of flow characteristics (substantially varying along a length of branches) as well as by the delta geological structure. For example, at crossing the territory abundant in specific landforms termed as Baer mounds, channel beds of the Volga River delta branches are mainly composed of eroded marine clays, rarely covered by some shell fragments eroded from those. Riffles composed of fine sand are observed only within a belt up to 100 m wide along the maximum flow velocity line. In contrast, fine-grained (Md = 0,15–0,25 mm) sandy dunes often occupy entirely width of deltaic branches outside the territory of the Baer mounds topography, especially downstream of confluences of deltaic arms and branches. In general, bedload sediment particle size within the delta part above the sea level rarely exceeds 0,35 mm at the Bakhtemir direction and 0,15 mm at the Belinskiy direction. Locally increased particle size of bedload sediment (up to 0,42 mm) is observed at places of abundant accumulation of shell fragments (from 15 to 42% of total bedload sediment in some pools) and downstream confluences with large tributaries (e.g. mouth of the Baklaniya branch in the Bakhtemir arm).

Artificial navigation canals beds (Volgo-Caspian, Belinskiy, etc.) built outside a seaward margin of the Volga River delta within the coastal waters of the Caspian Sea are covered by fine to very fine sands and silts. There are no mobile bedforms in artificial canals. However, echo sounding survey has allowed us to discover local bed scours up to 15–20 m deep.

Results of the bedload sediment survey and echo sounding-based mapping have shown that the majority of secondary deltaic branches formed within the territory of the dominant Baer mounds topography (the so-called mound area) experience a lack of bedload sediment (Fig. 2, 3). As a result, it is reflected by a widespread occurrence of sections with bare channel bed composed of bedrock clays. For example, the Shmagin branch channel has practically no bedload sediment from its inlet to the outlet (25 km), its bed being composed of plastic clays. Within the Kizan deltaic arm dominant type of bedload sediment is fine sand (mean particle diameter 0,17–0,20 mm). However, from the Bezymyanniy island upper end down to zone where the Kizan arm separates onto widened outlets of a few smaller branches (the Rytiy, Kulaginskiy and Nikitinskiy branches), for about 11 km, its channel bed is represented by uneven clayey surface, only at places covered by thin layer of sandy sediment. At the same time, most of smaller deltaic watercourses within the coastal zone are filled by clayey and silty sediment (the Bushminskiy canal, Nikitinskiy and other branches).

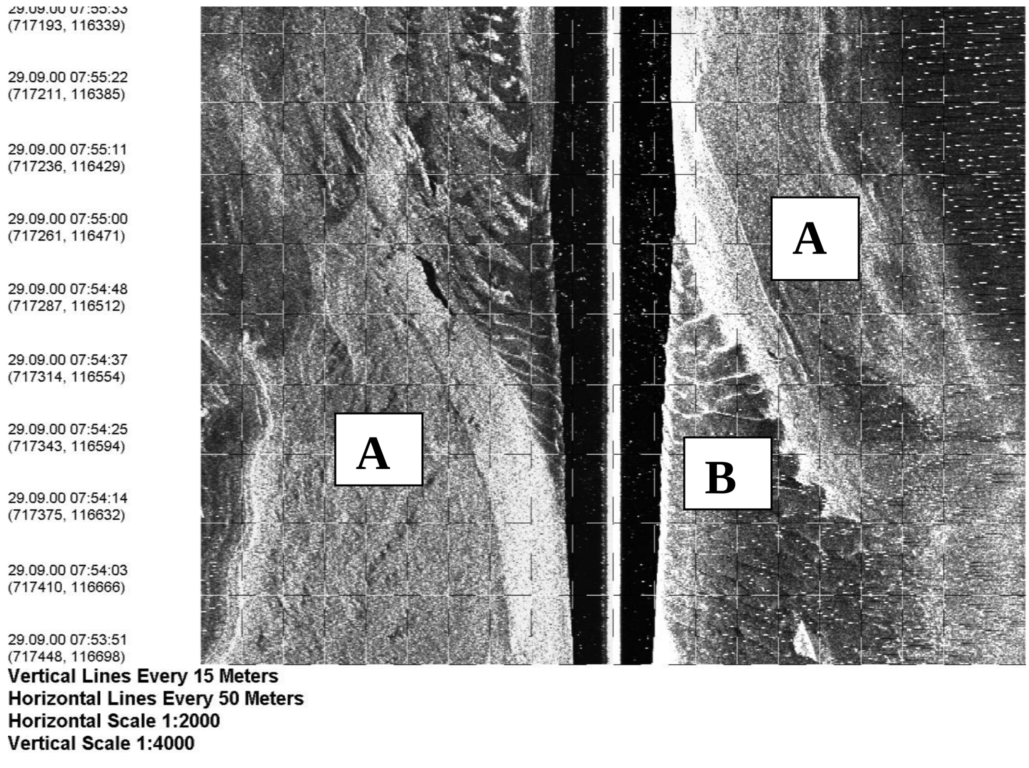

Fig. 2-3. Hydroacoustic survey image of the Volga River channel bed obtained from the SSD
A – clay bank, B – sand channel

Thickness of channel bed sediment layers was studied by means of coring and seismoacoustic profiling. First reliable information about the modern Volga River alluvium thickness infilling the Late Khvalyn incisions of the main channel and major deltaic arms were obtained from the State Oceanographic Institute coring program carried out during 1937–1939 [2]. Altogether there were 50 deep cores taken. Of those, largest thickness of the modern channel alluvium up to 21 m was observed at relatively depressed central part of the delta where the palaeo-Volga flow is believed to be concentrated. At slightly more elevated western and eastern parts of the Volga River delta there are systems of the deltaic watercourses (the Bakhtemir, Staraya Volga, Kizan and Kigach arms) incised to 5–11 m into bedrock represented by the Late Khvalyn marine deposits. At the coastal part of delta (outside zone of the Baer mounds development) and at its submerged part, uneven roof of the Khvalyn age marine deposits is observed at depth from 7 m (western part of the delta) to 18 m (central part) and 13 m (eastern part) from the deltaic plain surface.

Thus, only central part of the delta surface is composed from its apex to distal seaward edge by the modern alluvium infilling the deep and wide incision formed after the Khvalyn age marine deposition. At most of the other parts of delta, the Late Khvalyn marine deposits are exposed on surface in form of the Baer mounds. At places where the latter are absent, the Late Khvalyn marine deposit roof sharply sinks and becomes overlain by the Holocene alluvial and alluvial-marine deposits.

Thickness of channel sediment in deltaic watercourses generally varies from 0.5 m at crossings with the Baer mounds or in deep pools to 5–12 m at riffle zones. Most of the Bakhtemir direction (the Astrakhan city – the Bakhtemir ar–m the Volgo-Caspian canal) is characterized by a high variability of the eroded Khvalyn clay roof elevation (Fig. 3). Outside the delta distal coast there is a tendency of increasing elevation of the clay roof and decreasing thickness of the overlying alluvial sediment to 1–2 m. It increases back again gradually to 2–4 m at the submerged distal end of the delta in the open sea.

Continuous seismoacoustic profiling carried out in the Volga River main channel from the Akhtubinsk to Astrakhan city, in the Volga delta branches Buzan, Bakhtemir, Bushma, Krivaya Bolda and in some other branches has allowed to trace variations of the marine deposit roof elevation along the studied channels and determine precisely a real thickness of the modern channel bed sediment layer. Results of the seismoacoustic diagram interpretation and analysis has shown that bed sediment thickness in the Volga River main channel between the Volgograd city and the Verkhnee Lebyazhee settlement does not exceed 6–8 m on average. Along the eroded bedrock escarpments of the right valley side, where roof of marine clays lies close to the surface, the bed sediment layer thickness does not exceed 1–2 m. Some sections of the Volga River main channel bed are almost devoid of bedload sediment, and up to 1/3 of the bed surface area at such sections is represented by exposures of bedrock clay (*yar* Cherniy, Nikolskiy, Vetlyanskiy, Pechinistiy, Kopanovskiy, Seroglazovskiy, Zamyanovskiy) or floodplain loams – *pechina* – (yar Soleniy, Gerasimovckiy, Bolhunskiy, Chilimniy, Tsaganskiy, Nizhnekopanovskiy, Kuznetsovskiy, Danilovskiy, Enotaevskiy, Parashkin, Arbuzniy, Shambaiskiy).

Continuous seismo-acoustic profile of the Lower Volga River channel bed and side-scan sonar images of channel bed sections of the Volga River delta arms and branches have been acquired for the first time (Fig. 4). On basis of the extensive field data set, thickness and stratigraphy of the modern channel bed sediment have been evaluated. Analysis of side-scan sonar images and echo depth-sounding records have allowed us to study channel bed morphology and obtain quantitative parameters of dune bedforms.

CONCLUSIONS

1. Sonar surveys of channel beds of rivers and deltaic arms produce acoustic images from which morphometric parameters (length, width, relative elevation) of bed topography within a zone up to 250 m wide (for a single survey vessel traverse).

2. Continuous survey of the channel bed makes it possible to determine spatial variability of bedforms related to changes of the flow hydraulic conditions.

3. Developing the interpretation criteria for acoustic images of the channel bed produced by sonar surveys makes it possible to distinguish different types of bed-forming materials (silt, clay, sand, shell detritus, etc.) and localize their areals.

4. Acoustic profiling allows determining the bed sediment thickness (providing that reflective underlying layer such as clays or solid bedrock is present).

5. Sonar technique is essential for monitoring of river channel crossings by pipelines, bridge piers, foundations of dams and concrete embankments, as well as for assessment of environmental conditions in riverine ecosystems.

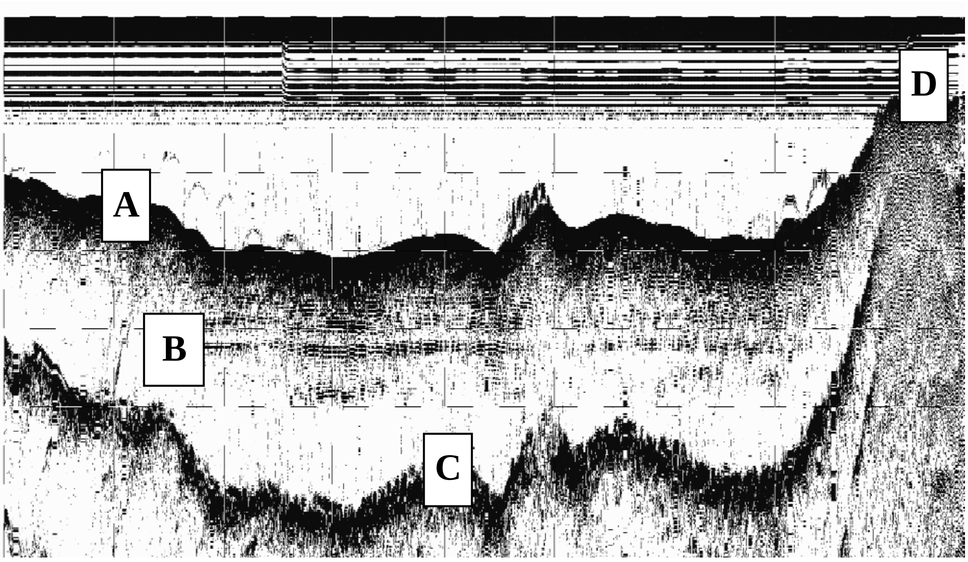

Fig. 4. The seismo-acoustic profile of bottom Volga deltaic branch near Astrakhan
A – surface of bottom, B – layers of marine clay, C – second echo of bottom, D – shore

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HEAVY METALS MASS-BALANCE IN THE VOLGA RIVER DELTA

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Keywords: Volga delta, heavy metals, geochemical fluxes, mass-balance

INTRODUCTION

River deltas are located in the lower part of the cascading landscape-geochemical systems [2]. A huge amount of dissolved and suspended materials has come in to the deltas with the river runoff. Part of this material is transferred to the receiving waters, other part is accumulated in the deltas aquatic systems. Among the pollutants that comes and deposited in the deltas considerable scientific attention is focused on heavy metals (HM). Quantitative assessment of geochemical fluxes in the deltas of big rivers is a great challenge for scientists, due to the highly dynamic of deltas systems, a considerable diversity of aquatic landscapes and the complex phenomenon of elements migration in the deltas.

Our study aimed to receive quantitative characteristics of geochemical fluxes of heavy metals in the Volga delta. Volga delta is one of the largest deltas in the world. It has a length of 120 km and a coastline width of 200 km. Volga delivers about 85% of the total river run-off to the Caspian Sea. It is the unique natural object having huge economic and ecological value. Processes of transformation and accumulation of chemical elements and compounds cause a diverse and dynamic geochemical pattern of this large area. A large number of studies have been done in the Volga delta [3,6 etc.]. Nevertheless its geochemical state remains insufficiently investigated. In the great extent it concerns a transport and accumulation of polluting substances, and determination of the geochemical fluxes and mass-balance of the elements. This paper presents the results of calculating the mass-balance of seven metals (Fe, Mn, Zn, Cu, Ni, Pb, Cd) in the Volga delta.

MATERIALS AND METHODS

One of the major issues in this work was to determine the levels of heavy metals concentration in the delta. For this purpose various water objects (main deltaic branches, large channels, small eriks and the near-shore zone of the Volga delta) have been investigated. The fieldworks were carried out in 2004-2006 and have captured the periods of a maximum high waters (May – June), recession high waters (July – August), autumn (September) and winter (December) low-water periods. We have sampled water, suspended matter (150 samples), and deltaic sediments (120 samples). Samples were analyzed for heavy metals contents by AAS, XRFS, and ICP methods.

RESULTS AND DISCUSSION

To calculate the HM mass-balance, we used the data on the average contents of suspended and dissolved forms of metals in the upper part of the delta (Table 1). As the table shows, heavy metal content in comparison with global averages is rather high especially for Zn, Cu and Cd. It can be explained by a number of reasons: very fine grainsize of the material, its enrichment with humus, sorption of HM by fine particles, water pollution, and deposition of contaminated aerosol particles. Most of heavy metal shows the general decrease of contents from high water to low water period. Obviously, this is caused by their inflow with hollow waters and thawed snow from polluted areas of the river basin. Low water HM levels in the Volga delta (September) are mostly close to the global averages. Different seasonal dynamics of dissolved forms of Fe and Mn (elements with variable valence) can be explained to seasonal changes in redox potential.

Table 1

Mean heavy metal content in water and suspended matter of the Volga delta

Subject	Month	Fe	Mn	Zn	Cu	Ni	Pb	Cd
Dissolved in water , mkg/l								
Volga delta average values	May (n=32)	154	16	133	16	3,9	4,1	0,51
	July (n=36)	293	31	25	9	2	5,6	0,48
	September (n=36)	430	21	27	8	1,4	1,1	0,13
Global average values [1]		410	10	20	7	2.5	1,0	0,2
Suspended matter , mg/kg								
Volga delta average values	May (n=32)	10444	1198	1689	1809	119	177	5,2
	July (n=36)	6375	2719	1318	509	107	204	2,8
	September (n=36)	6915	2900	856	750	82	203	3,9
The upper part of the delta	May (n=7)	5948	527	327	226	42	43	1,0
	July (n=7)	4792	678	308	182	48	94	1,0
	September (n=7)	3047	4947	428	369	79	83	1,9
River Volga [5]		89700	1740	425	75	54	37	0,44
Global average values [5]		77900	1650	343	98	76	89	3,2

*in parentheses – number of samples

The calculation of the elements mass-balance is based on data of water and suspended matter runoff of the delta received by V.F. Polonsky, N.I. Alekseevskii and others [4]. The calculation is based on the fact that the delta intercepts about 2-3% of water runoff and about 23% of suspended matter that come in to the delta. It should be noted that due to multiple factors of migration and accumulation only approximate average value of mass-balance can be obtained.

The mass-balance of the dissolved forms of heavy metals (Table 2) was calculated as the sum of seasonal balances. Seasonal balances were obtained as a product of the average seasonal runoff at the upper part of the delta and the average seasonal concentration of HM by the formula:

$$B_r = B_{r1} + B_{r2} + B_{r3} + B_{r4},$$

B_{r1}; B_{r2}; B_{r3} и B_{r4} – seasonal balances of dissolved forms
$B_{r1} = K_{r1}{*}\,Q_1$; $B_{r2} = K_{r2}{*}\,Q_2$ etc.
K_{r1}, K_{r2},… – average seasonal concentration of dissolved forms (mkg/l)
Q_1, Q_2,… – volume of water runoff for the different period (summer, autumn and winter low water).

The balance of suspended forms (Table 2) was calculated as the product of the solid runoff and the average HM concentrations in suspended matter of the upper part of the delta. We consider that solid stock is equal to the average turbidity of water multiplied by water discharge. The calculations were made separately for the period of flooding, summer, autumn and winter low water:

$$B_v = B_{v1} + B_{v2} + B_{v3} + B_{v4}$$

B_{v1}; B_{v2}; B_{v3} и B_{v4} – seasonal balances of suspended forms
$B_{v1} = K_{v1}{*}\,R_1$; $B_{v2} = K_{v2}{*}\,R_2$ etc.
K_{v1}, K_{v2},… – average seasonal concentration of suspended forms (mg/kg),
R_1, R_2,… – volume of solid runoff for the different period (summer, autumn and winter low water) ($R_n = Q_n{*}S_n$, Q and S – water discharge and water turbidity)

In different part of the delta sedimentation of suspended matter is also different. The most intense sedimentation takes place in the system of the Old Volga the Bolda and the Rychan branches [4]. This is also evidenced by the maximum concentrations of metals in the bottom sediments of the Old Volga system [3].

The total balance of heavy metals was calculated as the sum of suspended and dissolved forms balances (Table 2).

Table 2

Mass-balance of heavy metal in the Volga delta

Balance Components (thousand tons per year) / Elements	Fe	Mn	Zn	Cu	Ni	Pb	Cd
Inflow of dissolved forms							
flood period	15,4	1,6	13,3	1,6	0,4	0,4	0,05
summer low water period	9,7	1,0	0,8	0,3	0,07	0,2	0,02
autumn low water period	19,2	0,9	1,2	0,4	0,06	0,05	0,01
winter low water period	8,5	0,9	2,4	0,5	0,09	0,07	0,01
year	52,8	4,4	17,7	2,7	0,6	0,7	0,08
Inflow of suspended forms							
flood period	46,4	5,3	7,5	8,0	0,5	0,8	0,02
summer low water period	5,7	2,4	1,2	0,5	0,1	0,2	0,003
autumn low water period	13,2	5,6	1,6	1,4	0,2	0,4	0,007
winter low water period	7,8	0,5	0,7	0,6	0,1	0,2	0,001
year	73	14	11	11	0,8	1,5	0,03
Total inflow	126	18	29	13	1,5	2,3	0,1
Output from the delta	107	15	25	11	1,2	1,9	0,1
Accumulation in the delta	19	3	4	3	0,2	0,4	0,01
Accumulation in the delta (%)	15	18	13	19	16	17	11

Annually the Volga delta receives about 126 thousand tons of Fe, 29 thousand tons of Zn, 18 thousand tons of Mn, 13 thousand tons of Cu, about thousand 2 tons of Pb and Ni, and 100 tons of Cd. Transport of Mn, Cu, Pb, Ni and Cd occurs mainly in the suspended forms, while Zn in the dissolved ones. The most part of heavy metals goes through the delta as a transit. Only about 15-17 % is accumulated in the Volga delta sediments. The levels of heavy metal accumulation are: Cu, Mn (18%) – Ni, Fe, Pb (15%) – Zn, Cd (11%). Mn and Cu have maximum levels of accumulation. The Zn and Cd have high mobility potential in the deltas aquatic landscape.

CONCLUSIONS

The research has allowed revealing the basic geochemical features of heavy metal (HM) transport in aquatic systems of the Volga delta and its near-shore zone. On the basis of repeated geochemical sampling in aquatic systems, which has captured all phases of the hydrological regime, the quantitative estimation of HM geochemical fluxes in the Volga delta has been carried out. Annual input of heavy metals to the Volga delta includes about 126 thousand tons of Fe, 29 thousand tons of Zn, 18 thousand tons of Mn, 13 thousand tons of Cu, about thousand 2 tons of Pb and Ni, and 100 tons of Cd. Most of heavy metal comes in to the delta during high water period. Transport of Mn, Cu, Pb, Ni and Cd occurs mainly in the suspended forms, for Zn the dissolved forms are predominated in total balance.

ACKNOWLEDGEMENTS

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THE VARIABILITY OF CHEMICAL COMPOSITION VOLGA'S DISCHARGE IN THE MOUTH AREA

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Keywords: River discharge, nutrient, dissolved oxygen

INTRODUCTION

Volga's water flows into the Caspian Sea along deep water channels and over the shallow between armlets. Chemical composition of river runoff joined the sea by deep water channels is sensibly constant to the estuary of the Northern Caspian. Flow velocity of shallow water ("slow flow") decrease to 1–3 cm×second^{-1} against 30 – 50 cm×second^{-1} in deep water channels (Ambrosimov et al., 2009). Shallow water's considerably changed under the complex of hydrodynamic and biochemical processes. Such water's characterized by essential distinction from deep channels water ("rapid flow") as a result not only oneself transformations but considerable variability of Volga discharge especially in nutrient composition (Leonov, 2002). It is known that from 30 till 70% Volga's water flow into the sea over the shallow (Metreveli, 1989; Estuary – delta systems…, 2007).

Chemical composition of these waters in detail has been investigated by expeditions of P.P. Shirshov Institute of Oceanology during 2000 – 2003. No doubt the "slow flow" impact on hydrochemical regime of coastal water is great. A few cruises have been carried to find these waters by IO RAS in the northern and middle Caspian for 2006 – 2008.

RESULTS

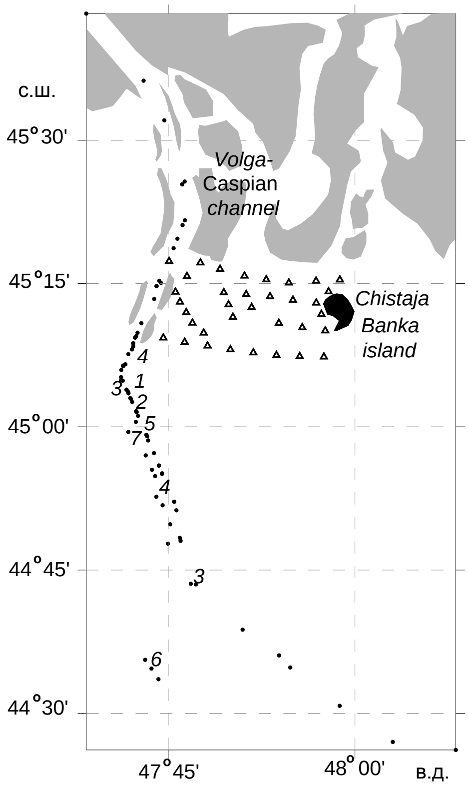

Fig. 1. A chart of the testing area "Chistaya Banka" with stations, 2002 – 2003 (triangles); sampling places of surface waters (dots); areas of maximal values of pH: 1 – October, 11; 2 – October, 2 – 16; 3 – June, 20; 4 – July, 1, 2006; 5 – September, 5 -9; 6 – December, 1, 2007; 7 – February, 25, 2008

Annual field researches were carried in the north-western part of Caspian near island Chistaya Banka from 2000 till 2003 (Fig. 1). There were vast fields of macrophytes within the scope of testing area (Potamogeton pectinalis, Vallisheria spiralis, Ctratophyllum demer). A few arias with clear sand bottom were observed. Studies in 2000 – 2003 show that there are few current systems and consequently waters with different bio- and geochemical features in shallow:

– river waters flow into deep part of the sea by rapid current along maim armlets of Volga;

– intermediate waters flow one part of way by rapid current along maim armlets of Volga and another through rushy and macrophytes filled shallow;

– waters slowly flow into deep part of the sea between channels through shallow.

It would be supposed that biochemical transformations all over these waters are different along their current into deep part of the sea.

Intensity of photosynthetic processes is so great that nonlinear coupling between concentrations of dissolved oxygen and pH values became significant over the shallow (Makkaveev, 2009). pH values were in exceed of 9 NBS (maximum is 9.29 NBS); concentration of dissolved oxygen exceed 9 ml/l at temperature 23oC or 8.5 ml/l at 26oC for nearly fresh waters.

Low transparency in channels (0.25–0.75 m) stimulates anomalous water features as photosynthetic processes could be developed only in thin surface layer. In the rest of waters oxidation processes of organic matter could be prevail. Over the shallow transparency increases and photosynthesis covers all over depth of water till bottom (1.5–2.5 m). Transparency increasing was occurred due to that majority of suspended matter settle with current slowdown (hydrodynamic barrier) and in condition of filtration through macrophytes fields. Nutrient concentration doesn't exceed ceiling for production even at the estuary. As a result concentration of dissolved oxygen and pH considerably increase and nutrient concentration decreases.

Maximum of dissolved oxygen concentration and pH were observed in the northern and north-eastern parts of the testing area, essentially above macrophytes fields. Concentration of dissolved oxygen was relatively low in the western and south-western parts of the testing area that were under the influence of river discharge (Fig. 2). Comparison of distributions of dissolved oxygen and temperature shows that hydrophysical parameters have an influence upon dissolved oxygen distribution less than biochemical processes. If not high concentration of dissolved oxygen would have been registered in the western and southern parts of the testing area covered by waters of low temperatures.

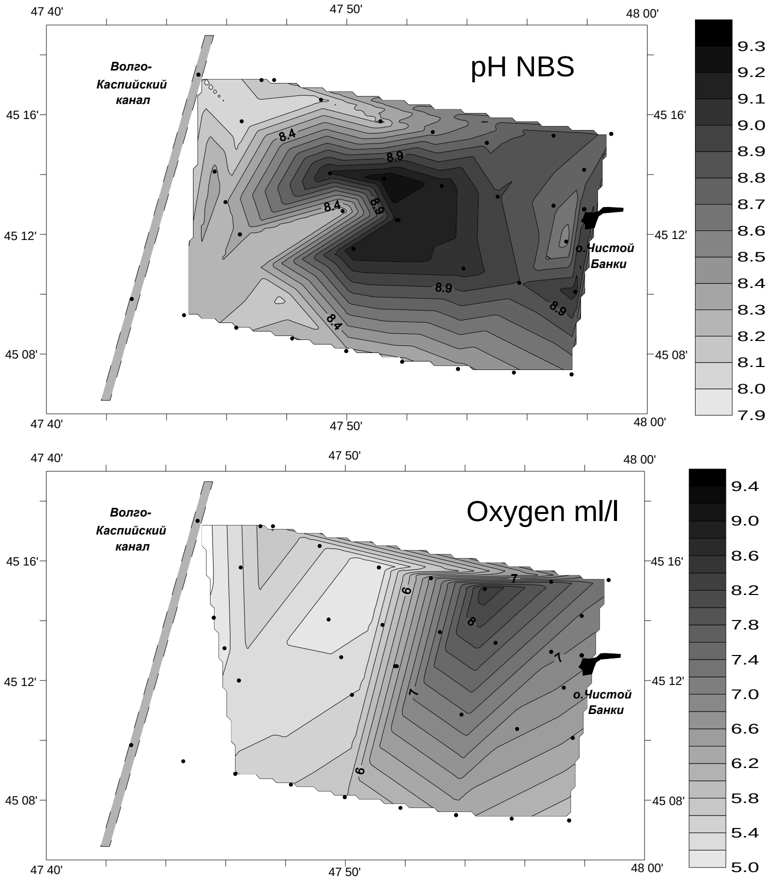

Fig. 2. Distributions of pH and dissolved oxygen in the surface water at the testing area "Chistaya Banka", 15.07.2003

Based on the results the second survey (July, 15) measuring range of pH was from 7.99 – 9.29 NBS (average pH 8.56 NBS with average T was about 26.3^{o}C). So high pH values are anomalous for fresh water. It can arise either due to alkalization of water as a result man-made injection of pollutants or due to extremely photosynthesis. There is doubt that the first reason was significant because the testing area is situated within the scope of nature conservation area. In addition the highest pH values were registered in the northern part of the testing aria (Fig. 2) that was away from navigation-canal as the most likely source of pollution transport.

For studies spreading of "slow flow" water samples were collected on a board R/V Rift along Volga-Caspian canal (Fig. 1). Asap typical river waters ("rapid flow") and sea water were collected in samples. It was 9 passages along Volga-Caspian canal: June, 20, July, 1, October, 11, 16, 2006; September, 9, 16, November, 27, December, 1 , 2007; February, 25, 2008. Frequency of sampling was varied from 10 minutes in the supposed zone of mixing sea and river waters till 1 – 2 hours at limits of passages.

Surface water of extra high pH values (more than 8.8 NBS) and high dissolved oxygen concentration was registered 5 times and in 3 cases it was not so clear. Only once its traces weren't registered in November, 26, 2007. Such waters were tracked as detached stripes for distance 7 – 15 miles from canals way out. Bandwidths of those waters could reach 1 – 3 km. Mineralization of those waters was from 1 to 2.7 psu. When mineralization reached 6 – 9 psu hydrochemical parameters become like usual for surface water in open part of Northern Caspian. In some cases (July, 1, 2006; September, 8, 2007) a few peaks of extra high pH values and dissolved oxygen concentration 20 – 25 km remote have been registered.

Probably hydrometheorological features cause shallow waters interleaved "rapid flow" waters. Dissolved oxygen concentration in these waters hoick at 1–2 ml higher than in "rapid flow" water, pCO2 decreased till 100–200 mln-1 atm or less and in "rapid flow" water was 700 – 1500 mln-1 atm. Concentration of total inorganic carbon decreased at 0.2–0.8 mmol/l nutrient concentration deflated. Fig. 3–4 show distribution of hydrochemical parameters during passage in June, 20, 2006 when observation was carried out along the longest part of the river. Decay of total nitrogen and phosphorous concentrations has been registered. Hydrochemical parameters of water rapid become level for brackish waters at the estuary. In certain cases after passage of water with the raised concentrations of dissolved oxygen and pH value small increase of nutrient concentrations was observed but in most cases their content has being fallen to marine part.

In consideration of hydrodynamic variability of concentrations of dissolved oxygen and nutrient downstream it is obvious that relation of changes of concentrations of dissolved oxygen, nitrogen and phosphorous disagree with Redfild's stoichiometric model. Indeed range of relations ΔP/ΔN, ΔP/ΔO, ΔN/ΔO increases in the zone of "extra" waters (Fig. 5). It is shows that there is not direct coupling between these waters and downstream waters. Take into account difference in current speeds in canals and above shallow the shallow water reaches the estuary with late from 3 to 6 weeks (may be longer). Chemical composition of "rapid flow" water cardinally changes.

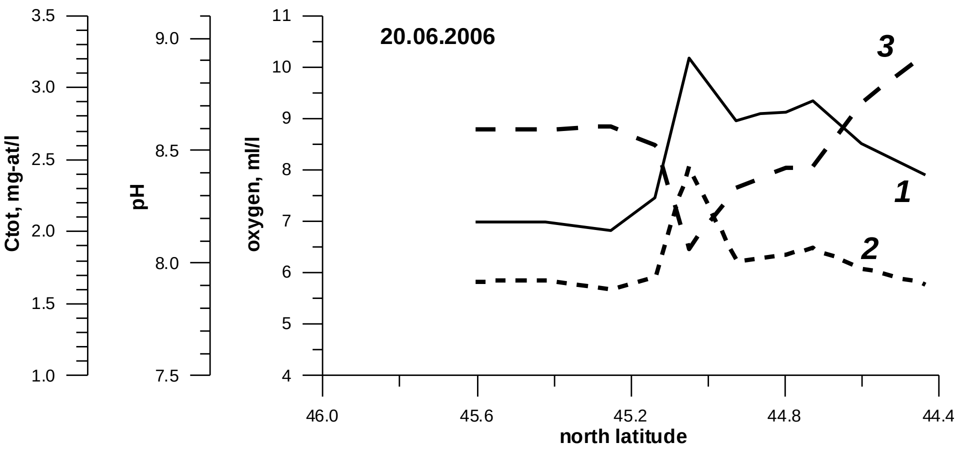

Fig. 3. Variability of pH (1), concentration of dissolved oxygen (2) and C_{tot} (3) in surface waters along the passage through Volga – Caspian canal

pH values to 9 NBS or higher were registered in Volga delta early particularly in VNIRO and GOIN expeditions (Savenko, 2007; Sapozhnikov et al., 2003). Water with high pH values and high concentration of dissolved oxygen were registered not only at the western boundary of Volga delta but in the another area such as central part (Savenko, 2007). Based on archival data such high pH values and high concentration of dissolved oxygen were registered on repeated occasions. So based on data from "Hydrochemical of World Ocean" and World Ocean Atlas 2005 it was found that pH values exceed 9 were registered in 1940s. At that time level of Caspian was similar to actual but when level of the Sea was fallen the testing area was dry.

Traces of modified water were registered as in warm as in cold seasons. Estimates of phytoplankton production in the area of genesis modified waters are 500 -1000 mg C × m^{-1} in day for spring – summer season. In winter production decreases, but remains enough high (from 50 to 500 mg C × m^{-1} in day). Production of macrovegetations is estimates higher (Meterevely, 1989).

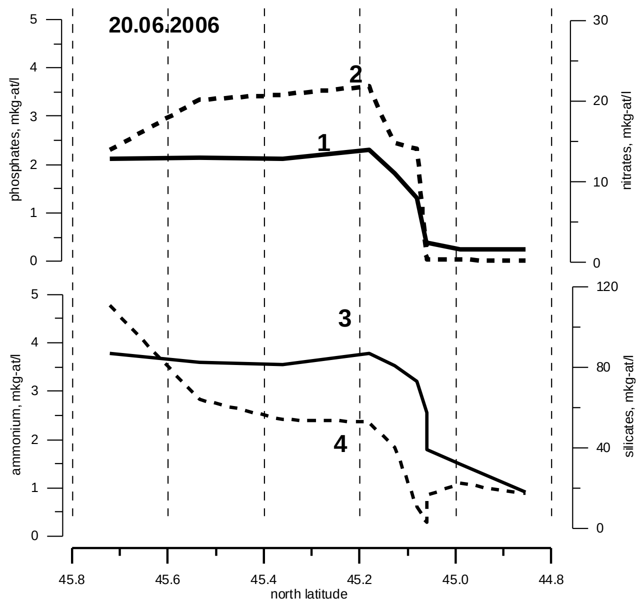

Fig. 4. Variability of concentrations of phosphates (1), nitrates (2), silicates (3) and ammonium (4) in surface waters along the passage through Volga – Caspian canal

CONCLUSION

Nutrient modification of river water occurs above shallow areas of Volga avandelta. Intensity of such transformations is as high as it allows comparing with “bioreactor”. At first the changes were reflected on concentration of dissolved oxygen and compounds of carbon. There no doubt the shallow water continuously interacts with channels’ water and with water at boundary of delta. Uninterrupted exchange between these waters occurs through numerous channels. Direction and intensity of exchange depend on hydrometheorology. In propitious wind the shallow waters are carried out into channels that explain high variability of water hydrochemical compounds in the canal low Bakhtemir horn. The shallowest water permanently runs off into open sea. These waters are registered as separate streams at a distance 7 – 15 miles from canal boundary.

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IMPACT OF THE CASPIAN SEA LEVEL CHANGES AND WATER MANAGEMENT ON HYDROLOGICAL REGIME AND MORPHOLOGICAL STRUCTURE OF RIVER MOUTHS

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Keywords: Caspian Sea, river mouth, delta, nearshore zone, sea level drop and rise, river water runoff and sediment yield, delta progradation, retreat and inundation

INTRODUCTION

River mouths including deltas, estuaries and nearshore zones are among the most vulnerable natural and socio-economic objects under the condition of present-day climate change and water management. River deltas first of all respond to natural and anthropogenic changes in sea level and river water runoff and sediment yield. Unfortunately, theoretical and methodological approaches to assessment of these events have not been developed yet. While the experience gained in studying the delta response to drop and rise of the Caspian Sea level in the XX century can help to solve these problems. Hydrological and morphological changes in the Caspian river mouths were investigated in many scientific works.

During the last two decades, new extensive studies were carried out with the assistance of the authors of this paper. All Caspian river mouths are considered in works (Mikhailov, 1997; Mikhailov et al, 2004). Several publications are devoted to hydrological and morphological processes at the mouths of the Volga (Channel processes…, 1997; Volga river mouth area…, 1997; Isupova, 2008), Terek and Sulak (Hydrology…, 1993; Mikhailov, Mikhailova, 1998; Mikhailova, 2006), Kura (Mikhailov et al., 2003). Theoretical approaches to study of river-sea interaction in deltas under conditions of changes in sea level and river regime are worked out in (Mikhailov, 1998; Mikhailov, Mikhailova, 2006; 2010). Purpose of the paper is to describe the regularities of response of the Caspian river mouths to changes in sea level and river water runoff and sediment yield. Data on water level in Baltic System (BS) at gauging stations in Makhachkala (the sea) and in different deltas, data on river water runoff and sediment yield, topographic maps and space images were used by the authors.

FACTORS IMPACTING ON THE CASPIAN RIVER MOUTHS CHANGES

Main factors impacting on regime and structure of the Caspian river mouths are the following: long-term variations in sea level, river water runoff and sediment yield; wave action; relief of coastal part of deltas and nearshore zone; local engineering measures. During the XX century, the Caspian Sea level was subjected to significant climate dependent changes, including a deep drop by 1,96 m in 1930–1941, a slow fall by 1,17 m in 1942–1977 and a fast and sizeable rise by 2,35 m in 1978–1995 (Table 1).

Table 1

Changes in water level of the Caspian Sea at Makhachkala gauging station

Period (number of years)	Water level Hs, m in BS		Water level change	
	Beginning	End	m	cm/year
1900–1929 (30)	–25,57	–25,88	–0,31	–1,0
1930–1941 (12)	–25,88	–27,84	–1,96	–16,3
1942–1977 (36)	–27,84	–29,01	–1,17	–3,3
1978–1995 (18)	–29,01	–26,66	+2,35	+13,1
1996–2009 (14)	–26,66	–27,21	–0,55	–3,9

Changes in river water runoff and sediment yield had both natural and anthropogenic reasons (Table 2). In 1956–1960, the Volga River was regulated by the Volga-Kama cascade of the large reservoirs. As a result of this river regulation, sediment yield decreased by 1,8 times. In 1978–1995, the Volga River water runoff increased under the influence of climatic factors. Changes in regime of the Ural and Terek rivers were inessential. As a result of the regulation of the Kura and Sulak rivers by Mingechaur (1952) and Chirkei (1974) reservoirs, sediment yield of these rivers decreased by 2,5 and 8,6 times respectively. The Caspian Sea is subject to moderate action of wave. Wave-induced alongshore sediment drift directs northward near the Sulak mouth and southward near the Kura mouth. Coastal parts of all Caspian deltas are flat and low. The nearshore zone of the Volga mouth is extremely wide and shallow. The nearshore zones of the Terek, Sulak and Kura are narrow and deep, while the Ural mouth nearshore is relatively shallow. Among the main local engineering measures in river mouth areas, one can notice the following: the Volga-Caspian Sea and Ural-Caspian Sea navigation canals passing through the deltas and nearshore zones; artificial straightening of channels in the Sualk (1958) and Terek (1977) deltas.

IMPACT OF THE SEA LEVEL DROP

Over the period of the sea level fall, most of the Caspian deltas rapidly prograded into the sea (Table 3). The areas of the Ural, Sulak and Kura deltas increased from 102 to 522 km^2 in 1862–1977, from 6,2 to 70,6 km^2 in 1862–1978, and from 29 to 189 km^2 in 1852–1976 correspondingly. The reasons of these large values of delta progradation consisted in river sediment deposition and sea level fall.

For example, during 1958–1978, the increase in the Sulak delta area and length comprised two components: an “active” component, associated with the deposition of a large amount of river sediments, and a “passive” component, associated with sea level drop. With the bottom slope in the nearshore zone equal to about 2‰, the “passive” progradation of the delta at a level drop by 1,74 m should amount to 870 m. However, the actual progradation was 2300 m (Table 3). Thus, the “active” progradation of the delta into the sea accounts for 1430 m (62%). Until 1978, the effects of river sediment yield and sea level drop on the delta growth had the same direction. A good correlation between delta area F (km2) and the cumulative sediment yield WR (109 m3) are typical of the period since 1830: F=22,1WR2–8,73WR (r=0,986). However, the correlation between F and cumulative WR disappeared when the sea level started rising since 1978. Correlation between the Sualk delta area F and the sea level Hs shows that this relationship was found to be virtually common both for the period of the sea level drop (1929–1978) and for the period of its rise after 1978: F= –12,63Hs–295 (r=0,975).

Table 2

Water runoff (W_Q), suspended sediment yield (W_R) and turbidity (s) of rivers flowing into the Caspian Sea

River (gauging station)	Period	W_Q, km^3/year	W_R, 10^6 t/year	s, g/m^3
Volga (Verkhnee Lebyazh'e)	1881–1955	245	12,9	55
	1956–1960	239	12,7	53
	1961–2000	248	7,2	29
	1978–1995	275	8,5	31
	2000–2005	261	–	–
Ural (Topoli, Makhambet since 1973)	1921–1957	9,2	2,9	320
	1958–2000	8,1	2,8	345
	1978–1995	8,8	3,1	345
Terek (Stepnoe)	1924–1956	10,2	21,1	2080
	1957–1998	8,8	16,9	1925
	1978–1995	8,7	16,0	1840
Sulak (Sulak)	1925–1974	4,8	14,7	3090
	1975–2000	4,0	1,7	410
	1978–1995	4,1	1,7	415
Kura (Saliany)	1930–1952	18,0	39,7	2180
	1953–2000	14,3	15,8	1060
	1978–1995	13,8	11,4	835

Table 3

Morphometric characteristics of deltas of the Ural, Terek, Sulak and Kura rivers: their length along main channel (L) and area (F)

River	Year	H_S, m in BS	L, km	F, km^2
Ural	1775	–	4	30
	1834	(–25,4)	10	80
	1862	(–25,9)	13	102
	1927	–26,23	19	234
	1945	–27,93	22	372
	1962	–28,53	30	492
	1977	–29,01	32	522
	1995	–26,66	32	(300)
	2008	–27,14	32	–
Terek ("new delta")	1977	–29,01	0,6	1,4
	1980	–28,57	1,2	2,5
	1987	–27,91	1,4	3,2
	1991	–27,26	1,8	5,0
	1997	–26,95	2,0	7,5
	2002	–27,18	2,2	9,0
	2008	–27,14	2,6	10,5
Sulak	1862	(–25,9)	2,2	6,2
	1913	–26,21	3,3	14,3
	1928	–26,07	9,1	30,5
	1941	–27,84	11,3	51,0
	1958	–27,21	5,6	62,1
	1978	–28,95	7,9	70,6
	1997	–26,95	6,3	45,1
	2000	–27,10	6,3	43,7
	2008	–27,14	6,2	44,0
Kura	1852	(–25,7)	7,7	29
	1929	–25,88	17,5	94
	1946	–27,87	21,7	161
	1976	–28,97	22,7	189
	1993	–26,96	14,0	111
	2000	–27,10	18,0	130
	2001	–27,21	18,0	136
	2008	–27,14	17,0	138

IMPACT OF THE SEA LEVEL RISE

The consequences of the Caspian Sea level rise turned out to be different in different deltas (Table 3). The comparison of space images of the deltas revealed that, over the period of 1978–1997 (the difference in the sea level ΔHs was +2,00 m), the Sulak River delta area decreased from 70,6 to 45,1 km2, i.e., by 36%; over the period of 1976–1993 (ΔHs=+2,01 m), the Kura River delta decreased from 189 to 111 km2, i.e., by 41%. In these cases, delta inundation was accompanied by wave-induced erosion of the delta coastline and formation of coastal bars and small lagoons. During 1977–1995 (ΔHs=+2,35 m), the maritime belt (up to 15–20 km wide) of the Ural River delta was submerged and the delta area decreased from about 522 to 300 km2. In spite of the Caspian Sea level rise, progradation of the "new delta" of the Terek River into the sea at the mouth of the main Kargala branch, went on; over the period of 1977–1997 (ΔH_s=+2,06 m), this progradation reached 1,4 km and 6,1 km^2. The delta coastline at the Volga River mouth virtually remained unchanged in the last 50 years.

Such different response of the Caspian river deltas to the sea level rise is primarily due to differences in the features of the nearshore zone of river mouths and surface configuration of deltas as well as due to the sediment yield value of these rivers. The nearshore zone at the mouths of the Terek, Sulak, and Kura rivers is rather deep, while it is relatively shallow at the Ural River mouth; the mean annual water level at the delta coastline at all these mouths was always in agreement with the mean Caspian Sea level; therefore, changes in these levels were synchronous and similar. The Volga River mouth has an extremely wide and shallow nearshore zone; at the low level of the Caspian Sea (below the elevation of –26,5 … –27,0 m in BS, as it was in 1940–1990, for example), the direct connection between the delta branches and the sea is broken and the water level in the area of the delta coastline appears to be higher than the sea level. By the beginning of the Caspian Sea level rise in 1978, this difference exceeded 2 m. At that time, the shallow part of the Volga River nearshore zone functioned as a large broad-crested weir. The bottom of the shallow nearshore zone represents the submerged surface of the ancient delta of the Volga River. The Caspian Sea level rise over the period of 1978–1995 resulted in gradual submergence of the shallow part of the nearshore zone. The water level at the gauging station on the Iskusstvennyi island (27 km offshore from the delta coastline) started to rise in 1982 and, by 1995, it increased by 0,9 m; during 1986–1995, the water level at the delta coastline proper increased only by 0,4 m and, by the end of this period, it was nearly equal to the sea level. The water level at the Olya gauging station in the Bakhtemir branch (24 km from the delta coastline) started to rise with a great time lag (in 1990); by 1995, the value of level rise during the low-flow period was 0,3 m. The water level at the Ikryanoe gauging station in the same branch (73 km from the delta coastline) began to rise still later (in 1993) and increased only by 0,1 m. The value of water level rise did not exceed 0,2 m in the lower reaches of branches in the eastern part of the delta. The response of the Volga River delta to the level fluctuations in the Caspian Sea is unique. It seems likely that, at present, there are no river mouths with such a vast and shallow nearshore zone on the Earth.

Two notions, i.e., a backwater prism ΔWbwp and an area of potential submergence Fsubm, should be introduced for the quantitative assessment of the response of deltas with deep nearshore zone to the sea level rise by a value of ΔHs and for the account of the impact of the delta relief and river sediment yield on this assessment. The backwater prism volume is calculated using the approximate equation ΔWbwp=0,5FsubmΔHs, where Fsubm is a potential area of delta inundation; 0,5ΔHs is a mean value of the sea level rise in the zone of potential submergence. The value Fsubm is calculated from the equation Fsubm=Lsubm$L$dcl=ΔHsidLdcl, where Lsubm is the mean width of the potential zone of submergence, Ldcl is the length of the delta coastline, i_d is the slope of the delta surface. The results of calculation using these formulas are generally in reasonable agreement with the observation results at the mouths of the Caspian Sea rivers having deep and relatively shallow nearshore zones.

Three cases are possible. Firstly, the river sediment yield is insignificant, the backwater prism is not filled with river sediments, passive submergence of the delta surface is observed and the area of actual delta submergence coincides with the area of potential submergence. Secondly, river sediments only partially fill the backwater prism, and part of the maritime zone of the delta gets submerged by sea water. Thirdly, the river sediment yield is significant, the backwater prism is filled with river sediments, sediments deposit in the channel and, in spite of the sea level rise, the delta goes on prograding into the sea. The first case was typical of the Sulak and Kura river deltas, whose sediment yield considerably decreased. Sediment yield of the Sulak River over the period of 1978–1997 totaled 30 mln m^3. This volume turned out to be noticeably less than the volume of the backwater prism (70,6 mln m^3) at the values ΔHS=+2,00 m and F=70,6 km^2, this fact predetermined the aforementioned considerable submergence of the Sulak River delta. Different situation, typical of the third case, was observed at the mouth of the main Kargala branch of the Terek River delta. The river sediment yield was rather considerable (15 mln m^3/year) and its total value (255 mln m^3) exceeded the volume of the backwater prism, which corresponded to the area of the small "new" Terek delta approximating 3 km^2 and to the sea level rise by 2,35 m over the period of 1978–1995 (about 6 mln m^3). Therefore, the "new delta" of the Terek River continues prograding into the sea in spite of its significant level rise.

To provide rough calculation of the distance of backwater propagation Lbw (km) at the sea level rise by the value ΔHs, it is reasonable to use a simple semiempirical formula Lbw=$k\Delta H$s/I0, where I0 is water surface slope prior to the beginning of the sea level rise (‰). Testing of formula using many deltas as examples showed that the value of coefficient k varied within narrow limits from 1,6 to 2,4 (k=2,0, on the average). During the last level rise of the Caspian Sea (1978–1995) by 2,35 m, the backwater moved from the delta coastline into the Volga, Ural, Terek, Sulak and Kura rivers by 75, 235, 31, 47 km correspondingly.

CONCLUSIONS

Regularities of the response of the Caspian river mouths to the sea level changes and river flow regulation were considered. Main hydrological and morphological processes at river mouths consist in "active" and "passive" progradation of the deltas into the sea at falling sea level, and delta inundation and delta coastline erosion and retreat at rising sea level. Some quantitative characteristics of these processes were obtained on the observation data.

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ORIGIN OF HYDROCARBONS IN THE PARTICULATE MATTER AND BOTTOM SEDIMENTS OF THE VOLGA DELTA

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The Caspian Sea is one of the richest oil-and-gas bearing regions with the hydrocarbon potential estimated as 16–32 billion barrels [Efimov, 2000]. Here, natural oil seepages are probable, as well as the supply of oil hydrocarbons (HC) with pollutants as a result of the intense production and transportation of hydrocarbon fuel [Dumont, 1998]. The main pollution sources for the northern part of the Caspian Sea are the coastal oil production, navigation, and the Volga River runoff [Dumont, 1998; Tolosa et al, 2004]. According to the model proposed by Academician A.P. Lisitsyn, the area of riverine and marine water mixing (marginal filter [Lisitsyn, 1995]) consists of three principal parts basically different in their functions: gravitation, physicochemical, and biological. The studies performed earlier in the coastal waters of the Caspian Sea showed that the sandy bottom sediments were characterized by rather low concentrations of organic compounds and contained from 0.031 to 0.59% C_{org} and from 19.8 to 142.1 μg/g of AHC [Nemirovskaya and Brehovskikh, 2008]. The weak statistical correlation between the distribution of C_{org} and AHC ($r = 0.14$) pointed to the supply of these compounds from different sources. On the contrary, the sediments sampled in 2004 in the channels of the Volga River (the gravitation part of the marginal filter) were characterized by high concentrations of both C_{org} (up to 8.6%) and AHC (up to 3881μg/g). The AHC fraction in the Volga River channels was, in several cases, as high as 16.8–23.9% of C_{org}, which was considerably higher than that in other aquatic areas with a permanent oil supply [Nemirovskaya, 2004; Tolosa et al, 2004].

In 2005, 2006 and 2009 the studies of the northern shelf of the Caspian Sea were continued and samples of particulate matter and bottom sediments were collected. In 2009 the studies of Volga river (from Konakovo to channels of the Delta Volga). The study was aimed to ascertain the genesis of aliphatic hydrocarbons (AHC) and polycyclic aromatic HC (PAH) and their transformation in the Volga delta (Fig. 1).

The contents of organic compounds in the particulate matter varied within the following ranges:0.18−5.77 mg/l of C_{org}, 130–710 μg/l l of lipids, 90−500 μg/l of AHC, and 20–108.6 ng/l of PAH in 2006 and 0.006 – 0.114 mg/l of C_{org} ,6.2-39.2 μg/l of AHC in 2009. In 2006 the highest concentrations over the coastal waters of the Caspian Sea were found near Tyulenii Island with the maximum at station (where ground dumping takes place because of the navigable canal cleaning). Increased AHC concentrations in particulate matter were registered at station near the exit from the navigab, the AHC was at an average of 140 μg/l, the standard deviation (σ) was as small as 20 μg/l. In the area of the riverine and marine water mixing, the content of dissolved and particulate forms of various compounds is controlled by the variations of the salinity [Lisitsyn, 1995]. With the distance from the zones of increased AHC concentrations in the direction of the main water flows, their concentration varied insignificantly, which may be caused by the small depths and by the supply from the bottom sediments at the formation of the nepheloid layer [Kravchishina, 2009; Lisitsyn, 1995]. In the coastal waters of the Caspian Sea, the lipids of particulate matter consist mainly of AHC, and a rigid correlation between the contents of these compounds was observed: r (lipids–AHC) = 0.93. The AHC of the particulate matter were character ized by a monotonous distribution of alkanes, because the ratio of odd and even homologues (CPI, the carbon preference index in the high-molecular range) in most of the samples varied within 1.0–1.3, which is characteristic of the HC of oil and phytoplankton [Kennicutt and Jeffrey, 1988]. In 2006 the content of total PAH (43.7 ng/l on average) is higher than that in open seawaters (20 ng/l) [Lisitsyn, 1995Nemirovskaya, 2004]. In harbor areas and coastal zones, the concentrations of polyarenes are usually increased. The amount and composition of HC are determined not only by the sources of their generation but also by their stability in the marine environment. Because of this, the content of prevailing PAH in the particulate matter in the area considered decreased, on average, as the sequence (in %): Ph (34.4) > Fl (20.1) > N (10.8) > BaAn (9.6) > Py (9.4) > An (7.5) >Chr (6.5) > Bp (1.5) > Pl (1.1). We assume a selective transformation of light polyarenes from dissolved forms into particulate matter by sorption and sedimentation, or by bioaccumulation and biosedimentation [Lipiatou et al, 1993].

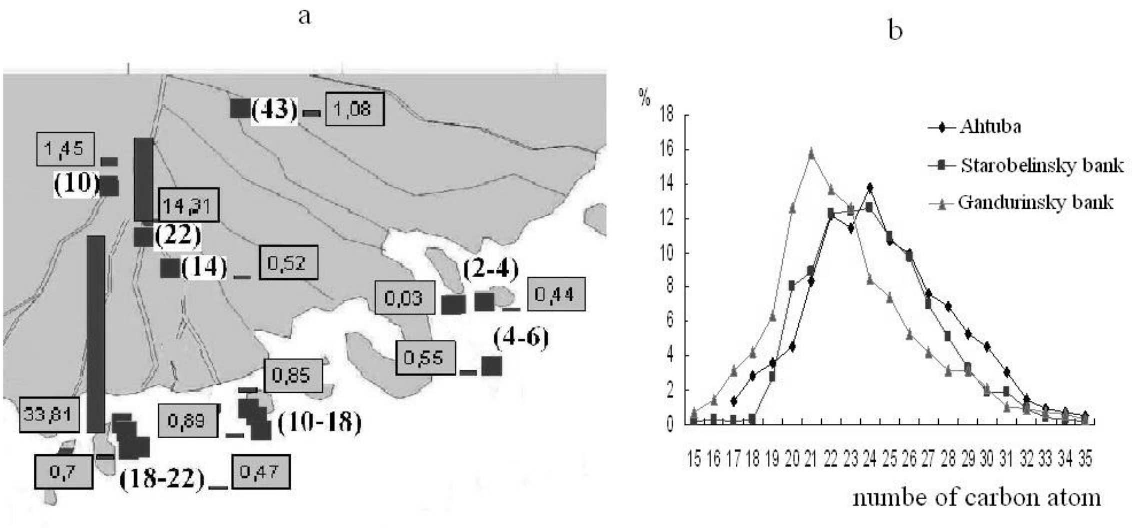

Fig. 1. Scheme of the sampling of bottom sediments in the Volga delta in 2009 – a (in brackets were concentration of AHC µg/g; in squares were part AHC of $C_{org.}$) and distribution of the alkanes separated from the bottom sediments (b).

The studied bottom sediments of the coastal waters of the northern part of the Caspian Sea are mainly presented by sandy sediments containing shells and algae, with a relatively low C_{org} content (0.197–0.582%). The exception is the silty–clayey sediment from station 5, in which C_{org} concentrations increased to 1.199%. The distribution of organic compounds depends, to a great extent, on the degree of the sediment dispersion. When passing from sands to silts, the C_{org} value usually increases [Nemirovskaya, 2004], and there is a correlation between the sediment dispersion and C_{org} in the area studied: r(C_{org}–moisture) = 0.92. The moisture of the sediments is mainly determined by their grain-size type. According to our data of 2004, for the surface layer of the sediments from the coastal waters of the Volga River mouth area, r(C_{org}–moisture) = 0.96 [Nemirovskaya and Brehovskikh, 2008].

The distribution of HC, in most cases, is also determined by the grain-size type of sediments (Fig. 2). Nevertheless, in the area studied, the AHC concentrations in coarse-grained sediments appeared to be higher than those in a fine-grained substance. Their values were characterized by a wide variability both with respect to dry sediment and in the OM composition: 70–4557 µg/g, 3.55–62.5% of C_{org}, in 2006 and 2.0-101.4 µg/g, 03-33.8% of Corg, in 2009 (Tabl.1). Even in the sediments from the Volga River channels in 2004, the AHC fraction amounted to 24% of Corg in the single case [Nemirovskaya and Brehovskikh, 2008]. The high AHC content in the Corg composition of the bottom sediments from the northern shelf of the Caspian Sea may also testify to the effect of oil HC. In 2005 at the closely located adjacent stations, Corg change by a factor of 1.5 corresponded to a change in the AHC content by a factor of 26.6, which was probably caused by the local supply of oil HC to the bottom sediments. Therefore, only a weak correlation between the distribution of C_{org} and AHC was observed (r = 0.26, n = 16). In 2005, the HC content in the bottom sediments appeared to be the highest over all the time of the surveys performed on the northern shelf of the Caspian Sea (Tables 1, 2). Evidently, the area treated in 2005 is associated to the avalanche sedimentation zone, which includes the physicochemical part of the marginal filter [Lisitsyn, 1995].

In 2005 the content of AHC at certain stations (1940–4558 µg/g) in coarse-grained sediments in 2005 is commensurable to the concentrations registered in the most polluted harbor aquatic areas [Nemirovskaya, 2004; Nemirovskaya et al, 2007; Tolosa et al, 2004]. The average value of 895.9 µg/g exceeds the background level in oozy sediments (50 µg/g). Even at AHC concentrations of 100 µg/g, the oozy sediments are said to be polluted [Tolosa et al, 2004]. In 2009, in spite of more low concentrations, composition n-alkane also points to oil origin AHC (Fig. 1b).

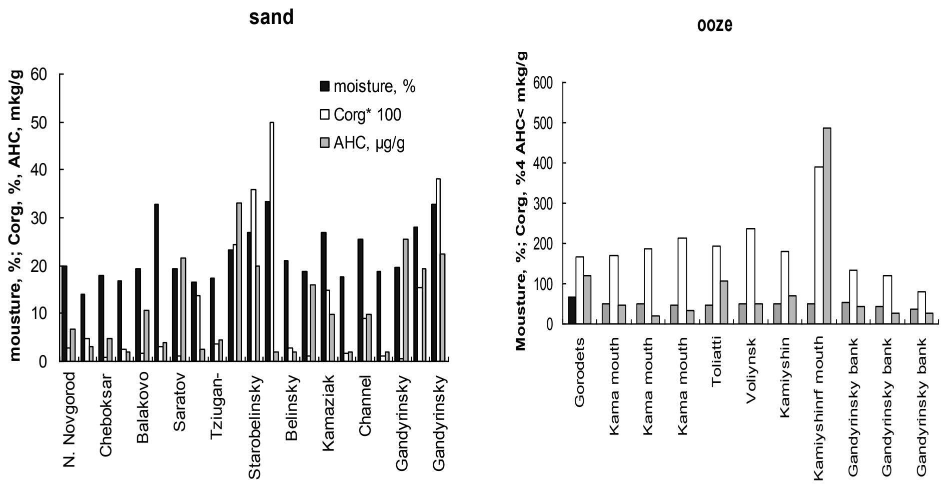

Fig. 2. Distribution of AHC in bottom sediments of Volga river in 2009

During the period of the studies from 2003 to 2009, all the three areas of the marginal filter of the Volga River were examined: the gravitational, which included the river channels; the physicochemical, or the zone of the avalanche sedimentation with the highest HC concentrations: and the biological, where the markers point, to the highest degree, to a natural origin of HC in the bottom sediments.

Table 1

Content of AHC (µg/g of dry weight) in the surface layer of the bottom sediments of the Caspian Sea

Region	Year	AHC	Reference
Azerbaijan shelf	2000	39-1515	[Tolosa et al, 2004*]
Iran shelf	2001	14-113	«
Northern part (Russian	2000	1-42*	«
aquatic area)	2001	2-14*	«
Kazakhstan shelf			
Northern shelf	2003	20-142	[Nemirovskaya and Brehovskikh, 2008]
Volga River channels	2004	59-3881	«
Northern shelf	2004	94-136	«
Northern shelf	2005	70-4558	This study
Delta Volga	2009	2-43	
Antarctica, background	2001, 2003	12-210	[Nemirovskaya, 2004]

Table 2

Content of PAH (ng/g of dry weight) in the surface layer of the bottom sediments of the Caspian Sea

Region	Survey year	Concentration, ng/g	Reference
Volga River mouth	1993	40	Winkels et al, 1998
Azerbaijan shelf	2000	338-2988 (Σ15 ПАУ)	Tolosa et al, 2004
Iran shelf	2001	94-1789 (Σ15 ПАУ)	
Northern part (Russian aquatic area)	2000	6-345 (Σ15 ПАУ)	

Kazakhstan shelf	2001	7-294 (Σ15 ПАУ)	
Northern shelf Volga River channels Northern shelf Northern shelf Delta Volga	2003 2004 2004 2005 2009	3-17 (Σ8 ПАУ) 8-154 (Σ8 ПАУ) 6-76 (Σ8 ПАУ) 4-4800 (Σ10 ПАУ) 2-25 (Σ10 ПАУ)	Nemirovskaya and Brehovskikh, 2008 This study

The low concentrations of suspension in surface waters are characteristic for mean waters. Diffusion and dilution play leading role at merge of Volga to its inflows. Concentration of hydrocarbons in surface waters and sediments deposits corresponded to their background level that can testify to insignificant of oil pollution. Change of the investigated parameters basically occurs under influence of natural processes. However increased part HC in C_{org} of arenaceous sediments of Volga river delta probably made for polluting oil compounds influence.

The composition of the HC in the particulate matter and bottom sediments in the area of the Volga River estuary undergoes regular changes due to the transformation and precipitation of both anthropogenic and natural compounds. The particulate matter is considerably finer than the bottom sediments, and the grains of biogenic particulate matter do not reach the bottom because of the dissolution in the water mass. Therefore, pronounced distinctions are observed in the composition of the filtered particulate matter and bottom sediments. The deviations from a simple dilution of riverine OM with marine substance are caused by gravitational, physicochemical, and biological processes. As a result, in the physicochemical part of the marginal filter, in the area of the avalanche sedimentation, the highest degree of HC accumulation in the bottom sediments takes place (up to 4557.9 µg/g for AHC and up to 4800 ng/g for the total PAH). Because of this, no correlation is observed between the HC content and the grain-size composition of the bottom sediments.

The synthesis of the data obtained in 2003–2009 showed that the geochemical barrier of the Volga River–Caspian shelf acts as a filter preventing the anthropogenic HC from penetration into the sea. Because of this, probably, despite the Volga River supplying a great amount of anthropogenic compounds, the northern shelf is one of the least polluted areas of the Caspian Sea [Tolosa et al, 2004].

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HYDROLOGICAL REGIMEN FEATURES OF DELTA VOLGA

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Keywords: the delta of the Volga, hydrology, regulated flow

The main peculiarity of delta Volga hydrological regimen is great rippling of water run-off, which leads to high waters. This makes the delta look like a continuous stretch of water and causes lack of water. The Lower Volga is characterized by extremely developed river which divides delta Volga into several little islands. The hydrographic network is developed in the middle and lower part of the delta most of all.

The largest passages of the delta from west to east are the branches Bakhtemir, Staraya Volga (Old Volga), Kizan, Bolda, Buzan and Kigach. These main branches 0,3-0,6 km wide divide into numerous canals and little streams approaching to the Caspian Sea like a fan. The basis of the hydrographic network are streams, which are little waterways 30 m wide.

There are two extreme phases in the hydrological regimen. They are low water and high water. During low water season many streams and passages dry or become shallow. During high water period they turn into functioning branches. The high natural degree of drainage of the delta intensifies with the help of some fish bypass channels.

The regulation of the Volga flow is made on several levels. The first level, which is the main level of the regulation of the Volga flow, is realized by the cascade of Volga reservoirs.

Since 1959 the hydrological regimen of The Lower Volga is regulated artificially by the cascade of the Volga reservoirs (Novikov, Ilyin, Saphronov, 2000), though the regulation of the Volga flow began from the construction of the Ivankov reservoir in 1937. The last dam on the Volga (The Volgograd dam) was built in 1959 and it saved the region from disastrous flood twice, like, for instance, in 1908 or 1926. In 1979 and 1991 great loss wasn't avoided, but it could be less in case when the dam had dropped the greater volume of water during winter season, including March.

The functioning of the waterworks facility system changed the hydrological regimen of the river Volga that leads to cut of high water tops and decreasing of their duration (Grin, 1971). The volume of annual flow didn't almost change. In 1931-1958 the volume of the annual flow of the River Volga near Volgograd was on average 237 km^3 and from 1959 to 2006 it was on average 248,7 km^3 (Picture 1). However, the whole volume of flow during high water season (April-June) essentially reduced in comparison with the whole volume of the annual flow (Picture 2). In 1931-1958 the volume of high waters was on average 135,5 km^3, and since 1959-2006 it came to 106,3 km^3. The decreasing of high waters level, the reducing of its duration period, the changing of high waters raising intensity and abatement were mainly caused by increasing of flow in winter season. Thus, before regulation flow volume in winter season was 24 km^3, and after that it came to 49 km^3.

In 1931-1958 the summer flow was in the interval 93-212 km^3, in 1959-2006 it was in the interval 75-159 km^3. In the second period redistribution between months of annual flow took place dew to the power engineering specialist's demands and to the real possibility of floods avoiding, and as a result peak-to-peak value of spring high waters essentially decreased. Winter fault from the Volgograd reservoir increased on average on 20 km^3, in 1959-2006 the annual fault rather increased in comparison with the natural annual fault in 1931-1959 (it's the reflection of the planet tendencies).

In 1979 and 1991 the catastrophic flood of the delta happened where the similar volumes of the annual (320 km^3) and spring (April-June) floods of 146 and 159 km^3 size took place. The peak level was fixed on the grades 3,87 m and 3,70 m. The excess of water is 25-30 km^3 and it is a half of the excess of the year 1929 and if not the dam and the winter fault the loss from flood would be much greater. In redistribution of annual flow in dangerous and forecasted situations it is necessary to drop much water in winter period, including march, reducing the volume of water higher the dam for reception of high waters and, thus, saving sufficient stock of water for summer-autumn period. In both cases (which the hydrological data testify) there wasn't supplementary fault during winter and at the beginning of spring in comparison with autumn period of the previous year.

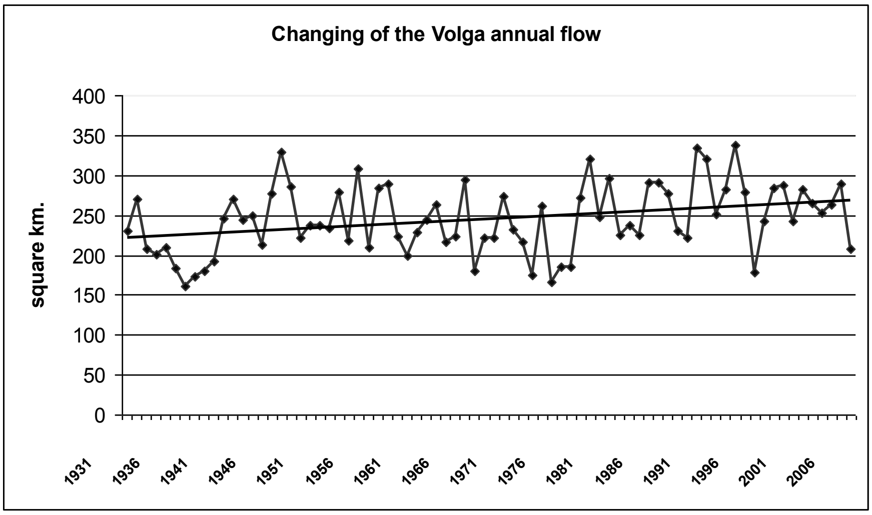

Fig. 1.

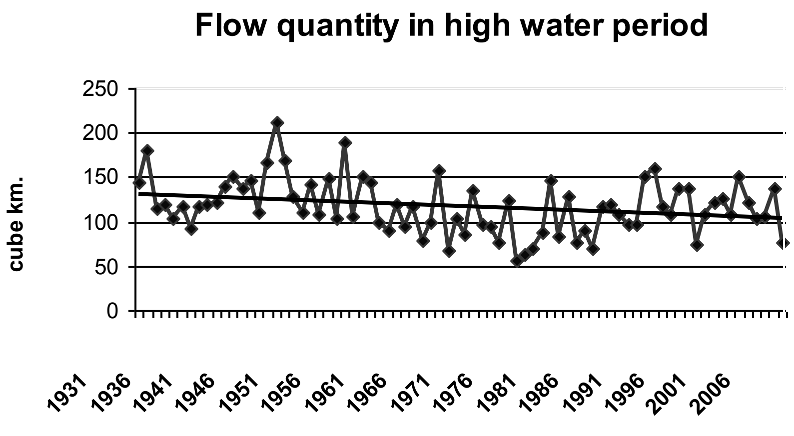

Fig. 2.

In 2005 when the volume of spring fault was less then in 1991 (about 135 km^3) the dam flooded the region with much loss, the peak level of water grade was higher than 3,7 meters. During winter there was weak beginning of discharge and great high waters weren't awaited. But the power engineering specialist's flooded the region very rapidly and rapidly as well reduced the fault, thus to June, 25 the level dropped on 2 m. The "augmented" fault in 30 thousand m/s is 26 km^3 for 10 days. It is an excess which was mentioned above. It should be dropped beforehand or, if the stock of the reservoir allows, it should be left there without coming the fault speed to the critical point.

Blocking of the river doesn't change either size of annual flow or its annual rippling, dew to climate conditions on a huge drained area of the river basin. That's why on the scheme of annual flow for the last century no changes can be seen, but only the middle line (trend) shows a slow growing of the river flow from 1931 to 2006 (it's the reflection of the planet tendencies). The rippling of annual flow itself lies in a large interval between 150-350 km^3 for the period of instrumental changes where the average value is 250 km^3.

Before building of the dam more than 50% of annual flow fell on April and June, some years high waters caused damage to the environment and human. And the dam is built in order to arrest the excess of season water in the reservoir, using it economically during all the year and saving the stock for winter period. However the abilities of season redistribution of annual flow for the lower territories with the help of any dam (independently on its height and volume of the reservoir) are restricted because of technical factors (here the limit of water fault speed is meant).

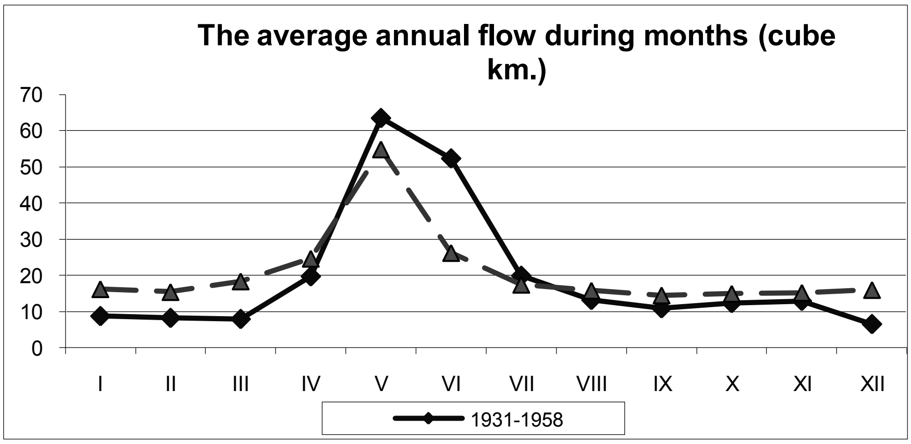

Fig. 3. The average annual flow during months.

The top of high waters (maximum level of water) is achieved 10-15 days earlier, though spring raise begins at the same time (the end of April and the beginning of May) or just 2-3 days earlier. The end of high waters can be seen a month earlier than before regulating of flow (Shchuchkina, 1996).

Spring volume of water, dropped by the Volgograd dam reduced to 30-50% of annual flow, and the main value of water is dropped in May as earlier. The average decreasing of high waters volume from 135 to 105 km^3 didn't almost change the time of its beginning (the end of April), the speed of raising of water and the date of its maximum level (the end of May and the beginning of June), speed of water fault, the duration of high waters period diminished from 80 to 60 days and. As a result, the flooded territories area decreased that is favourable for agriculture (banking of territories demands less time).

The specific peculiarity of artificial regulation period of water flow in The Lower Volga is winter prior to high waters period levels of water, caused by faults from the Volgograd reservoir. The main changes of Delta Volga hydrology are shown in the Table 1.

Table 1.

Hydrological indexes	Before regulation (before 1959) km^3	After regulation (since 1959-2006)
Volume of annual flow	237	248,7
Volume of high waters	135,5	106,3
Date of high waters beginning	the end of April	the end of April
Date of high waters end	the middle of June	the beginning of June
Total duration of high waters period	70-80 days	60 days
Date of maximum level of water	the beginning of June	the end of May
Rising water speed	5,5 sm/day	7,5 sm/day
Lowering water speed	6,4 sm/day	7 sm/day

After regulation water flow during high waters period began to depend on its duration, but before regulation it depended most of all on its height. The lowering of the height of high waters caused diminishing from 90% to 40-60% of annual flooded territories area. Partially it is the result of sprayed agricultural grounds banking (200 thousand hectares since 1950s) (Lewmens, 2006).

At present, almost all the delta territory is subjected to banking (except for part of the delta front). It is in order to save not only sprayed and pasturable grounds, but also recreation objects, that reflects on distribution of water among different ecotopes.

The next level is Delta Volga flow redistribution with the help of bifurcation gate, which came to exploitation in 1977 and was meant for improving of the regimen of irrigation of the delta Eastern part owing to decreasing of water flow into its Western part and ilmens under prairies (Musatov, Katunin, 1977; Musatov, Krasnozhon, Fedoseev, 1981).

In the beginning of 1960s the project of creation of the Lower Volga HPS in the Enotaevka region, integrated with the bifurcation gate of the reservoir with the backwater to Volgograd and huge dam was worked up. It would save from flood all Volga and Akhtubinsk flood-lands and near upland territories. However, because of catastrophic ecological consequences of HPS building, the project was canceled and it was decided to limit by building of the bifurcation gate near Verkhnelebyazhie village. The Volga bifurcation gate was planned when intense growth of water impressment from the Volga took place for spraying needs, and that coincided with the natural Volga low waters period in 1970.

Since 1977 to 1988 the bifurcation gate was put on five times (1977, 1978, 1982, 1983, 1988). After 1990 the bifurcation gate doesn’t function. First of all, low waters natural cycle of 60-70s finished, secondly, the Volga water is less used for spraying. Besides a number of negative ecological consequences for the delta is found, for example, there is insufficient watering of the Volga Western part. V. Golub, N. Novikova and N. Chorbadze (1986) point out that on the territory of Western ilmens under prairies the growth rebuilding scales in kserophitisation and halophitisation directions entailed by lowering of biological and agricultural production are more considerable than in Volga and Akhtubinsk flood-lands and in Delta Volga. The bifurcation gate work in project regimen will cause speeding-up the processes of plants changes and appearance of this process on a huger territory.

The third level of hydrological regimen transformation is realized directly in the delta. It is a complex of land-improvement activities aimed to the regulation of flood of Ilmen-Bugor region territory of (the western ilmens under prairies). They are building of dams, bulkheads, road embankments, partitioning the water flows, laying of artificial water sections with forced (with the help of pumps) supplying of water in the ilmens, widespread usage of spraying and drainage of large ilmens. Creation of water-ways with forced supplying of water is meant for it artificial watering of ZPI. At the same time the natural network of waterways and ilmens is mainly used. The last one in some cases plays a part of natural reservoirs for agricultural spraying needs. For the purpose of compensation of deteriorating ilmens natural irrigation it was planned to build 21 water way. In the beginning of 90s only 7 ways come into exploitation, in which connection 5 of them were created according to a temporary scheme with moving pump stations, which were less powerful than it was projected (Golub, Novikova, Chorbadze, 1986).

Anthropogenic transformation of river flow changes all processes of the delta formation, water-landing and alluviality, as a result it breaks ecotone landscape structure and creates the danger of hydromorphic ecosystems vanishing from the deltas of rivers in arid regions (Novikova, 1997).

Thus, in most cases, that is in middle waters years, the characteristics of flood (annual flow and high waters) don’t have differences from middle indexes of the “before-dam period”. In low waters periods the power engineering specialists limit water flows (in comparison with usual practice) in April and May, defending their own interests and navigation ones, and also agriculture interests (it needs a short flood period) and the Delta fauna. In years abounding of water the power engineering specialists defend the Lower Volga from flood. That’s why the balance of all spheres of national economy, including energy, includes only one thing: it prevents catastrophic floods. Wasn’t the removal of emergency situations presupposed after the regulation of Volga flow?

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«DEGRADATION» AND CRISIS PROCESSES OF DELTA VOLGA LANDSCAPES

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Landscape functioning is provided by integrated processes promoting coupling of facies and stows. Landscape stability is connected with the necessity of its components to save its structure and functioning in external influences. For example, trigger mechanism with specific behaviour of system (hysteresis) lies in the basis of phytocenosis stability provision in ecotone zones [7, 10, 12]. Stability of ecosystems existence of the delta plains should be observed as space and time continuity supported by ecotone landscape structure [5]. As a natural system each landscape has important qualities: self-organization, self-regulation, self-renewal thanks to which stable development of ecosystem and ability to resist degradation and crisis processes are provided.

To reveal the degree of degradation and utmost admissible loadings on ecosystems it is necessary to create informational base to realize ecological monitoring which includes indicators of dynamics of abiotic factors and indication objects [9].

Landscape degradation (transformation) differs by the following features: 1) simplification of spatial structure and species composition of stows; 2) breaking of biogeochemical barriers (firstly, in soils) and, as a result, violation of migration cycles in ecosystems; 3) dismissal and accumulation of toxic substances; 4) breaking of functional connections in landscapes, appearing of anthropogenic landscape forms [15]. For practical exposure of degradation processes in landscapes it is necessary to know not only signs, but also mechanisms and symptoms of these processes.

Crisis is an inalienable condition of existence of any system. A.D. Armand [1] points out that "… it is not far time when we will learn to control passing of crises in order to get maximum return in form of useful innovations with minimum destructions and loss.

Crises are natural and regular stage of development of any natural systems, including ecosystems. Positive role of crises is proved by the fact that during critical moments of development in particular it is possible that structure will be rebuilt and innovations will appear though they bring up in their usual state because of stability mechanisms maintenance. Crisis processes in systems of different nature have a number of similar patterns. In critical points changing of system behaviour programs and their elements takes place, however the rules of these changes are based on universal self-organization processes. Knowing of these processes can allow making an analysis of causes of crisis phenomena appearing, to make the diagnostics of system state, to define stage of crisis. It will allow to make forecasting of crisis phenomena dynamics and to define character of necessary managing influences. Crisis development happens according to definite rules. Ways of crisis development can be different; they are determined by degree of crisis deepness, by character of external influences and by specifics of system organization under studies. Depending on degree of crisis deepness, ecosystem can undergo various changes: from insignificant structural changes to total breaking of system. The crisis dynamics can be described as a consecutive process, passing from phase to phase, where each previous crisis stage prepares (but not predetermines) the next one, influences on character, tempos, direction of the following dynamics, makes for ability of its continuation [14].

Violations of natural zone cause fast transformations and often shape degradation of natural systems – ecosystems and landscapes. Violations in ecosystem structural organization composition and inter-system connections break landscape ergodicity that is functional community of genetically connected landscape groups. On this basis secondary endogenetic mechanism of self-breaking of landscape and ecosystems interactions system. It causes permanent species regroupings in biotic associations, that serves as a base for appearing of spatial self-enlargement of violations centre phenomenon [2].

V.S. Zaletaev [2] points out a number of events in system transformation:

1) changes in habitats (soil, surface integrity, moisture conditions of territories, hydrological regimen of reservoirs, etc.);

2) changes in compositions of biotic associations, elimination of some species, including foam generators and violation or weakening of bioproduction process;

3) development of erosion processes and reinforcement of substances transport, changing and energization of geochemical streams;

4) energization of biota settling and substantial changes in species and associations correlation, development of rapidly passing succession;

5) breaking of zonal landscapes structure and appearing of organisms and casual interrelations during the period of chaotic transference;

6) appearing of districts where conditions of "second order life optimum" arises, that is optimum for a few specific species and local little-rate plant associations form on these territories, and they can create flashes of quantity of some species and splash of bioproduction energization process;

7) the mosaic structure of ecological conditions rises steeply and higher division and contrast of biotic covering;

8) in such conditions formation of a new structure of compositionally changed biotic associations happens, which differs from the initial one and more simple scheme by initial connections, absence of forming and casual character of external interactions. Combination and territorial neighbouring of new and actively functioning microgroups and organisms associations with rapidly repeated reproductive cycle (for example, annual and biennial plants – *Salicomia europaea, Suaeda altissima*) and epibiotic degraded former associations and their fragments as well as districts, territories practically lacking in orderly biotic covering, create ecotone system which is typical for rapidly changing conditions of ecologically destabilized environment [3, 4].

Thus, V.S. Zaletaev [2] revealed the main characteristics of destabilized natural environment. Transformation covers different levels of organization: functional and structural, landscape connections and systems stabilization mechanisms. Changes of dynamical characteristics, qualitative ecosystem changes and tendencies of biocomplexes development are shown.

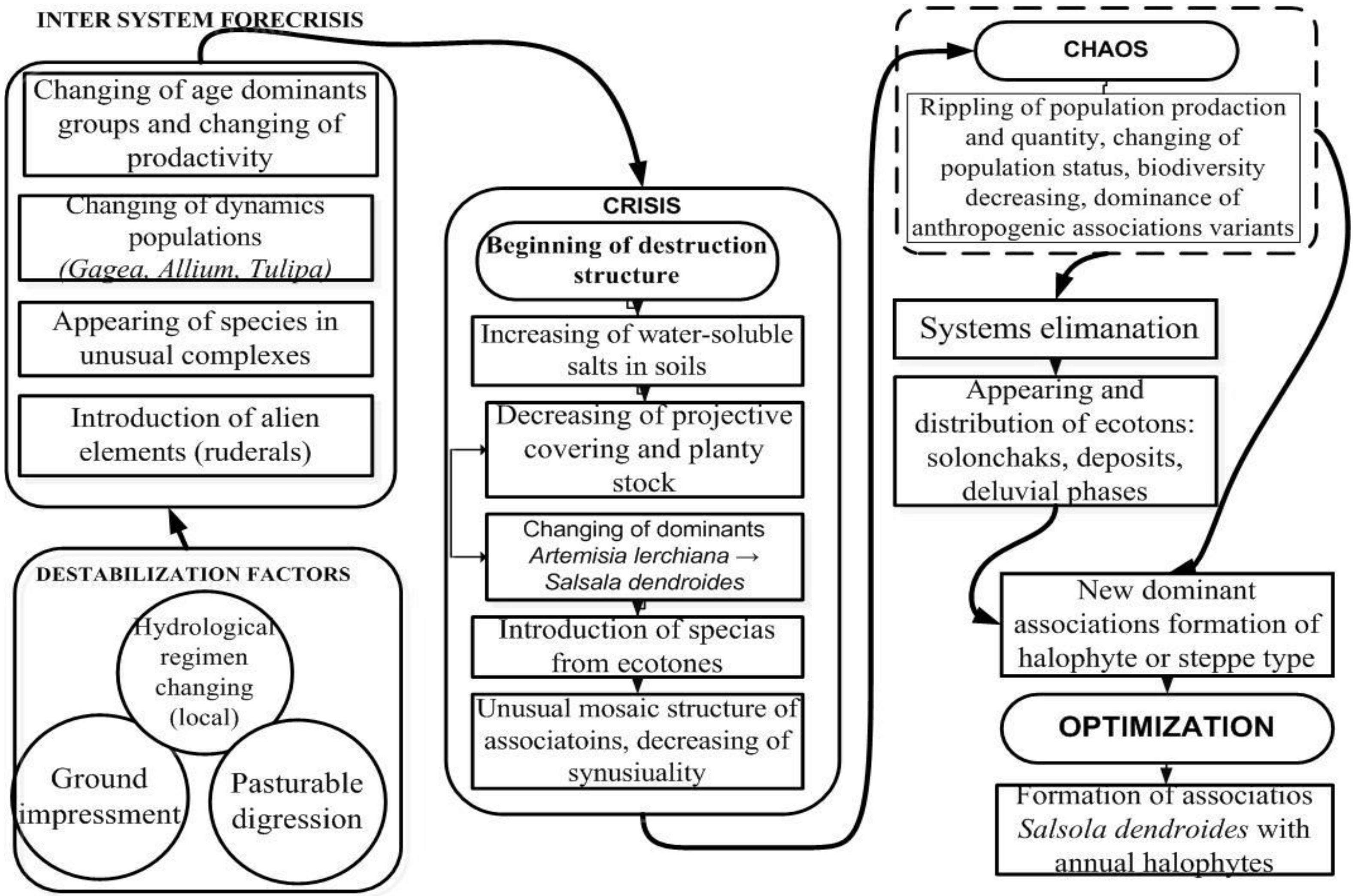
D.A. Slavinsky [14] worked out a universal stage-by-stage approach to passing of crisis processes, including the most general phases and crisis processes: 1. fore-crisis; 2. Structure breaking; 3. Chaos; 4. Nucleus of crystallization; 5. The first structure formation; 6. The secondary crisis; 7. The secondary structure building. On the base of the worked up system model of crisis processes passing the analysis of crisis phenomena in Delta Volga landscapes is made.

The indicators of crisis processes in ground ecosystems in delta Volga in the conditions of constantly changing hydrological regimen are the following (Picture 1):

FORE-CRISIS LEVEL (ORIGIN OF CONFLICT)

The external factors provoked the crisis are changes in hydrological regimen and pasturable depression. There are three processes on the fore-crisis level: changing of structural sub systems peculiarities; violation in management system and structure "loosening". Each process is characterized by the symptoms with a definite number of indicators:

1. Changing of age groups and species phytomass correlation;
2. Changing in the quantity, correlation and dynamics of populations (for example, *Gagea, Allium, Tulipa);*


INTER SYSTEM FORECRISIS
Changing of age dominants groups and changing of prodactivity
Changing of dynamics populations (Gagea, Allium, Tulipa)
Appearing of species in unusual complexes
Introduction of alien elements (ruderals)
DESTABILIZATION FACTORS
Hydrological regimen changing (local)
Ground impressment
Pasturable digression
CRISIS
Beginning of destruction structure
Increasing of water-soluble salts in soils
Decreasing of projective covering and planty stock
Changing of dominants Artemisia lerchiana → Salsala dendroides
Introduction of specias from ecotones
Unusual mosaic structure of associatoins, decreasing of synusiuality
CHAOS
Rippling of population prodaction and quantity, changing of population status, biodiversity decreasing, dominance of anthropogenic associations variants
Systems elimanation
Appearing and distribution of ecotons: solonchaks, deposits, deluvial phases
New dominant associations formation of halophyte or steppe type
OPTIMIZATION
Formation of associatios Salsola dendroides with annual halophytes

3. Stabilization of high subsoil waters level (SWL) causes fluctuation substitutions of edificators in phytocenoses. For instance, substitution of *Elytrigia repens* by *Eleocharis palustris* on the middle-level meadows.

4. Changing of microclimatic biotopes characteristics;

Changing in the intensity of biogenic elements entrance (alluviality);

5. Weakening of environment forming role of edificators *(Elytrigia repens Cynodon dactylon*, *Agropyron fragile);*

6. Changing of elementary soil processes (for example, gleization);

7. Erosion processes (deflation and water erosion);

8. Changing of microbe associations structure [13];

9. Appearing of nonrelevant species (ruderals, cenophobes, explerents);

Violation of spatial correlations in biotopes thanks to ecotones appearing (destroying of the Baer knolls causes local appearing of salinized soils and alkaline land);

10. Lowering of associations integrity and stability.

LEVEL OF THE SYSTEM DESTRUCTION

On system breaking stage the following processes are distinguished: influence of provoking factor(s), elimination of the dominant, destroying of ceno-generative connections and system fragmentation. Each process is characterized by symptoms with a definite number of indicators:

1. Growth of threshold index of hydrological indicators higher than fluctuation diapason: high waters, flood, subsoil waters of chemical compound level in the environment: water-soluble salts, separate ions, biogens, toxic level, salinization;

2. Changing of species habitat conditions thanks to constitution of new ecotones as a result of territories banking and soil harvesting;

3. Introduction of new species (pest outbreak of *Xanthium strumarium* and *Alhagi pseudalhagi* on Delta Volga meadows);

4. Elimination of edificators, dominants and specialists → chain reaction of destroying (the elimination of one population causes structural and functional changes in another);

5. Changing (decreasing) of production in older groups in phytocenosis. Phytocenosis and separate populations' biomass has a cyclic character and is subordinated to intraspecific dynamical structure. The biomass wavering period is strongly specific that's why in optimum ecological conditions the species biomass can be on a low level. In meadow phytocenoses mechanism of substitution of one edificatory by another is found [8].

6. Changing of phyto-variation. This indicator has diversified character. For phytocenoses (especially monodominant) having achieved climax low biodiversity indexes are indexes of dynamical balance in ecosystem [7];

7. Changing of growth speed of some species thanks to additional substances gains in biotope and soil microbiote energization [13];

8. Changing of species status. Separate species change their status while structural changes in ecosystem take place. This way, for example, *Salsala dendroides* is an edificatory for plants associations of Baer knolls during pasturable digression, but in conditions of intact structure of soil covering this species is single and can be found on slopes and talus materials;

9. Destroying of spatial structure and changing of temporal dynamics.

CHAOS LEVEL

The following processes are typical for this stage: departure and destroying of system, formation of new associations and connections. Each process is characterized by symptoms with a definite number of indicators:

1. Reinforcement of environmental factors (hydrological, anthropogenic) promotes following destroying;

2. Reinforcement of conflict among phytocenoses and connections rupture;

3. Sharp waving of biomass and species quantity;

4. Mass elimination of environment forming flora-elements of *Poaceae* and *Asteraceae* families [11];

5. Flash of early small species abundance (reactive bank-seeds, explerents);

6. Formation of new ecotones and encreasing of ecotones area (buffer zones) and as a result "exertion" zone expansion;

7. Changing of morphological and ecological species perculiarities (species of *Artemisia*) [6];
8. Widening of ecological diapason of *Chenopodiaceae* and *Brassicaceae* family species;
9. Short-term stabilization of internal area thanks to new unstable plant associations;
10. Prevalence of life forms with a short life cycle [11].

LEVEL OF "CRYSTALLIZATION NUCLEUS"

1. Energization of subdominants or new life-forms *Artemisia lerchiana*;
2. Appearing of attendant species around subdominants and cenoses formation;
3. "Cristallization centers" formation;
4. Consistent change of subdominants *Agropyron fragile → Artemisia lerchiana*; *Artemisia lerchiana → Salsola dendroides*;
5. Conflict or integration of local structures;
6. Appearing of new dominants *Salsola dendroides*, *Anabasis aphylla*, *Salsola australis*;
7. Appearing of attendant species *Climacoptera brachiata*, *Descurainia sophia*, *Goldbachia laevigata*, *Capsella bursa-pastoris*, *Cardaria draba*, *Lepidium perfoliatum;*

Giobotany investigations in Delta Volga from 1996 to 2006 allow to precise some crisis passing positions:

1. *Crisis drawing:* It is typical for ecosystems to have regular changes of states in time. Each change of states is characterized by a definite number of active and passive peculiarities. Depending on their combination and stadiality so called "enters" of non-orderliness (chaos) are formed. Changes in ecosystems are possible in the following cases: a) system functioning dew to interaction of ecological conditions fluctuations; b) character of dynamics thanks to creation processes and substances accumulation; c) the general landscape evolution.

2. *The cause of crisis:* When the developing system passes the first stages, main cause of formation and distribution of crisis processes is often disturbing influences (degree of influence) of ecological factor. Systems being in state of dynamical balance have a high stability threshold and weak disturbing influence is not always able to play apart of a "trigger" having started crisis.

3. *Experiments:* It is not typical for ecosystems to react adequately on external influence. The building of a new structure will depend on deepness of system structure violation and kind systems touched by "experiment". If crisis touched only one of sub systems than system will approach to initial state thanks to different stability mechanisms, acting, for instance, in the frameworks of geochemical soils subordination, landscape memory, new ecological rows building (ecological sequence), mosaic structure or substitution.

Anthropogenic influence often has a catalytic character and leads to a faster passing of stages of natural ecosystem successive development.

Desertification of the delta plains ecosystems is a natural process of their development, defined by natural evolution of the delta landscapes in the direction of zonal complexes formation. It happens with the help of successive changes one ecosystem by another in the process of halo-, xero- and psammophitization [5].

For crisis and stable stages in ecosystems one and the same processes are typical: changing of inner environment and structure, change and elimination of the elements, ecotones distribution. If stable stage is characterized by duration and adaptation, crisis stage has short time interval and structures breaking.

Ecosystem in developing process and disturbing factors create presuppositions for crisis process development (through anthropogenic influences) and on some stages anthropogenesis quicken thief passing.

Absence of natural irrigation of hydromorphic ecosystems (meadows, alkaline soils). The system of pasture rotation and landscape structure (nucleus) breaking are risk factors for ecosystem especially in periods of its weak stability. These factors can serve as a "trigger" which gives start a zoom crisis for Delta Volga ecosystem.

An optimum decision on problems of rational natural reaches management, deltas irrigation management and saving of species diversity is possible in case of joint observation and revelation of process passing rules in ecotones landscapes [5]. For defining of crisis stage, specifics of its passing and forecasting of ecosystems state system monitoring investigations and selection of universal indicators of the crisis processes passing are necessary.

Changes taking place in Delta Volga landscapes reflect conceptual statements of ecologically destabilized environment theory, worked up by V.S. Zaletaev and proves universality of system development crisis stages scheme worked up by D.A. Slavinsky [14].

Leaving of problem-oriented approach in science and practice to preventive will help to avoid many negative phenomena in nature management. The crisis theory and system approach as methodological ensuring will allow forecasting changes in ecosystems with the help of bioindicates and bioindicators collection with a big likelihood ratio.

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THE INFLUENCE OF FLUCTUATIONS IN THE LEVEL OF THE CASPIAN SEA ON THE DIVERSITY OF HELMINTHES OF WILD GRAY GOOSE*(ANSER ANSER)* AND WILD DUCK *(ANAS PLATYRHINCHOS)* IN THE DELTA OF VOLGA

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Keywords: sea level, helminthes, biodiversity, cestodes, trematodes, nematodes, proboscis

INTRODUCTION

Parasitic worms (hearta) – helminthes – are the necessary link of biocenoses, who perform important functions in it:

- there are no single species of animals in the nature, which would not be invaded;
- in the implementation of life cycles, biohelminthes unite into a single unit of invertebrate and vertebrate animals – hosts (owners);
- larval forms of many species of helminthes serve as food to other animals;

- helminthes provide one of the mechanisms that regulates the size of their hosts, etc.

The studying of helminthes of wild gray goose and wild duck (mallard) in the delta of the Volga River began in the 40-th years (Dubinina, 1940), she studied 41 specimen and found 16 species of parasitic worms. In 1941 T.A. Ginetsinskaya (1949) studied helminthofauna of ducks, including wild ducks (mallards). Some information about the helminthes fauna of wild gray goose and wild duck (mallard) is in the work of T. Ilyushina (1968).

MATERIAL AND METHODS

51 individual of wild gray goose and 78 specimens of wild ducks were examined in the Delta of the Volga in 1985 – 2005 with the help of the method of complete helminthological autopsies (Skrjabin, 1928), and sometimes the quantitative data is given: extensiveness of the invasion (EI, %) and the intensity of the infection, limits (AI, ind.)

RESULTS AND DISCUSSION

35 species of helminthes (8 species of cestodes, 23 species of trematodes, 4 species of nematodes) were found in the wild gray goose, and 76 species (26 species of cestodes, 36 – trematodes, 12 – nematodes 2 – proboscis) were found in the wild ducks (mallards).

The basis of helmintocenosis of wild gray geese from cestodes comprises *Drepanidotaenia lanceolata* (Bloch, 1782) (EI 31,4%; AI 2 – 32 ind.), *Myxolepis collaris* (Batsch, 1786) Spassky, 1959 (EI 1 – 70 ind.), *Retinometra longicirrosa* (Fuhrmann, 1906) (EI 15,7%; AI 2 – 200 ind.), *Tschertkovilepis setigera* (Fröhlich, 1789) Spassky et Spasskaja, 1954 (EI 15,7%; AI 2 – 20 ind.), *Sobolevicanthus aspirantica* (Zaskind, 1959) Maksimova, 1963 (EI 13,7%; AI 2 – 20 ind.). From the 8 species the biology of only 4 species of cestodes was studied. Intermediate hosts are represented mainly by crustaceans: copepod copepods and amphipods.

Apatemon minor (Yamaguti, 1933) – (EI 45,1%); *Echinostoma dietzi* Skrjabin, 1923 (EI 27,4%; 1 – 104 ind.); *Prosthogonimus ovatus* Rudolphi, 1803 (EI 27,5%); *Echinostoma paraulum* Dietz, 1909 (EI 24,5 %); *Echinostoma chloropodis* (Zeder, 1800) (EI 23,5%); *Echinostoma revolutum* (Fröhlich, 1802) – (EI 17,5%); *Psilotrema simillimum* (Muhling, 1899) (EI 15,7%) are the most widely spread trematodes in wild gray goose. The biology of 17 species of trematodes is also known. The development of the majority of the species is connected with clams, in some cases, leeches, insects and amphibians.

Helminthofauna of wild gray goose contains 4 species of nematodes. The development of a single biohelminth – *Tetrameres fissispina* (Diesing, 1861) Travassos, 1914 is connected with amphipods and other crustaceans.

The fauna of mallard's cestodes is represented by 26 species. The maximum extensiveness of invasion was found in *Microsomacanthus abortiva* (Linstow, 1904) Lopez-Neyra, 1942 (EI 25,0%; AI 1 – 32 ind.), *M. collaris* (EI 13,3%; AI 2 – 22 ind.), *Echinocotyle rosseteri* Blanchard, 1891 (EI 11,7%; AI 1 – 4 ind.).

The biology of 15 species of cestodes is known. The development takes place mainly through crustaceans: copepods, sinks, amphipods, one species develops through copepods and cladocerans (intermediate hosts) and gastropods (additional masters).

There are 36 species of trematodes found in wild ducks (mallards). The maximum extensiveness of invasion was found in *Bilharziella polonica* (Kowalewski, 1895) (EI 24,4%; AI 1 – 6 ind.); *Psilochasmus oxyurus* (Creplin, 1825) (EI 11,5%; AI 11 – 300 ind.); *A. minor* (EI 11.5%; AI 4 – 31 ind.). The biology of 26 species was studied and, as in a gray goose case, the development of wild ducks takes place mainly through the mollusks, insects, leeches, and amphibians appear to be additional hosts in four cases and the fish – in six cases.

12 species of nematodes with low extensiveness invasion were found in wild ducks (mallards). Biology of 9 species is known, 4 species of them are geohelminthes. The development of biogelminths of one type takes place with the participation of other amphipod crustaceans, the Cyclops and diaptomusy are the intermediate hosts of the other two species, – fry fish, frogs, tadpoles and dragonfly larvae-are reservoir hosts, two species develop with the participation of earthworms. Acanthocephalans are presented only in the helmintofauna of wild ducks: *Polymorphus minutus* (Goeze, 1789) (EI 1,9%; AI 1 ind.) develops through gammarids and *Filicollis anatis* (Schrank, 1788) (EI 1,3%; AI 1 ind.) develops through *Asellus aquaticus.*

As the researches of fauna of parasites of wild gray geese and wild ducks (mallards) were conducted earlier (in the 40-ies and 60-ies years), we have an opportunity to compare infestation of birds in different periods (tab. 1, 2).

Table 1

Extensiveness of invasion of wild gray geese by helminthes according to different authors

Helminthes	EI according to data	
	Dubinina, 1948	Our data, 1985-2000
Genus Apatemon	-	45,1
Genus Echinostoma	34,3	3,9-24,5
Genus Drepanidotaenia	22,9	35,3
M. collaris	-	15,7
Pr. ovatus	2,4	27,5
Genus Psilotrema	7,3	21,9
Genus Reyinometra	77,1	15,7
Genus Sobolevicanthus	4,9	2,0
S. falconis larvae	-	15,7
Tsch. setigera	34,3	15,7

Table 2

Extensiveness of invasion of wild ducks (mallards) according to different authors

Helminthes	EI according to data		
	Ginetsinskaya, 1949	Iljushina, 1968	Our data 1985 – 2000
Genus *Apatemon*	8,0	33,3	23,0
B. polonica	1,9	-	24,4
C. megalops	Widely spread	-	-
Genus *Cotylurus*	1,9	33,3	23,3
E. recurvatum	-	25,0	3,9
M. abortiva	8,0	-	25,0
M. collaris	1,9	-	13,3
Notocotylus attenuatus	100,0	41,7	6,7
Pr. ovatus	-	16,7	5,1
P. oxyurus	-	-	18,5
Genus *Psilotrema*	-	16,7	13,3
Sch. rarus	30,0	-	1,8

The dynamics of the fauna of parasites is connected with the changes in the lower reaches of the Volga River delta under the influence of abiotic (crustal movement, long-term dynamics of climate, changes in the level of the Caspian Sea, etc.), biotic and anthropogenic factors (regulation of the Volga runoff, dredging in periods of recession of the Caspian Sea, the acclimatization of animals, economic growth in water consumption, exploration of oil in the North Caspian Sea and many others).

The period of 1935 – 1958 years is characterized by a drop in the level of the Caspian Sea – from 1940 to 1956 it declined by 64 cm according to Makhachkala’s rail, the shallows’ area increased, new strips of land were formed etc. Phytophilous and psammoreofilny complexes prevailed, chironomids and crustaceans, especially mysids dominated. Among the shellfish, filter-limnoreophyle bivalves dominated. (Ivlev, 1940; Kosova, 1958).

The species of Notocotylus, *S. falconis* larvae, *Schisthogonimus rarus*, *C. megalops* were most prevalent for mallards, and the species of Retinometra, *Tsch. setigera*, genus of *Drepanidotaenia*, genus of *Echinostoma* were correspondingly prevalent for gray goose**.** Only those types and kinds reach the maximum development, whose development is associated with phytophilous organisms such as intermediate hosts, or crustaceans, or insects.

The extensiveness of invasion of a number of the helminthes species of wild duck (mallards) (*B. polonica, E. revolutum*) and wild gray goose (s. Echinostoma) increased from the 40-ies to the 90-ies. All these species of helminthes have large circle of intermediate and additional hosts (mollusks, insects, frogs, tadpoles, fish) and if the situation in biocenoses changes, they find favorable conditions for their development.

In the 60-ies, the role of limnophils and pelophils increased, some reophils dropped, the number of pulmonary mollusks increased 10 times: snails, holes and valvata (Filchakov, Chuykov, 1990). It was during this period, that the Caspian Sea reached the lowest point – 29 m 03 cm, and the Volga flowing became fully regulated due to the construction of the Volga Hydroelectric Station. It was the period when the basis for helminthes invasion in wild ducks was comprised by the genus of *Cotylurus, H. conoideum*, the genus of *Apatemon*, the genus of *Notocotylus*, the genus of *Echinoparyphium*. The genera of *Cotylurus*, *Tylodelphys*, *Apatemon*, *Echinostoma* and *H. conoideum* took the first place according to the invasion extensiveness , and such genera as *Cotylurus*, *Tylodelphys* and *Apatemon* were not recorded before, which is connected with the lymnophylous mollusks as intermediate hosts. Besides mollusks, leeches also (the genus of *Cotylurus*, the genus of *Apatemon*) take part in the development of some of these species, with fish and amphibians (the genus of Tylodelphys, *H. conoideum*) as the additional hosts, the species whose development is connected exceptionally with crustaceans has the extensiveness of the invasion which sharply reduces.

Since the late 70-ies the level of the Caspian Sea rises. Shift towards lower density of amphibian's insects, oligochaetes occur in the biocenoses, there appear impoverishment of the composition of species and reduction of the density of pulmonary mollusks and crustaceans (Filchakov, Chuykov, 1990).

The genus of *Echinostoma*, fam. Schisthosomatidae, the genus of *Apatemon*, the genus of *Microsomacanthus* are the basis of the complex of helminthes in the wild ducks (mallards) during this period, and the genera of *Echinostoma*, *Apatemon*, *Prosthogonimus*, *Notocotylus*, *Psilotrema*, *Drepanidotaenia*, *Retinometra* in wild grey goose. The genera of *Apatemon*, *Diorchis*, *Microsomacanthus* show the maximum extensiveness of invasion (table 1, 2).

2/3 of species develop through clams (the genera of *Echinostoma*, *Tylodelphys*, etc), however, some species have crustaceans and/or insects (*Pr. ovatus*, the genera of *Diorchis*, *Retinometra*, *Microsomacanthus*) as intermediate and additional hosts, fish and amphibians (the genera of *Apatemon*, *Tylodelphys*, etc.) participate in the developement of the majority of the species. Similar trends in the dynamics of the extensiveness of invasion are observed, for instance, in the genus of *Apatemon*, *Pr. ovatus*, *H. conoideum* in wild ducks (mallards). All of them have phytophilous and limnophilic shellfish as intermediate and/or additional hosts. Another dynamics of the invasion extensiveness was noticed in *Tsch. setigera*, *C. megalops*, *S. falconis* larvae, the genus of *Notocotylus* (Mallards). Sometimes it falls very sharply.

CONCLUSION

Among abiotic factors that form the fauna of helminthes of the wild gray goose and wild duck (mallard) in the Volga delta hydrological factor plays an important role, especially changes in the level of the Caspian Sea, which affect the composition of biocenoses, the components of which are intermediate and supplementary hosts for parasites.

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THE INFLUENCE OF THE CASPIAN SEA LEVEL CHANGING ON FORMATION OF THE HELMINTOFAUNA OF FISH IN THE VOLGA DELTA

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INTRODUCTION

Periodical fluctuations of the Caspian Sea level cause structural and functional reorganizations in the populations of the delta Volga ecosystem, including fishes, which participate in life cycles of many species of helminthes.

Formation of the parasitofauna of any region depends on many factors, therefore finding-out the reasons which cause changes of infectiousness of fish in the delta of the Volga, is possible by revealing of the correlated processes that occur in plant communities, quantitative and qualitative distribution, composition and number of invertebrate and vertebrate animals – hosts of helminthes.

In the given work we attempt to analyze the reasons of perennial changes of the helmintofauna of the fish caused by the transformation of their environment under the influence of the Caspian Sea level.

MATERIAL AND METHODS

Parasitological works were carried out in various areas of the delta of the Volga in 1976 – 2009. 4120 specimen of fishes were examined with the method of complete Helminthological autopsies and 35 species – with traditional methods (Skrjabin, 1928; Bikhovskaya-Pavlovskaya, 1985). The factor of the extensive invasion (EI) is used in the text, which shows the percentage of the host's infested specimen to the number of the examined ones.

RESULTS AND DISCUSSION

The fall of the Caspian sea stage, that began in 1930 – 40-ies, has led to the transformation of the delta's biotopes which was expressed in increasing of the area of shoals, in formation of new spits, intensive overgrowing of the delta Volga. Meanwhile cancroids, Oligochaeta, molluscums, chironomids` larvas prevailed in benthos (Ivlev, 1940).

This period was favorable for many species of helminthes of the fishes which life cycle occurs with the participation of the listed groups of the invertebrates. Maritas of such species as *Asymphylodora tincae*, *Orienthocreadium siluri*, *Sphaerostomum bramae*, *Bunocotyle cingulata*, *Bucephalus polymorphus*; metacercarias *Diplostomum spathaceum, Posthodiplostomum cuticola, Hysteromorpha triloba*, *Tylodelphys clavata*, *Bucephalus polymorhus* and *Ichthyocotylurus variegatus* were dominant in the trematodesfauna of carps (Dogel, Bikhovsky, 1938; Dubinin, 1952). Molluscums of such sorts as *Bithynia*, *Iymnaea*, *Unio*, *Gyraulus*, *Planorbis*, *Valvata*, *Hydrobia* participate in the development of these trematodes as intermediate hosts.

As a part of cestode fauna prevailed the species that were developing with the participation of *Oligochaeta* and crustaceous: *Caryophyllaeus laticeps*, *C. fimbriceps*, *Ligula intestinalis*, *Proteocephalus osculatus* (Dogel, Bikhovsky, 1938). The basis of nematode fauna was made by such species in which life cycle crustaceous, *Oligochaeta*, insects` larva participate: *Camallanus lacustris*, *C. truncatus*, *Raphidascaris acus* (Dogel, Bikhovsky, 1938). The alternate hosts of acanthocephaliasis *Corynosoma strumosum* are sandhoppers, and their definitive hosts are Caspian seal and big cormorant, the alternative hosts of *Pomphorhynchus laevis* are *Gammarus,* and definitive hosts – predatory fish.

The level of the Caspian Sea rises since 1978. In the first part of the sea level rising it didn't occur radical changes in the fish population, however there were tendencies to depression in hauls a portion of tangleloving and to increasing of semicheckpoints and limnoreophyle water species of fish (Kizina, 1995). The increasing of depths has led to changing of a hydro chemical regimen therefore there were shifts in biocenoses towards growth of number of invertebrates psammophitofilous and phitoreophilous complex against the background of depression in 2.5 times of a biomass of pulmonary molluscums (Filchakov, Chuykov, 1990).

Essential changes in the helmintofauna of the fish haven't been occured, though the depression of EI by some kinds of parasitic worms was outlined. The trematodes` infection rate compounds 91,1 – 100,0% for the species *D. spataceum*, 52,5 – 60,2% for *H. triloba*, 58,4 – 70,5% for *P. cuticola*, 54,2 – 61,1% for *T. clavata*, 17,3 – 60,0% for *A. tincae*, 42,5 – 60.0% for *S. bramae*, 12.8 – 14.5% for *B. polymorphus* (Ivanov, Semyonova, 2002). *C. laticeps* had 23,2 – 38,8%, *L. intestinalis* – 14,7 – 35,1%, *P. osculatus* – 46,8 – 54,3%; the nematodes *C. lacustris* – 25,8 – 50,7%, *C. truncatus* – 41,1 – 7,2%, *R. acus* – 20,2 – 38,7%; proboscis worms *C. strumosum* had 38,8 – 82,3%, *P. laevis* – 12,4 – 40,1% of EI by cestodes.

The sign phenomenon in the formation of the helmintofauna of the Volga delta animals is recording of metacercarias *Apophallus muehlingi* (family *Heterophyidae*) which were found in gusteras, redeye, bream and zope with the low EI (Ivanov and others, 1986). A little bit later (in 1980) the other representatives of heterophyid were found in perch fish – metacercarias of the species *Rossicotrema donicum* and also with the low EI (Ivanov, 1990).

The appearance of metacercarias of these species in fish is connected with the penetration of paratenic hosts of trematodes – dippers *Lithoglyphus naticoides* and *L. pyramidatus* (*Gastropoda; Prosobranchia*) – into the Volga delta from the Black Sea basin through the Volga-Don channel. It is remarkable that the appearance of litoglifs in the Volga delta has almost coincided on time with the beginning of transgression of the Caspian Sea and as these molluscums are reofils, the conditions for their diffusion and growth of their number have appeared as much as possible favorable.

The further changes of the level of the Caspian Sea have considerably changed the habit of deltoid biocenoses. Rising of the sea level in 80 – 90-ies of the last century has caused the changing of a hydrological regimen in the delta Volga, which is shown in increasing of the strength, in the area of the water areas, depths. As the result there was a replacement in thickets of bur-reed into the assemblages of cane, macereed, nimfeynik, rush flower, lotus and sanghara-nut in kultuchny and island zones of the delta, the vegetation areas in the kultuks were reduced. Thickets of pond grass have disappeared in an opened zone of predelta, there was a mass degradation of thickets of cane, macereed, lotus, assemblages of plants with floating leaves and submersed plants (Zhivoglyad, 1984).

The rising of the sea level was favorable for fluvial anadromous fish because their fattening zone was expanded. At the same time the chores for Limnophilic thicketloving fish that were dominating before in all premouth of the sea coast have considerably improved (Kizina, 1995). The species composition and abundance of the pulmonary mollusks, the insects' larvae, oligochaetes and crustaceans is much emasculated with this sea level (Filchakov, Chuykov, 1990). The reduction of organisms' biomass that belongs to phytophilous complex was against a background of increasing numbers and biomass of the limnoreophyle shellfish of *Lithoglyphus*, *Viviparus*, *Pisidium* genera.

During these years there was a decrease of contamination of fish by metacercariaes of thrematodes *D. spathaceum* (EI 20,4 – 62,1%), *H. triloba* (EI 19,4 – 22,5%), *P. cuticola* (EI 25,2 – 42,9%), *T. clavata* (EI 28,8 – 45,0%), that is connected with the continued decrease of the intermediate hosts number of these trematodes (Limneides, Planorbides, Unionides) and their main hosts (gulls, herons).The contamination of fish by metacercariaes *Metorchis bilis*, *M. xanthosomus*, *Pseudamphistomum truncatum*, *Holostephanus cobitidis* (*B. tentaculata* is the intermediate host of these species) is slightly decreased. The same trends were observed for EI of fish by Marita *A. tincae* (EI 0,7 – 12,5%), *S. bramae* (EI 5,2 – 7,1%), *O. siluri* (EI 10,4 – 18,8%). The infection by cestodes is reduced that develops with the oligochaetes and the crustaceans: *C. laticeps* (EI 20,8 – 31,7%); *L. intestinalis* (EI 15,1 – 27,7%), *P. osculates* (EI 32,5 – 45,4%); with the nematodes and the acanthocephalans whose intermediate hosts are crustaceans, and oligochaetes: *C. lacustris* (EI 26,3 – 38,8%), *R. acus* (EI 22,1 – 27,3%), *C. strumosum* (EI 30,5 – 64,2%), *P. laevis* (EI 10,7 – 30,9%).

However, the favorable conditions for the development of limnoreophyle shellfish (*L. natricoides, L. pyramidatus*, *V. viviparus. P. amnicum*) led to the increasing of fish contamination by metacercariaes *A. muehlingi* (EI 54,7 – 100,0%), *R. donicum* (EI 46,7 – 73,2%), *P. ovatus* (EI 45,0 – 85,7%), and Marita *A. lucii* (EI 50,0 – 63,2%), *B. polymorphus* (EI 15,0 – 21,1%). The range of hosts of metacercariaes trematodes is significantly expanded: the additional hosts for *A. muehlingi* are 20 species of carp fish and 4 species of perch fish, 4 species of perch fish and 7 species of carp fish are for *R. donicum*, and 35 species of many other families are for *P. ovatus*.

The level of the Caspian has been continuing to rise and it was 26,66 m in 1995, it means that it has risen by 2,35 m from 1977 to 1996, the sea level dropped to 0,14 m in 1996 in the comparison with 1995 (Channel processes …, 1997) and it has stabilized in the next years with the slightly differences.

Nowadays the contamination of fish by helminthes has slightly changed. EI has fallen a little bit for the most of trematodes and it amounts 28,0 – 40,3% for *T. clavata*, 17,7 – 20,1% for *H. triloba*, 0,8 – 11,3% for *A. tincae*, 4,8 – 7,0% for *S. bramae*, 11,3 – 15,5% for *O. siluri*. However, the degree of fish contamination by metacercariaes *D. spatheceum* and *P. cuticola* has increased and it amounts accordingly 45,8 – 68,1% and 33,2 – 50,2%. Maybe there is “status quo” of these thrematodes’ species that is restoring in nature, but perhaps the reasons are of different nature – the situation requires further observations and systematic researches.

The contamination of fish by cestodes, nematodes and acanthocephals remained at the level of the 90-ies of the previous age and was 22,5 – 30,4% for *C. laticeps*, 14,7 – 28,1% for *L. intestinalis*, 29,7 – 48,8% for *P. osculatus*, 25,5 – 44,3 % for *C. lacustris*, 24,3 – 26,8% for *R. acus*, 30,1 – 62,2% for *C. strumosum*, 10,1 – 30,5% for *P. laevis*. It is characteristic that the wide range of intermediate and reservoir hosts is peculiar to these helminthes species, it means that some “reserve of safety” is laid in their life cycles, what allows to the parasites to survive under all sorts of changes in biocenoses.

CONCLUSION

The retrospective analysis of changes in the helmintofauna of fish shows that the high level of the Caspian Sea impacted on their infestation, which led to the transformation of the biocenoses in the Volga delta. As the result the helminthes’ species that were dominating in the fish during the period of lowering of the Caspian Sea level passed into the category subdominant in a very short period of time, and their degree of contamination is significantly reduced. Those helminthes’ species for whose hosts the existing conditions were favorable became widespread in the Volga delta.

The current state of the fish helmonthofauna should be recognized as the transition. The degree of the infestation by many species of trematodes, cestodes, nematodes and proboscis is stabilized. Those helminths’ species whose large number of hosts of different ranges participates in their life cycle are widely extended.

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MINERAL AND CHEMICAL COMPOSITION OF RECENT SEDIMENTS IN THE VOLGA RIVER DELTA AND NORTHERN CASPIAN SEA

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Keywords: sediment, mineralogical analysis, chemical composition, grain-size analysis

INTRODUCTION

Collected sediments in the Volga River delta and Northen Caspian Sea on the areas 4-6 (fig. 1) for the following analysis of their mineral and chemical composition.

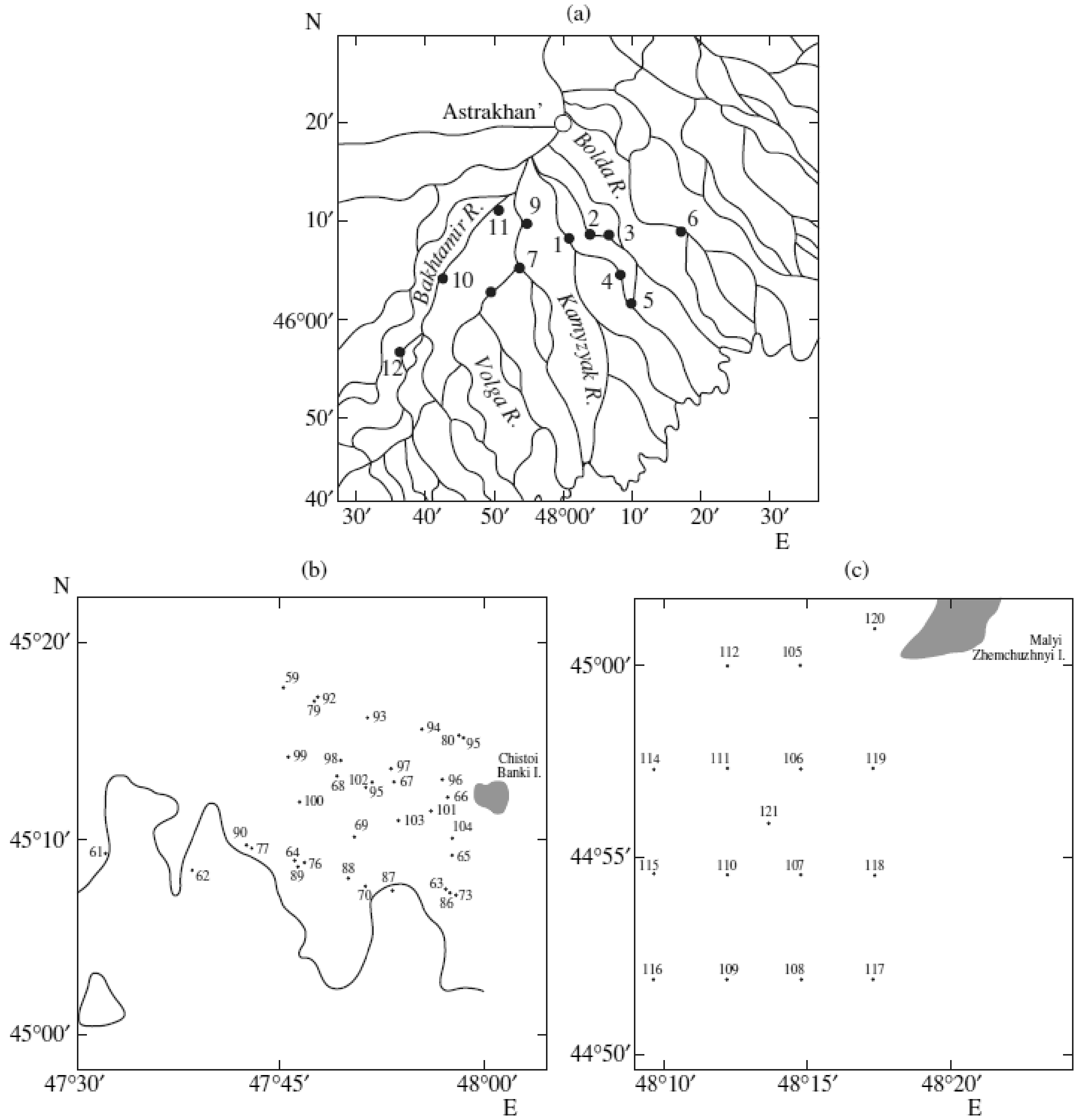

Fig. 1. Location of stations in the Northern Caspian Sea and Volga River delta: (a) Volga River delta; (b) areas 4 and 5; (c) area 6

RESULTS AND DISCUSSION

On the areas 4-6 are developed yellowish gray terrigenous sands and aleurites with a touch of intact shells and bivalve detritus (right to coquines). Generally, bellow deposited dark gray resilient clays, enriched in sand-aleuritic terrigenous material and biogenic detritus. In the fraction less 0.25 mm generally predominance quardz with different intensity of roundness. Pellite represented by clay minerals – illite (main component), smectite, chlorite and kaolinite, depend transport rivers Volga and Ural. In fractions more 0.25 mm dominated biogenic remainders – fragments and entire shells. With dislocation in the south course (area 6) in the sediments often prevail biogenic components.

Delta volga recent sediments on the depths 0.15-1.0 m represented by yellowish gray sands and aleurites, which generally underlying by resilent dark gray clays with a touth of terrigenous sand-aleuritic material. For sediments typical remainders of land and inshore plants. Composition of pelitic fractions audited by Volga river transport: dominate illite with visible amounts attented kaolinite, clorite, smectite. In the fractions less 0.25 mm recent sediments all streams dominated quartz angular and poorly rounded. For the fraction 0.5-0.25 mm characteristic good rounded remainders of quartz, chalcedone, cherts. To more heavy fractions gravitated vegetable remainders, bivalve detritus, debris rocks, brown gray clay-aleuritic crust, sometimes covered white and yellow white films. In the sediments of Volga river delta is considerably less fragments and intact shells then in areas 4-6.

After division fraction 0.1-0.05 mm by bromoform mineralogical analysis of light and heavy subfractions was conducted with the help of immersion liquid.

In the coarse aleuretic fraction of Volga River delta and areas 4-6 sediments sharp dominated light minerals, at that time as part of heavy components property composed <0.01-11.11 и 0.40-3.52%, though they differ large variety of mineral appearances.

Among heavy transparent minerals on the areas 4-6 (see tabl. 1) clear prevailed group of epidote (middle 49.8%). Comparatively high contents characteristic for garnets, ordinary hornblende and zircone. Black ore minerals complited averaging up to 28.7% heavy ore subfraction without convetrting,

In the light subfraction absolutely dominated quartz (up to 87.1%), relatively significant part of potash feldspars (maximum 32.9%). Quartz-feldspar relation varying from 1.8-8.0 (middle 4.8). Maximum 35.6% light subfraction without converting consist of fragments of change rocks and minerals.

Delta Volga sediments we may considered as a base for interpretation mineralogical lookouts towards sea, heavy transparent minerals introduced by the group of epidote (middle 50.4%). Next in descending order followed garnets, ordinary hornblende, zircon, apatite, titanium minerals. Black ore minerals contained in the heavy subfraction without converting 26.6% (middle). Light subfraction generally consists of quartz (up to 81.4%) and potash feldspars (maximum 28.4%). Extents of the quartz-feldspar relation varying from 3.2 up to 6.1 (middle 4.3). In the light subfraction without converting maximum fragments of change rocks and minerals amount to 28.7%.

Air-dried samples of sediments from surficial horizonts (0-3 cm) were ground for the chemical analysis. Contents of C_{org} varies from 0.06 to 1.57% (see table 2). The sediments of station 105 were sharply enriched in C_{org}, while sediments of the station 73 and 89 were depleted in C_{org} contents. Average concentrations of C_{org} are 0.40% in sediments from areas 4 and 5, 1.04% in area 6 and 0.48 in Volga delta.

Contents of $CaCO_3$ varies from 1.26 to 79.95%. Average concentrations of $CaCO_3$ compose 7.34 in areas 4 and 5, 47.38 in area 6 and 3.48% in Volga delta.

The main component of the sediments Volga River delta is silica (62.56-81.24% SiO_2), that check out with dates of mineralogical analysis (dominate quartz). Next in descending order followed Al_2O_3 (5.99-14.92%), CaO (2.28-8.90%), Fe_2O_3 (1.81-5.40%), K_2O (1.19-2.43%), MgO (0.96-2.52%), Na_2O (0.69-1.17%), TiO_2 (0.31-0.72%). Explored sediments depleted by manganese (not more 0.16% MnO), chlorine (often less 0.07%), phosphor (0.10-0.19% P_2O_5) and sulfur (0.05-0.40%).

Sediments areas 5 and 6 for macrochemical composition near sediments Volga delta. In the sediments of areas also naturally prevailed silica (54.78-86.28% SiO_2). Deletion complited limy sediments on the stations 100 and 121. Relative Volga River delta ground sediments of areas depleted by titanium (0.01-0.44% TiO_2), aluminium(0.60-8.96% Al_2O_3), iron (0.38-2.69% Fe_2O_3), manganese (0.01-0.05% MnO), magnesium (not enough 0.10-2.27% MgO), potassium (0.08-1.71% K_2O), sodium (0.53-0.89% Na_2O, two analysis), phosphor (0.08-0.09% P_2O_5, two probes), sulfur (0.05-0.07%, two examples), but milled calcium (2.37-47.8% CaO) near content chlorine (менее 0.01-0.27%).

The main geochemical difference between sediments of areas and Volga River delta consist in lesser content of clay minerals in the ground sediments of areas, what, probable, associated with impact addition factors decanted sediments on the areas (of storms, near-bottom currents).

Rare-earth elements take shape in all sediments of areas 5 and 6 by neutron-activation metod. Concentration REE rippled in reasonobly broad ranges. But in common wih superficial suspension in the recent sediments dominated light and middle REE, observed inheretance bands rare-earth elements in the sistem suspension-ground sediments.

Table 1

Average mineral compositi on coarse aleuritic fraction of recent sediments (%)
Northern Caspian Sea (areas 4-6) and Volga River delta

Mineral grains	Areas			Volga River delta
	4	5	6	
Heavy subfraction				
After converting				
Garnets	12.9	15.3	15.1	14.9
Ordinary hornblende	12.4	11.3	9.7	9.4
Tremolite-actinolite	0.5	<0.1	0.2	0.3
Clinopyroxenes	2.7	3.9	2.9	2.4
Orthorhombic pyrohenes	0.4	0.6	0.2	0.2
Olivine	0.3	0.1	0.2	0.1
Spinel	0.4	0.2	<0.1	0.1
Group of epidote	44.7	43.6	49.8	50.4
Biotite	0.1	0.4	0.4	0.1
Muscovite	0.3	0.1	0.1	0.1
Chloritoid	0.2	0.1	0.1	0.1
Clorite	1.1	1.5	1.4	1.8
Apatite	2.5	2.6	2.1	3.9
Zircon	9.0	8.2	7.2	6.6
Sphene	1.2	2.0	1.8	1.1
Rutile+anatase+leucoxene	4.1	2.6	1.8	3.4
Disthene	2.6	1.9	2.0	1.3
Sillimanite+andalusite	0.3	0.4	0.2	0.2
Staurolite	2.5	2.7	3.5	2.0
Tourmaline	2.0	1.5	1.2	1.6
Heavy spar	0.1	<0.1	<0.1	<0.1
Without converting				
Black ore minerals	23.5	25.3	28.7	26.6
Fe-oxyhydroxides	4.3	3.3	2.6	4.2
Pyrite	0.2	<0.1	<0.1	<0.1
Fragments of change rocks and minerals	5.3	7.7	9.3	7.5
Fragments carbonates	0.1	0.1	0.2	-
Light subfraction				
After converting				
Quartz+chalcedone	74.1	79.6	81.4	75.1
Potash feldspars	21.1	18.3	17.6	21.9
Acidic plagioclases	2.8	1.7	0.8	2.0
Basic and average plagioclases	0.4	0.1	0.1	0.2
Glauconite	1.6	0.3	0.1	0.8
Quartz-feldspar relation	4.2	4.2	4.8	4.3
Without converting				
Fragments of change rocks and minerals	22.2	18.5	19.5	21.6
Fragments carbonates	1.9	0.4	1.5	0.1

Table 2

Content of C_{org} and $CaCO_3$ in the recent sediments (% вес.)
Northern Caspian sea and Volga River delta

№ station	C_{org}	$CaCO_3$	№ station	C_{org}	$CaCO_3$
Volga River delta			Area 5		
1	0.22	1.26			
2	0.52	3.97			
3	0.54	4.69	86	0.13	2.70
4	0.84	3.80	87	0.62	13.62
5	0.25	1.68	88	0.18	7.00
6	0.76	5.71	89	0.06	3.12
7	0.59	3.63	90	0.12	2.51
8	0.61	6.37	92	0.68	8.98
-"-	0.60	3.54	93	0.75	15.69
9	0.92	2.12	94	0.27	7.85
10	0.29	3.39	96	0.38	9.88
11	0.21	2.61	97	0.63	16.38
12	0.17	1.80	98	0.86	24.30
12*	0.18	4.19	99	0.30	4.81
Area 4			100	0.20	47.31
62	0.46	13.01	102	0.22	35.91
65	0.15	7.88	103	0.15	8.11
Area 5			Area 6		
73	0.07	2.53	105	1.43	30.04
73*	0.19	3.18	105*	1.57	32.15
			121	0.12	79.95

CONCLUSION

In comparison with delta Volga sediments the sediments from areas 4-6 (except Eu), Ca, Au, Ni, Se, Ag, As, Sr, but they contents are lowered in Na, Rb, Cs, K, Ba, Fe, Cr, Co, Sc, Br, Zr, Ta, U, Th.

SESSION IV.

CURRENT CONDITION OF THE CASPIAN SEA

COMPARISON BETWEEN TWO CASPIAN ZOOPLANKTON; INVASIVE MNEMIOPSIS LEIDYI AND ACARTIA TONSA IN SENSITIVITY TO OIL POLLUTION

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Keywords: Caspian Sea; Crude oil, LC_{50}, WAF, zooplankton survive.

INTRODUCTION

Ctenophores are marine invertebrates that develop rapidly and directly into juvenile adults. They are likely to be the simplest metazoans possessing definitive muscle cells and are possibly the sister group to the Bilateria (Martindale and Henry, 1999).

According to Boltovskoy (1999), *Mnemiopsis leidyi* belongs to the Class Tentaculata, Order Lobata and Family Bolinopsidae.

In 1999, *Mnemiopsis* was first identified in the Caspian Sea, presumably after being introduced a few years earlier with ballast waters. The Caspian Sea is a completely isolated basin with mostly favorable conditions for *Mnemiopsis* development throughout the year. *Mnemiopsis* has expanded in the Caspian Sea, in 2001 at a rate sufficient to reach levels that could critically endanger the current functioning of the ecosystem and pose grave risks of extinction to a range of species, mainly invertebrates, but also fish (kilka and other species, including beluga sturgeon). (The first *Mnemiopsis* adversary group workshop, 2001).

Mnemiopsis leidyi reproduces rapidly and has a high ability to adapt new situations and places. It can survive without any food for 3 weeks or even more by decreasing the body size. It can also live in many marine habitats with various salinities, temperatures and water qualities. However its ecological features may intensively vary in different ecosystems around the world (Yazdani et al, 2007; Esmaeili *et al.*, 2001).

So the entrance of industrial, agricultural and other pollution to the Caspian Sea is of great importance. For example the estimated total Oil load to the Caspian Sea is 122350 t/y (CEP, 1,2; 2001).

Oil and gas extraction, along with transportation and industrial production, has been the source of severe air, water, and soil pollution in the Caspian region. Systematic water sampling in different parts of the Caspian basin shows contamination by phenols, oil products, and other sources. Mineral deposit exploration, particularly oil extraction and pipeline construction, have contributed to the pollution of about 30,000 hectares of land. Iran has a small share from polluting point of view, but it gets a much extensive part of pollution created in other regions because of the sea currents in the Caspian Sea. Study of different species sensitivity to its pollutants, is an important biological subject in the Caspian Sea. Considering the lack of information about the effect of pollutants on *Mnemiopsis leidyi*, it seemed necessary to know more about its resistance to Caspian Sea circumstances. For this purpose we have used LC50 method. LC50 can be used to compare various species sensitivity to different pollutants and as a result of it obtain their survival rate and competition ability in the sea.

MATERIALS AND METHODS

The individuals of *Mnemiopsis leidyi* and *Acartia clausi* were caught from the Caspian Sea at a distance of 3 to 4 Km from Khazar abad coast. A Plankton-net with a mesh of 500µ and a diameter of 54 cm was used to collect *M.leidyi* individuals from a depth of 2 m to the surface area. The *A. clausi* individuals were also caught form the surface water by a zooplankton-net with a mesh of 100µ.

After being transferred to the laboratory, the individuals were kept at the sea water same theirs surroundings to have enough nutrition and return to the usual manner before beginning the experiment.

The experiment containers consisted of 1.5 litre bottles containing 1 litre 55 µm filtered sea water. For the Survival experiment, 6 of them with 10 8-12 mm (most size frequency) *M.leidyi* in each 3 ones and 10 *A.clausi* in copepodity stage in the other 3 ones were used. The experiment time was 8 days (twice as the main experiment time) and the samples were checked out every 24 hours to determine their mortality. During the 8 days, the mortality should be less than 10% in the total 3 repetition. If it is more, the experiment conditions must be changed and then repeat the survival experiment for another 8 days. In the present study no mortality was observed between the *M.leidyi* individuals and the *Acartia* mortality was 6.6%. So we could continue the experiment at the same conditions.

The second stage was determination of the lethal range which involves 2 concentrations of the pollutant; the highest one with no observed mortality and the lowest with 100% mortality.

WAF of the crude oil was prepared according to the method of Anderson et al, 1974). One part of Aghajari crude oil was mixed with nine parts of filtered sea water in a specific container prepared for this purpose for 23 h, and then left to settle for 1 hour. The aqueous phase was collected and used as the stock solution for subsequent experiments.

Toxicity tests were carried out under static conditions in which the test circumstances were the same during the whole experiment. The recently caught *Mnemiopsis* and *Acartia* were first placed in the filtered sea water for 24 hours to avoid their nutrition. Then they were assigned to prepared containers for the lethal range determination test. In this stage, test concentrations with 3 controls were used for each series of experiments. WAF used concentrations were 0.25, 0.5, 1, 2, 4, 8, 16 ml/l and 0.1, 0.25, 0.5, 1, 2, 4, 8 ml/l for *M.leidyi* and *A.clausi,* respectively. The animals were not fed during the experiment. The mortality was recorded daily. Physico-chemical parameters were also recorded in each container daily; temperature, salinity, pH dissolved Oxygen ranged from 19-21°C, 12.5-12.7 ppt, 8.38-8.48, 11.2-13.2 mg/L, respectively. After 96 hours, concentration range of WAF for the final toxicity test were determined.

These ranges were divided to 7 equal parts and then the animals were exposed to these 7 concentrations with 3 repetitions for each of them by the same method as the lethal range determination (10 individuals in each container). 3 controls were also used for each experiment. Concentrations used for each experiment consist in:

– WAF for *M. leidyi*: 4, 3.5, 3, 2.5, 2, 1.5, 1 ml/l;

– WAF for *A. clausi*: 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 ml/l.

The mortality rates were recorded every 24 hours and the final results were obtained after 96 hours. Each pollutant LC50 for *Mnemiopsis* and *Acartia* was earned by Probit Value Analysis and Pharmacologic Calculation System software, the charts were prepared and then the animals sensitivity were compared according to obtained LC50s (Fini, 1964).

RESULTS AND DISCUSSION

The study indicates that *A.clausi* is more sensitive to WAF of the crude oil than *M. leidyi*.

Tables 1-2 contain the data of mortality caused by WAF of crude oil in *M.leidyi* and *A.clausi* in every 24 hours.

Pollutant's LC_{50} for the under experiment animals were determined by Pharmacologic Calculation System software; also the upper and the lower confidence limits were obtained for both 2 species by the same software. 24, 48, 72 and 96 hours LC_{50}s were gained for WAF. The results are in tables 3. By comparing both LC_{50}s and their confidence limits, it is concluded that *M. leidyi* is more resistant to WAF of the crude oil than *A. clausi*. Their differences are significant.

Results show that *Mnemiopsis leidyi* seemed to be more resistant to WAF of the crude oil than *Acartia clausi*. This difference was probably caused mainly by the dissimilar composition of these 2 species structures.

Some other comb jellies like *Mnemiopsis mccradyi* have been previously used in acute toxicity testing of chemicals such as Mercuric chloride, Copper sulfate, etc (Prato et al, 2006).; however, this is the first study on *Mnemiopsis leidyi* to exposure petroleum hydrocarbons as toxicant and to compare with zooplankton like *Acartia clausi* and it indicates that high resistance of *Mnemiopsis leidyi* to the marine pollutants in comparison with other marine zooplankton may be the main result of its highly distribution in the Caspian Sea.

Table 1

Total mortality rate of M.leidyi exposed to WAF of crude oil in all 3 repetitions minus the controls mortality

Hours → WAF Conc. (ml/l) ↓	24h	48h	72h	96h
1	3	4	4	5
1.5	3	4	4	5
2	5	8	9	9
2.5	7	13	12	12
3	12	14	13	13
3.5	12	16	14	14
4	14	15	18	20

Table 2

Total mortality rate of *A.clausi* exposed to WAF of crude oil in all 3 repetitions minus the controls mortality

Hours → WAF Conc. (ml/l) ↓	24h	48h	72h	96h
0.1	3	5	11	12
0.2	3	11	17	18
0.3	7	12	20	20
0.4	11	14	20	20
0.5	11	17	20	21
0.6	14	19	24	24
0.7	14	19	23	24

Table 3

LC_{50} for crude oil WAF and their confidence limits in *M. leidyi* and *A. clausi*. Their differences are significant

Hours↓	M. leidyi			*A. clausi*		
	LC_{50}(ml/l)	Lower C.L.	Upper C.L.	LC_{50}(ml/l)	Lower C.L.	Upper C.L.
24h	4.633	3.677	5.837	0.770	0.578	1.024
48h	3.5	2.85	4.3	0.401	0.301	0.532
72h	3.466	2.832	4.241	0.167	0.117	0.236
96h	3.311	2.676	4.098	0.148	0.104	0.212

CONCLUSIONS

This study is the first to quantify the toxicity of WAF of crude oil to *Mnemiopsis leidyi* and *Acartia clausi.* Also there have been no definite experiments on *Mnemiopsis leidyi* resistance to environmental pollutions, especially in the Caspian Sea. So further studies on the tolerance of *Mnemiopsis leidyi* population to various marine pollutants including other oil products. Comparison with other marine zooplankton are strongly recommended.

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PECULIARITIES OF SEASON AND YEARLY FLUCTUATIONS OF SEA-WATER TEMPERATURE IN MAKHACHKALA AREA ACCORDING TO THE DATA OF LONG-TERM OBSERVATIONS

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Keywords: The Middle Caspian, Makhachkala, Daghestan coast, analysis of hydrologic conditions, sea-water temperature, fluctuation

INTRODUCTION

A great number of research works describes the peculiarities of space and time fluctuations of sea-water temperature influenced by the river flow. It can be explained by the fact that these regions, as a rule, contain a lot of biological resources and have become the places of prospecting and hydro-carbon mining. Therefore it is under great anthropogenic influence. It is necessary to obtain the detailed information on hydrologic living conditions of local biological groups for monitoring and managing the quality of these regions.

According to the works on hydrologic regime and conditions for formation of productive capacity in the Caspian Sea the temperature of sea-water in the western coast is influenced by the advection of the northern Caspian waters. As a result the temperature of coastal water in the western coast of the Middle Caspian is lower than in the eastern coast. Taking into account that one of the main factors in the formation of the northern Caspian water mass is Volga flow [6] it can be considered to have an indirect influence upon the temperature of the Caspian waters in the coast of Makhachkala. According to the works [2, 3] the processes in the shelf of the western coast of the Middle Caspian are one of the important links in general process of mixing Volga and sea waters within the interaction of the northern and middle-Caspian waters.

Constant observations under temperature in the hydro-meteorological station of Makhachkala (for the period from 1921 up to 1999) were used for analysis of hydrologic conditions in the western shelf of the Middle Caspian and calculation of average month temperature, median and dispersion there. These periods can be characterized as stable from the point of view of methods used and the terms of observations. The information on the severity of winters (the number of degrees and days of frost) in the period from 1933 up to 1987 has been obtained from (Hydrometeorology and hydrochemistry of the sea, 1996), the information on the sea level in the hydro-meteorological station of Makhachkala (1920-1999) and Volga flow in the Upper-Lebyazhie Village (1936-1999) has been obtained from the archives of Daghestan and Astrakhan center of the hydro-meteorological station and the information on recurrence of the form of atmosphere macro-circulation (1900-1996) has been taken from the catalogue published in [2] with supplements made by Scientific Research Institute of the Arctic and Antarctic.

Owing to the strip throughput filters (“MEZOZAVR” program) short term periods (less than 6 years) and long term periods (from 6 up to 24 years) of fluctuations have been specified on the basis of temporal series of the above-mentioned parameters including water temperature. The index of line correlation has been calculated at the final stage of analysis between all the parameters within the period of time from1933 up to 1987, general for all the series.

According to the works on hydrologic regime and conditions for formation of productive capacity in the Caspian Sea the temperature of sea-water in the western coast is influenced by the advection of the northern Caspian waters. As a result the temperature of coastal water in the western coast of the Middle Caspian is lower than in the eastern coast. Taking into account that one of the main factors in the formation of the northern Caspian water mass is Volga flow [6] it can be considered to have an indirect influence upon the temperature of the sea waters in the western shelf of the Middle Caspian.

The average winter temperature of the sea water in Makhachkala is 3,0^{o} above zero. The lowest temperature of the sea (+0,2^{o}) was fixed in the winter of 1954 and the highest one (+6,6^{o}) in the winter of 1948. According to the data of spectral analysis the fluctuations with the period of 2-3, 4-5 and 11-12 years much contributes to the long term variability of the average winter temperature of the sea. At the same time the average winter temperature of the sea water started to increase gradually in the 20th century. As a result it increased up to 0,8^{o} in the period from the twenties to the end of the century. Judging by the parameters of the sliding standard deviation along with the increase of the winter water temperature the quantity of its inter-annual fluctuation was gradually decreasing during the 20th century. It is necessary to stress out that the range of the inter-annual fluctuations reached the maximum point in the periods when the average winter temperature of the sea water was below the long term standard and the minimum point in the periods with high temperatures.

The average spring temperature of the sea water in Makhachkala is 9,0^{o} above zero. The lowest temperature of the sea (+5,1^{o}) was fixed in the spring of 1969 and the highest one (+11,1^{o}) in the spring of 1966. According to the data of spectral analysis the fluctuations with the period of 2-3 and 4-5 years much contributes to the long term variability of the average spring temperature of the sea. In the last century the average spring temperature of the sea water started to increase gradually. As a result it increased up to 0,4^{o} in the period from the twenties to the end of the century which is half as many than in the winter. Judging by the parameters of the sliding standard deviation sharp and steady decrease of the quantity of the inter-annual fluctuation of the average spring temperature happened in the seventies against the background of high temperatures.

The average summer temperature of the sea water in Makhachkala is 22,1^{o} above zero. The lowest temperature of the sea (+18,6^{o}) was fixed in the summer of 1950 and the highest one (+24,3^{o}) in the summer of 1999. According to the data of spectral analysis the fluctuations with the period of 2-3, 4-5 and 15-16 years much contributes to the long term variability of the average summer temperature of the sea. The average summer temperature of the sea water started to increase gradually in the 20th century. As a result it increased up to 0,4^{o} in the period from the twenties to the end of the century, just like in the spring. According to the parameters of the sliding standard deviation the quantity of the inter-annual fluctuation of the average summer temperature in the sea water had been comparatively low for quite a long period (about 30 years in the second half of the 20th century). Despite the increase of the summer temperature by the end of the century the period under study experienced the decrease of the inter-annual fluctuation range if compared with the first half of the century.

The average autumn temperature of the sea water in Makhachkala is 15,5^{o} above zero. The lowest temperature of the sea (+13,1^{o}) was fixed in the autumn of 1993 and the highest one (+18,2^{o}) in the autumn of 1937. According to the data of spectral analysis the fluctuations with the period of 2-3, 4-5 and 8-9 years much contributes to the long term variability of the average autumn temperature of the sea. Unlike the other seasons the autumn was characterized by decreasing the average temperature during the 20th century. From the twenties to the end of the century it decreased down to 0,4^{o}, that is it decreased as much as it increased in the spring and summer. It is necessary to point out that the decrease occurred primarily in the first half of the period under study when the quantity of the inter-annual fluctuations of the average season temperature in the water was comparatively high (see Picture 1). Then the range of the fluctuations decreased. Thus, the autumn, just like the other seasons, experienced the decrease of the inter-annual fluctuation of the average season temperature in the sea during the 20th century.

The average annual temperature of the sea water in Makhachkala is 12,4^{o} above zero. The lowest temperature of the sea (+10,6^{o}) was fixed in 1969 and the highest one (+14,1^{o}) in 1966.

According to the data of spectral analysis the fluctuations with the period of 4-5 years much contributes to the long term variability of the average annual temperature of the sea. Fluctuations of high and low frequency which are peculiar to the long term variability of the average season temperatures are not clearly pointed out here in contrast to positive linear trend indicating to the gradual increase of the average annual temperature in the sea during the 20th century.

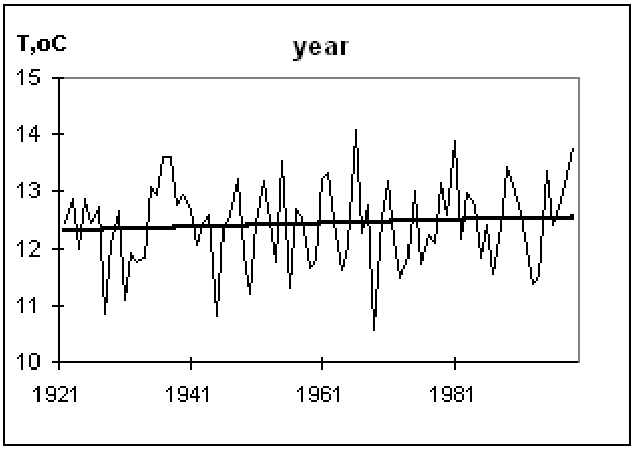

Fig 1. Long term fluctuations of the sea water in Daghestan shelf of the Caspian sea according to the observations of hydro-meteorological station of Makhachkala (1921-1999)

It should have been expected considering that all the seasons except for the autumn experienced the temperature increasing. From the twenties up to the end of the century the average annual temperature of the sea in Makhachkala increased up to 0,3°. The range of the inter-annual fluctuations of the average annual temperature in the water reached its maximum point in the sixties. But in the fifties the range was higher on average than in the following decades and therefore the quantity of the inter-annual fluctuation of the average annual temperature of the sea decreased during the 20th century.

The long term fluctuations of the water temperature in different parts of the Caspian Sea have much in common according to Knipovich N.M. and other scientists [1]. In particular, positive linear trends and its role in the long term fluctuation of the winter, spring and summer temperatures as well as average annual temperature of the sea and negative trends of the average autumn temperatures in the northern part of the Caspian Sea are mentioned in the general report (Hydrometeorology and hydro-chemistry of the sea, 1982). According to the above-mentioned authors temperature increasing in the sea water indicates to warming and softening of the Caspian Sea climate in the 20th century. The conclusion is confirmed by the author's research based on the long term temporal series of observations.

The indexes of temperature line correlation with the severity of winters, sea level and Volga flow volume in different parts of the temporal fluctuation were calculated within the period of time from1933 up to 1987, general for all the series. As a result it was found out that the fluctuations of the average winter temperature in the water, as it was supposed, were best correlated with the severity of winters in the Caspian Sea (Table #2). It is natural that the temperature of the sea was increasing when the index of the winter severity was low and vice versa.

The average spring temperature of the sea was also in the negative correlation the winter severity, even closer than in the winter. It is quite clear considering that after severe winters the process of sea warming is much slower than after warm winters. The short term fluctuation of the sea temperature (less than 5 years) has weak correlation with Volga flow**.** The reason of it can be found in the strengthening of advection of the northern Caspian Sea waters rapidly warming in the spring and their spreading in the Middle Caspian with increasing Volga flow.

Correlation of the long term fluctuations of the average summer temperature of the sea in Daghestan shelf with the other parameters has been elicited only in the long term fluctuations (more than 5 years). It is necessary to point out that negative correlation of the long term fluctuations of the sea level with the water temperature in Makhachkala indicates to the correlation of the shelf waters of Daghestan with the Northern Caspian. The fluctuations of the temperature regime of the latter depend on the fluctuations of the sea level [7], that is when the sea level is high the temperature of the water is low and vice versa.

Table 2

The correlation of the long term fluctuation of the sea water temperature in Daghestan shelf of the Caspian Sea with the climate and hydrological factors (indexes of line correlation) (1933-1987)

Climate (hydrological) parameters	Short term fluctuations (less than 5 years)	Long term fluctuations (more than 5 years)
SPRING		
Severity of the winter	-0,74	-0,76
Sea level	0,02	-0,17
Volga flow	0,46	-0,24
SUMMER		
Severity of the winter	-0,37	0,02
Sea level	0,33	-0,55
Volga flow	0,13	-0,30
AUTUMN		
Severity of the winter	-0,11	-0,09
Sea level	0,35	0,20
Volga flow	0,26	0,06
WINTER		
Severity of the winter	-0,75	-0,72
Sea level	0,06	0,29
Volga flow	0,30	-0,31
ANNUAL PERIOD		
Severity of the winter	-0,74	-0,55
Sea level	0,34	-0,06
Volga flow	0,52	-0,22

The long term fluctuations of the average annual temperature of the sea happened to be connected with the severity of the winter as close as the fluctuations of the average winter and spring temperatures of the water. Therefore the speed of warmth stocking during hot seasons of the year depends upon the loss quantity of the warmth reserve in the sea in the autumn and winter.

It was found out that the short term fluctuation of the average annual temperature of the water is correlated with the Volga flow volume. This correlation indicates that the latter has an influence not only upon the salt advection but on the advection of the warm and cold from the Northern Caspian into the Middle Caspian as well. Besides this correlation confirms the opinion that Volga flow is below the standard during cold years in the Caspian Sea and during hot years it is high.

CONCLUSION

There is a positive trend in the long term fluctuation that indicates to its gradual increase during the 20^{th} century. From the twenties up to the end the century the average annual temperature of the sea in Makhachkala increased to 0, 3 ^{0}. The increase occurred in all seasons of the year except for the autumn that was characterized by the decrease of the average season temperature. The long term fluctuations of the average annual temperature of the sea water happened to be correlated with the winter severity. Therefore the speed of warmth stocking during hot seasons of the year depends upon the loss quantity of the warmth reserve in the sea in the autumn and winter.

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FEATURES SALINITY FRONTAL ZONE IN THE NORTH CASPIAN AND THEIR DETERMINANTS

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Keywords: Northern Caspian Sea, frontal zone, salinity

Recent studies have showed that long-term variability of hydro-physical parameters of the oceans can be represented as a superposition of two processes – quasi-periodic oscillations and very fast transitions (1–3 years) from a statistically quasi-stationary state to another, the so-called regime shifts. The former, for example, the cycle of El Niño-Southern Oscillation. With respect to regime shifts is remarkable second half of 1970. When substantially changed the nature of many large-scale processes in the oceans and global atmosphere.

In the deep areas of the Caspian Sea regime shifts in the late 1970 associated with the significant influx of fresh water not only due to runoff, but the difference between precipitation and evaporation after 1978. This has led to changes in the type of vertical thermohaline structure of waters from the mediterranean quasihomogeneous vertical salinity at a steady moderate salinity stratification.

Extensive shelf areas in the north of the Caspian Sea taking the bulk of river runoff (85%). Therefore the effect of long-term variations in river runoff changes of hydrological characteristics are manifested most clearly here. Choosing salinity as the subject of research due to its particular importance in the mouth area for the formation of its hydrological regime. Continuing the current in the North Caspian salinity frontal zone is very sensitive to external influences and thermohydrodynamic is an indicator of the response by the shelf zones of seas.

Objective this work – determination of regional peculiarities salinity frontal zone in the northern Caspian Sea in the spring at different external influences with the help of numerical simulation.

Restoring the salinity in the nodes of regular grid according to certain oceanographic stations were made with help the Bergen Ocean Model. Application for restoration of oceanographic fields of mathematical models of ocean to avoid the shortcomings of statistical methods. The essence of this approach is that the temperature and salinity at selected oceanographic stations remain constant throughout the simulation time. Temperature and salinity at grid-point do not coincide with the position of the stations are beginning to change with the defined values at these stations, water circulation, river runoff, wind stress, bottom topography and configuration of the basin. The calculation stops when the output of the sea level and currents at steady state in all nodes of a regular grid.

Bergen Ocean Model – a three-dimensional, unsteady, nonlinear numerical model in σ-coordinates. Taken into account by the Earth's rotation, baroclinity, horizontal and vertical viscosity and diffusion. Calculate the internal (baroclinic) and external (barotropic) mode. The boundary conditions at the sea surface can be set atmospheric pressure, wind stress and heat fluxes and salts. At the bottom is given by the friction condition. The model is adapted for calculating the influence of river runoff. The coefficients of horizontal viscosity and horizontal diffusion calculated by the Smagorinsky formula. The sea water density was calculated from the state equation ES-80. The vertical eddy viscosity and vertical eddy diffusion coefficients are determined by a closed turbulent scheme. The model is solved numerically. The horizontal finite-difference scheme is separated and used C-grid Arakawa.

The computational domain, the location used oceanographic stations and bottom topography are shown in Fig. 1. X and y grid steps – 3 km. For vertical axis was set by 12 σ-coordinate. At open boundary used Neumann condition for the components of velocity, temperature and salinity. At the sea surface wind stress was specified. Was taken into account river flow of the river Volga.

Calculations were made according to mean annual hydrometeorological data for April for two intervals – 1958–1977 and 1978–1987. Their selection was the fact that they are characterized by particularly large differences in the magnitude of the external fresh water budget of the Caspian Sea and the associated significant opposite changes in salinity water in a river discharge zone. At the first interval of the average annual water flow of the Volga River in April was 7300 m^3/c, on the second – 8400 m^3/c. Wind stress was calculated from reanalysis data NCEP. In the first stage prevailing west winds, on the second – the south-west.

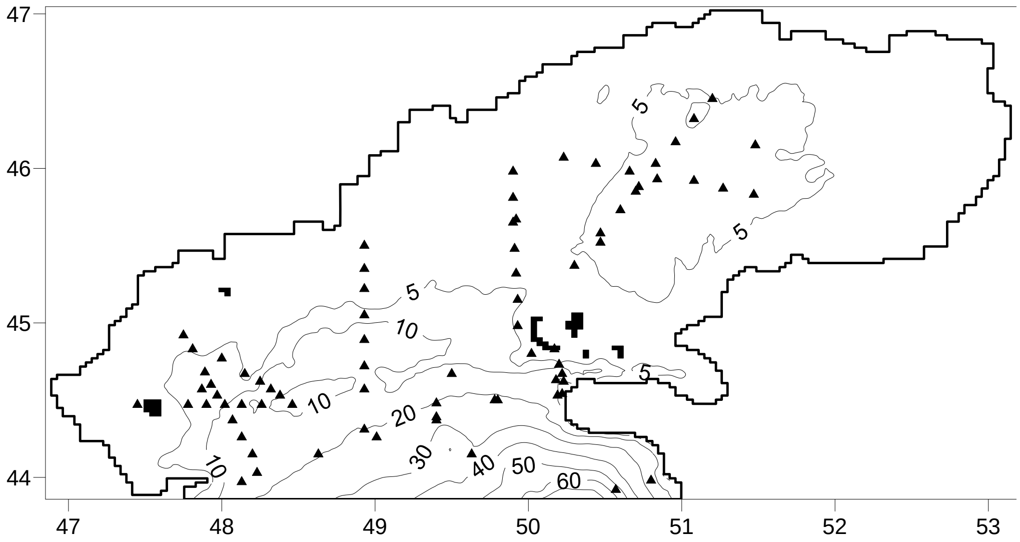

Fig. 1. The computational domain, the oceanographic stations location (black triangles) and bottom topography

Fig. 2 and 3 shows the calculation results of for the above intervals.

It is evident that the parameters of salinity frontal zone (position, width, horizontal gradients of salinity) at different intervals differ quite strongly. In the interval 1958–1977, it is located closer to the shore, more narrow and has a much larger horizontal salinity gradients than the interval 1978–1987. These features salinity frontal zone in April of 1958–1977 years are due to the prevailing western and north-westerly winds, which prevent the spread of river water from the pre-mouth areas in other areas of the Northern Caspian. Conversely, the prevailing south-westerly winds in April 1978–1998 years washouts salinity frontal zone and contribute to the infiltration of river waters farther out to sea.

Another distinguishing point is that in during the westerly winds period parts of desalinated water near the west coast of the North Caspian Sea are turning from the south to the north.

At the same time for the south-westerly winds there is a greater penetration of more saline waters from the Middle Caspian Sea to the North.

Thus, long-term variability of wind conditions – one of the main factors changes in salinity in the North Caspian.

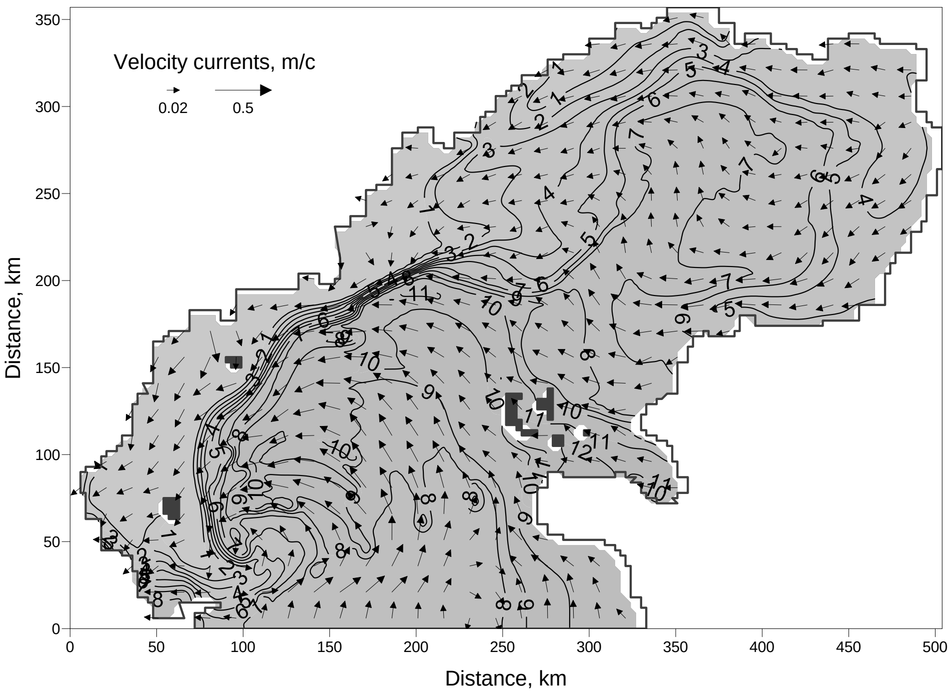

Fig. 2. Surface salinity (psu) and waters circulation in the North Caspian, calculated with help the Bergen Ocean Model for the mean annual hydro-meteorological data for April for the interval 1958–1977

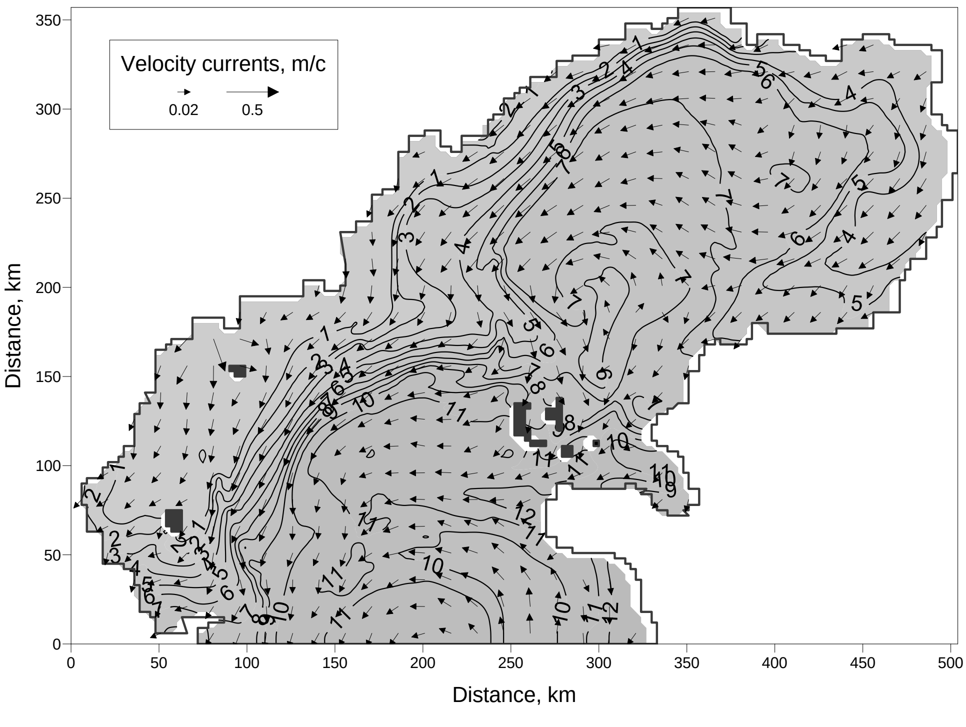

Fig. 3. Surface salinity (psu) and waters circulation in the North Caspian, calculated with help the Bergen Ocean Model for the mean annual hydro-meteorological data for April for the interval 1978-1998 years.

ON THE INCONSTANCY OF UNDERGROUND SHORES AND WATER VOLUME OF THE CASPIAN SEA

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Keywords: Caspian Sea, water balance, underground hydrosphere

INTRODUCTION

Data of sea and ground-based geological studies make it possible to examine the Caspian Sea with its unique endemic fauna and flora as fundamentally new genetic type reservoir, which was formed in the Pliocene as result of sharp reconstruction of the earth's crust structure under isolation from the World Ocean due to unloading the local resources of underground waters concentrated in the North-, Middle- and South-Caspian groups of artesian basins, natural regime of which is regulated by geodynamic factor and with XIX of century noticeably changes under the strong pressure of the steadily increasing technogenic loads.

The aim of report is to consolidate that point of view by means of solution three main tasks: a) to describe the errors in calculations of the Caspian Sea water balance; b) to reveal the forms of its connection with underground hydrosphere and hollow space in depths of adjacent territories; c) estimate underground components of the sea water balance and outline the ways the best reliability forecast fluctuations of its level.

ON THE ERRORS IN CALCULATIONS THE WATER BALANCE

The “evolution” of the water balance equation of the Caspian Sea may be divided on the initial, intermediate and contemporary stages.

In the initial stage (1763 – 1929 yr.) the water balance formula took the form:

$$Q + xF = zF,$$

where Q – river runoff in the sea; x – sea-area precipitation; z – free-water-surface evaporation; F – sea water-surface. This is the expression of the cartographer F.I. Soymonov thought (1763): “The Caspian Sea loses as much water by evaporation, as the rivers take into the sea”. The same plan of the sewageless locked reservoir with the impenetrable bottom was characteristic for the A.I. Voyeykov, N.M. Knippovich, L.F. Rudovits, M.D. Dundukov constructions and other. In this plan was absent underground component, and also discrepancy of the water balance: its income and expenditure components were automatically equalized by the speculative estimate of the quantity of evaporation.

Intermediate stage (1930-1978 yr.) is divided on two phases. During the first phase (1930-1964 yr.) the formula of the water balance had another form: $Q + q + xF = zF + S + \delta$, where new components were introduced: q – the inflow of underground waters in the sea (it was discovered in 1924 and evaluated by different researchers from 23,9 to 49,3 km3/yr; S – flow into the Kara-Bogaz-Gol bay; δ – discrepancy of the water balance. The significant additional supply of Caspian Sea by underground waters through its “perforated” bottom was not coordinated with the picture of the progressive shallowing of sea, complicated the procedure of the water balance, forced to appeal the low accuracy of determination the volume of underground water unloading and reduce that volume to 3–5 km^3/yr by volitional way. Against the background the discrepancy of the water balance, equal to approximately 3–5 km^3/yr, underground flow into the Caspian Sea was obviously converted into the negligible value. “Uncomfortable” inflow of underground water was “depressed” also by hypothesis of extraordinary evaporation from the Kara-Bogaz-Gol bay. But as before, the value of free-water-surface evaporation was not measured physically and remain as speculative abstract parameter. Is it true that image of the Caspian Sea was imitated as “perforated saucepan”, into which was allowed the leakage of the negligibly small portions of underground waters. And only Kh.K Ulanov in 1964–1965 yr. it asserted that the value of underground flow into the Caspian Sea is unjustifiably decreases and must be not less than 17,3 km^3/yr.

At the second phase (1965–1978 yr.) the formula of the water balance was complicated:

$(Q - \Delta Q) + (q_g + o_f\, q_a) + (x + \Delta x)\, F + (H_e + H_r) = (zF + z\Delta F) + S + Z_x + (\Delta H - \Delta h\delta)\, F + \delta$,
where Q – flow of catchment in the sea according to the data of hydrometric controls; ΔQ – loss of flow from the control to the sea; q_g and q_a – groundwater and artesian flow in the sea; $x + \Delta x$ precipitation of sea surface with the correction for instrument insufficient; $H_e + H_r$ – the volume of the river and eolian deposits in the sea basin; zF – evaporation from the sea surface; $z\Delta F$ – evaporation from the flood and bared areas of sea during the rise and fall of sea level; S – flow into the bay; Z_x – draft from the sea for the industrial needs; ΔH – observed sea level; $\Delta h\delta$ – density changes of sea level in the dependence on the temperature and the salinity of its water.

In this formula are distinguished: nonpressure (ground) and pressure (artesian) components of unloading underground waters into the Caspian Sea, the effect of anthropogenic activity in the Caspian Sea basin (without the technogenic disturbances the depths state) and detailed value of evaporation from sea surface. To the 60's it was established that long-period instrumental data of the vaporizers indications, established on coasts and islands of the Caspian Sea, considerably disperse from the speculative values of evaporation, which blow endanger the taken root image of this sea as closed drainless reservoir with the impenetrable bottom. But instead of revision that point of view hydrologists rejected of instrumental data, assuming the Caspian Sea is closed and drainless, the vaporizers are imperfect and it is acceptable to use speculative value of sea-surface evaporation for the levelling water balance (which automatically reduced practically to zero underground hydrosphere influence on the Caspian Sea life).

Contemporary stage (after 1978) is significant that in the equation of the Caspian Sea water balance was included the value of “visible evaporation” (difference between the amount of precipitation and the humidity of air above the sea surface). But indeed it is not physically determined value, but only the modification of speculative adjustable parameter for formally closing the equation of the Caspian Sea water balance accordingly the concept of drainless and closed reservoir with negligible value of underground drain. The parameter “visible evaporation” found circulation in the period of extremely sharp and prolonged anomalous raising of the Caspian Sea level, which arose in 1978 (in spite of the forecasts) and continued until 1995 with the phenomenally high speed (32 – 40 cm/yr by time). The explain of that uncommon jump was that “visible evaporation” from the sea-surface during this period decreased to 0,675 m/yr (against 0,778 m/yr in the previous periods). But that hypothesis will not be agree with the raising of the Caspian Sea level and expansion of its surface, especially in the shallow northern part of the sea, where the evaporation, as hydrologists are considered, 1,5 -2 times exceeds the values of evaporation from the deep water areas. I.e. the parameter “visible evaporation” is the same as stick-baton for juggle with facts in order to veil the defects of the Caspian Sea image as closed “saucepan” with the impenetrable bottom. This speculative parameter is actually the discrepancy of the Caspian Sea water balance, in structure of which are hidden “surface” and “underground” both natural and technogenic constituting.

ON THE FORMS OF CONNECTION THE CASPIAN SEA WITH UNDERGROUND HYDROSPHERE

The Caspian Sea is the forming geological body in the form of thin water layer, which crowns the Pliocene-Quaternary deposits of the Caspian Sea neotectonic depression and occupies the most submerged part of the Aral-Caspian neotectonic trough area. The Caspian Sea lies on the thickness water, petroleum- and gas-saturated deposits of the North-, Middle- and South-Caspian groups of the sedimentary artesian oil-gas-bearing basins. The volume, dynamics and chemistry of the Caspian Sea waters are unstable and regulated by as external factors also by endogenous geological (natural and technogenic) processes: impulses of seismicity, unloading of underground waters, oils and gases, filtration of sea waters into the hollow space of depths of adjacent territories, etc Therefore transgressive-regressive series of the Pliocene-Quaternary deposits of the Caspian Sea depression have the tracks not only the climate rhythms of, but also numerous forms of connection with the underground hydrosphere.

The volume of free underground waters, concentrated now in the pore space of sedimentary rocks directly under the bottom of the Caspian Sea and on the more extensive spaces of its neotectonic depression is equal respectively 10-20 and 40-50 to volumes of the Caspian Sea open part waters. I.e. underground hydrosphere possesses powerful potential for the additional supply the Caspian Sea, which mechanism is determined by the regime of the fluid-dynamic systems of: a) open gravitational- convection type; b) half-open elision type; c) closed compression type; g) hydrothermal-convection type.

In systems of open gravitational-convection type the distribution of pressures directly depends on the weight of the column of liquid (with concrete distribution of its density) and on pressure losses during the filtration. In that case underground waters have a connection with the relief. The heterogeneity of their density is caused by differences between the mineralization, gas saturation, temperature, by topographic roughness, etc. On that background is carry out the usual motion of underground waters in the artesian basins from the accumulation areas to the unloading places. Calculated according to this diagram The value of underground drain from the near-surface water-bearing horizons into the Caspian Sea from the land side is equal to 3-5 km^3/yr. [Dzhamalov et al, 1977].

Systems of half-open elision type are located on areas of neotectonic descending motions, which ensure the accumulation of powerful sedimentary cover, packing of deposits, reduction their porosity, wring waters contained in deposits from the axial parts of the depressions to their wings and unloading the wring waters on the sea bottom. On the basis the experimental data of quantity wring water from the different age clay sediments of region, it is established that for last 3,6 mln. years the volume of elision waters that were unloading into the Caspian Sea depression reached 500-600·103 km^3, i.e. it exceeded the modern volume of sea waters at 5-6 times. In the conversion for year this gives near one km3/yr. So the contemporary contribution of elision type systems to the Caspian Sea water balance is modest and does not exceed the value of underground flow from the land side, but it is additive to it and as a whole increases the income underground part of the Caspian Sea water balance to 4- 8 km^3/yr.

Systems of closed compression type contain the high-pressure fluids, pinched in the closed hollow space of the rock massifs. These systems are characterized usually by the anomalous high layer pressures (AHLP) of the fluids, which considerably exceed the hydrostatic pressure (exerted by the weight of the column of liquid with height from the measuring point to the surface of liquid). For the approximate quantitative calculation the volume of unloading press water into the Caspian Sea we used the results of detailed hydrogeological study of the Pre-Aral artesian basin [Veselov et al., http://www.unesco]. Assuming that visible area of the Caspian Sea is equal 378 400 km^2, the module of unloading the pressure underground waters everywhere composes 10 m3/day.km^2 (3650 $m^3/yr{\cdot}km^2$), we obtain, that in the Caspian sea yearly must flow to 378 400 × of 3650 = 1381160000 m^3 of underground waters (1,38 km^3/yr). This value is equal approximately to the volume of unloading the pressure water into the Aral sea (1,2 km^3/yr) and is understated. The Caspian Sea depression is more extensive, more active in geodynamic sense and in its depths are concentrated more powerful fluid-dynamic systems than in the stable Pre-Aral artesian basin. So the maximal for the Pre-Aral basin values of the module of unloading pressure underground waters, equal to 100 $m^3/day{\cdot}m^2$, can be considered as standard for the Caspian Sea depression. Accordingly the volume of this unloading into the Caspian Sea grows to 13,8 km^3/yr (roundedly 14 km^3/yr). This estimation assumes the constancy the filtrational properties of geological medium, but actually the permeability of the rocks sharply grows in the periods of the increased geodynamic activity, and the shielding ability of water-fluid-bed, on the contrary, falls. Therefore the volumes of unloading high-pressure underground waters into the Caspian Sea sometimes can considerably exceed the value of 14 km^3/yr and level the inflow of surface water in the sea.

Systems of hydrothermal- convection type are located to the centers of the modern land and submarine volcanism of the Caspian Sea depression, and also, probably, to the tube-shaped bodies (prospected by high-precision seismic survey), which pierce old deposits and modern sediments of the North Caspian. The insignificant debits of the wells, which revealed thermal metalliferous brines, make it possible to consider that unloading of such brines is not noticeably for fluctuations the sea level, but has substantially influences on the chemistry of sea waters and bottom sediments.

ON THE UNDERGROUND SHORES OF THE CASPIAN SEA

In the calculations of the water balance, and also in the coasts classification of the Caspian Sea are not considered usually the losses to filtration and intrusion of sea waters into the hollow space of the rocks of adjacent territories, where they are distinguished: a) the cover complex of coastal plains and river paleo-valleys; b) karstic cavities; c) the crack of rock massifs and fractural zones.

Filtration into the cover complex and paleo-valley of rivers. The level of ground water in coast strip of the Caspian Sea often falls not to the sea, but from it, into the depths of the lowland. Here is formed area, where flow waters from the side of sea and from elevated land, which corresponds free (from the reservoir) and supported (into the reservoir) regimes of filtration under the Caspian Sea. The synchronous fluctuations of sea level and some lakes of the Pre-Caspian lowland, for example, Shelkar lake, removed from the sea up to the distance more than 300 km, makes it possible to suspect, that waters of the Caspian Sea can penetrate so far into the depths of the land in well permeable Pliocene-Quaternary deposits of cover complex. For evaluation the scales of this phenomenon was used the structural map of the cover complex bed, data of its filtrational properties and the following original assumptions: a) the level of the Caspian Sea rests upon the mark minus 28 m (state of 1978 yr.); b) the water plane in the permeable soils of adjacent territories is reduced into the depths of the land to the mark minus 50 m (taking into account the losses for pressure and evaporation); c) structure contour of the bed of cover complex with mark minus 50 m is approximately corresponds to contour of the water table and outline the underground shore of the Caspian Sea in the loose deposits of this complex. This outline draws four large subterranean gulfs located in the lowered parts of the Pre-Caspian, Terek-Kumsk, Kura-river and Western- Turkmen coastal plains, against the background which is separated the network of the buried paleo-valleys of rivers, filled with alluvial sediments of the increased permeability. Such paleo-valleys are channels for intrusion the Caspian Sea water to the great distances into the depths of the land. The mentioned Shelkar lake is located near the paleo-valley of Urals river. The summary area of subterranean gulfs composes according to the minimum estimations 250000 km^2, thicknesses of the of cover complex deposits, which lie lower than structure contour minus 50 m, it is equal to in average 0,1 km, a volume of the thickness of these deposits is equal to respectively 25000 km^3. Assuming the porosity of this irrigated thickness is equal to 10%, we will obtain that the static volumes of the Caspian Sea waters concentrated in the hollow space of cover complex of adjacent territory are equal to 2500 km^3. This is approximately the thirtieth part of the open Caspian Sea volume. The Caspian Sea waters that intruded in depth are evaporated, mixed up with the infiltration waters of eolian, alluvial, lake and other deposits, and also with the deep pressure waters in the centers of their unloading and as result had noticeably influence on the sea level fluctuations.

The intrusion of the Caspian Sea waters into the karst space is distinctly manifested on the eastern shore of the Middle Caspian Sea, where the porous, cavernous karsted carbonate deposits of miocene, which are developed on the Mangyshlak and Ustyurt plateaus. These deposits lay on the the waterproof Paleogen clays, which roof lies on the absolute marks lower than the level of Caspian Sea (- 28 m). Structural line of these clays roof with mark – 28 m contours to the east of the Caspian Sea, at the removal to 100 km from it, the massif of the rocks with volume about 1000 km^3. Assuming that the hollow space of karstic caves composes here 10%, we obtain, that 100 km^3 of the Caspian Sea waters is concentrated in the underground space of adjacent territory.

In karstic cavities of the Ustyurt plateau penetrate also the Aral sea waters, whose level was located on the mark +54 m until 1961. So in this plateau the sea waters are concentrated in the form of eastern (Aral) and western (Caspian) “wedges”, whose outlines by the roof of the waterproof Oligocene clays are determined by structural lines +54 m and -28 m respectively. The sea surface terraces, horizontal karst tunnels and other signs indicate that in the geological past the level of the Caspian Sea rose, cross-peace dam disappeared and the underground connection of the Aral and Caspian Sea irregularly appeared. In the end of the 60's of the past century this cross-peace dam was drilled and destroyed by three powerful underground nuclear explosions, which provoked the drainage of underground waters of eastern “wedge” to the side of the Caspian Sea. Therefore in 1969 the Aral sea beginning swiftly to shallow, and after this, since 1978, followed sharp raising the level of the Caspian Sea, which lasted until in 1995 was not exhausted the flow of underground waters from the Aral side .

The Iranian geologists estimated the volume of the Caspian Sea waters, absorbed on its southern shore in the voids of carbonate karst as equal from 0,5 to 1,5 km^3/yr [Espahbod, Fallah, 2006]. On the western shore the waters of Middle Caspian Sea can penetrate into the karst holes in carbonate deposits of Miocene and, possibly, Upper Cretaceous age, while in the North Caspian Sea – into the voids of the salt and gypsum karst, developed in the salt domes.

Intrusion into the crack collectors of the crystalline rock massifs and fractural zones. Prerequisites for intrusion the Caspian Sea into the crack space of the crystalline rock massifs exist only on the small spaces of the southern shore of Krasnovodsk peninsula, along the Iranian shore near the city Khasan -Kiade and along the Talysh ridge. The sections for the intrusion of sea water into the network of the cracks of fractural zones are more extensive. The analysis of the map of fault tectonics of the Caspian Sea depression makes it possible to consider that the summary length of the irrigated fractural zones around the sea comprises not less than 1000 km. Assuming power and depth of the zone of the irrigation of the equal to respectively 0,001 km and 0,1 km, we obtain, that the summary volume of rocks in irrigation zone will compose 1 km^3. With the volume of the pore space, equal to 10%, we obtain, that volume of sea waters accumulated in the fractural zones of adjacent territories is equal 0,1 km^3, which can not change substantially the water balance of the Caspian Sea. But these waters, undoubtedly, exert a substantial influence on the stability and geodynamic activity of the rock massifs, especially during the earthquakes, when sharp drops in the pressures of underground waters generate the hydraulic fracturing of the continuity of the rock massifs, which as a result had influence on the sea level fluctuations. Furthermore, cracks and fractural zones are "hydrogeological windows", which ensure the hydraulic connections between the water-bearing complexes of artesian basins and the Caspian Sea.

CONCLUSION

The authenticity of the calculations the water balance and forecast of the Caspian Sea level fluctuations can be increased under next two main conditions.

The first of them is to refuse of superfluous absolutization the climatological concept of the Caspian Sea as closed and drainless reservoir.

The second condition provides for the need in such calculations the data of connections the Caspian Sea with the underground hydrosphere, and also the data about area and volume of its waters in the underground hollow space of adjacent territories.

The practical methods for solution that are well known now and do not contain the insurmountable barriers. There are something different difficulties connected with the inability to understand that goals by oil-producing companies, and also in the uncoordinated actions of the states of the Caspian region.

BIOGENIC SILICEOUS SEDIMENTATION IN THE MIDDLE CASPIAN SEA

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Keywords: siliceous sediment, diatoms, Caspian Sea

INTRODUCTION

The main silica carriers in ocean and seas are skeletons of radiolarian and diatoms. The forming of siliceous muds in oceans is controlled by positions of cyclonic macro circulation systems with zones of elevated biological productivity – northern-temperate, near-equatorial, and near-Antarctic. These zones represent discrete latitudinal belts of biogenic silica accumulation. Biogenic silica accumulation in the World Ocean, including nearshore upwelling areas, is sufficiently well known [Sval'nov V. N and Kazarina G.Kh., 2008] in contrast to that in isolated sedimentation basins. In this connection, the Upper Quaternary diatomaceous oozes discovered in the Derbent Basin (Middle Caspian Sea) is of certain scientific interest.

RESULTS AND DISCUSSION

The sediments were sampled with a large-diameter gravity corer at 10 geological stations located in an area 5 x5 km in size (coordinates of the center: 42 °46' N, 49 °42'E), from the depth interval of 450 to 469 m. at the foot of the western slope of the Derbent Basin during cruise 19 of R/V *Rift* in 2005. The insignificant difference in the sampling depths and the small size of the study area determined, the great uniformity of the sediments recovered, which were 2.97– 5.71 m thick (Fig. 1).

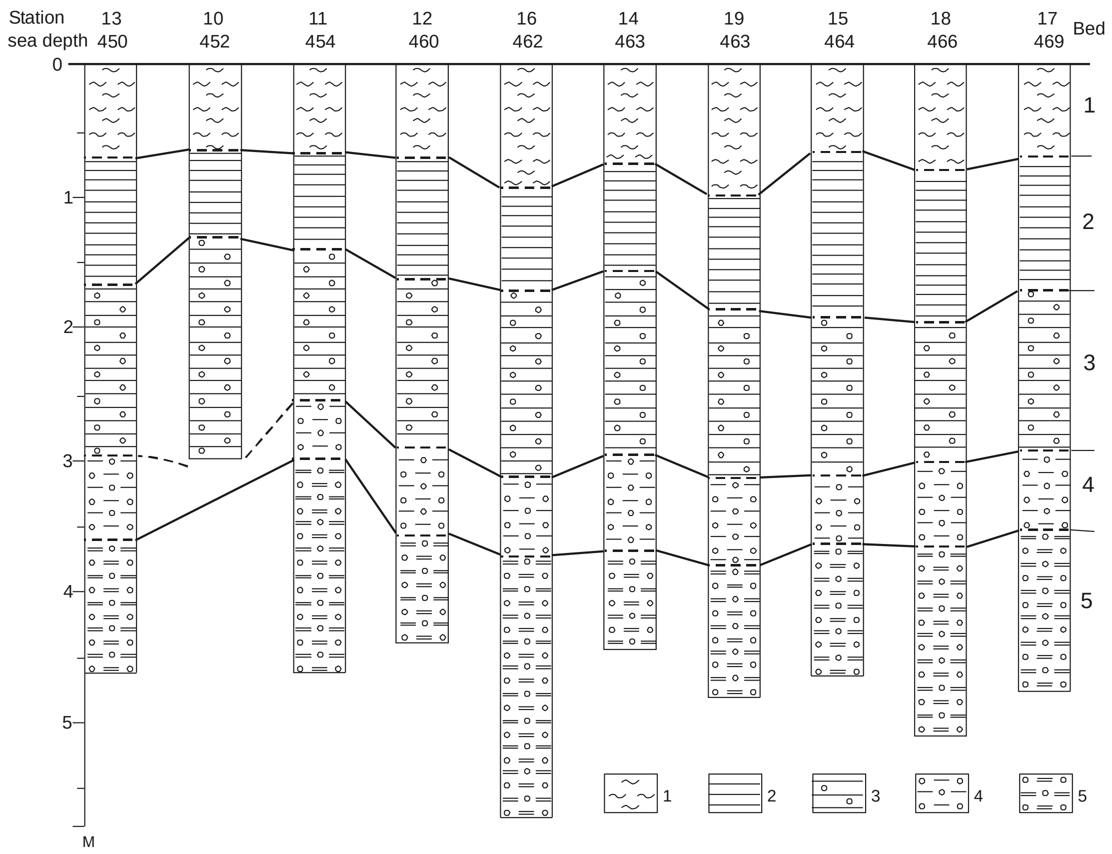

Fig.1. Lithostratigraphy of the sediments in the study area.
1—Diatomaceous ooze; 2—clay with occasional admixtures of hydrotrolite; 3—the same with obscure laminas enriched in hydrotrolite; 4—the same with numerous distinct laminas enriched in hydrotrolite; 5—the same with numerous vague lenses, spots, and laminas enriched in hydrotrolite

The longest core was obtained at station 16. The section of this reference core is subdivided into 5 lithological units (from the top downward) [Sval'nov V. N and Kazarina G.Kh., 2008].

Bed 1 (0–92 cm) is composed of jellylike and clotted diatomaceous ooze, which is generally greenish gray to grayish brown in the interval of̃ 5 cm; greenish brown in the intervals of 30–43 and 50–56 cm; and brownish gray in the intervals of 24–28, 37–39, and 43–50 cm. The abundance of diatoms gradually decreased down the section.

Bed 2 (92–170 cm) is represented by soft viscous greenish gray clay with occasional admixtures of hydrotroilite and rare brownish gray laminas; the transition to the underlying and overlying sediments is gradual.

Bed 3 (170–313 cm) consists of soft viscous greenish gray clay enclosing obscure laminas with hydrotroilite; the transition to the underlying and overlying sediments is gradual.

Bed 4 (313–372 cm) comprises soft light gray clay with numerous distinct laminas enriched in hydrotroilite; the transition to the underlying and overlying sediments is gradual.

Bed 5 (372–571 cm) is composed of soft greenish gray clay with numerous vague spots, lenses, and laminas enriched in hydrotroilite. Spotty patterns are particularly characteristic of the interval of 497–540 cm. At depths of 432, 434, 449–492, 500, and 502 cm, clay acquires a brownish tint. Downward, it gradually becomes more compact.

The study area is characterized by a uniform structure of the sections recovered (Fig. 1), which indicates the synchronism in the changes of the sedimentation conditions. Terrigenous clayey sediments with a subordinate role of silty–clayey varieties dominate them.

The upper parts of all the cores are composed of terrigenous and biogenic (diatomaceous) clayey muds, which, at the base of the section recovered, are replaced by silty–clayey terrigenous sediments with numerous obscure spots, lenses, and laminas enriched in hydrotroilite. The relative coarsening of the sediments in the lower part of the section is likely determined by the changes in the hydro dynamical settings. The positive role of the near-bottom currents in the secondary concentration of diatom valves that determined the accumulation of diatomaceous oozes cannot be ruled out.

The abundance of diatoms was estimated in semiquantitative categories: “abundant” (5 or >25–30 valves in one horizontal row of the preparation), “frequent” (4), “common” (3), “few” (2), and “single” (1 or <10 valves in the entire preparation).

The following zones were defined in the section recovered at station 16 based on the changes in the quantitative, taxonomic, and ecological compositions of the diatom assemblages (Fig. 2).

Zone A (0–70 cm) is saturated with diatoms (“abundant,” “frequent”). The assemblage is dominated by marine euryhaline mostly oceanic–neritic species of the *Coscinodicus* genus such as *C. radiatus* Ehr., *C. perforatu*s, and *C. perforatus* var. *cellulolus* Ehr. These species dwell in the Caspian Sea under a salinity of 12 – 13 ‰, although they tolerate oceanic and marine conditions with a normal salinity of 35 ‰ as well [Makarova I. V., 2002; Zakovshchikova T.K. 1970]. They are accompanied by the rare neritic euryhaline species *Actinocyclus ehrenbergii* Ralfs and *A. eherenbergii*var. *crasus* (W. Sm.) Hust. Rare fragments of freshwater pinnate forms occur in this zone.

Zone B (70–250 cm) is characterized by a notable decrease in the total abundance of diatoms (down to the category “rare”). Dominant species are the neritic dwellers of coastal freshened waters: *Actinocyclus ehrenbergii* Ralfs and *A. ehrenbergii* var. *crasus* (W. Sm.) Hust. Rare brackish-water representatives of the Thalassiosira genus such as Th. incerta Makar., Th. variabilis Makar., and others accompany them. Single valves represent the freshwater flora. Oceanic species are practically missing.

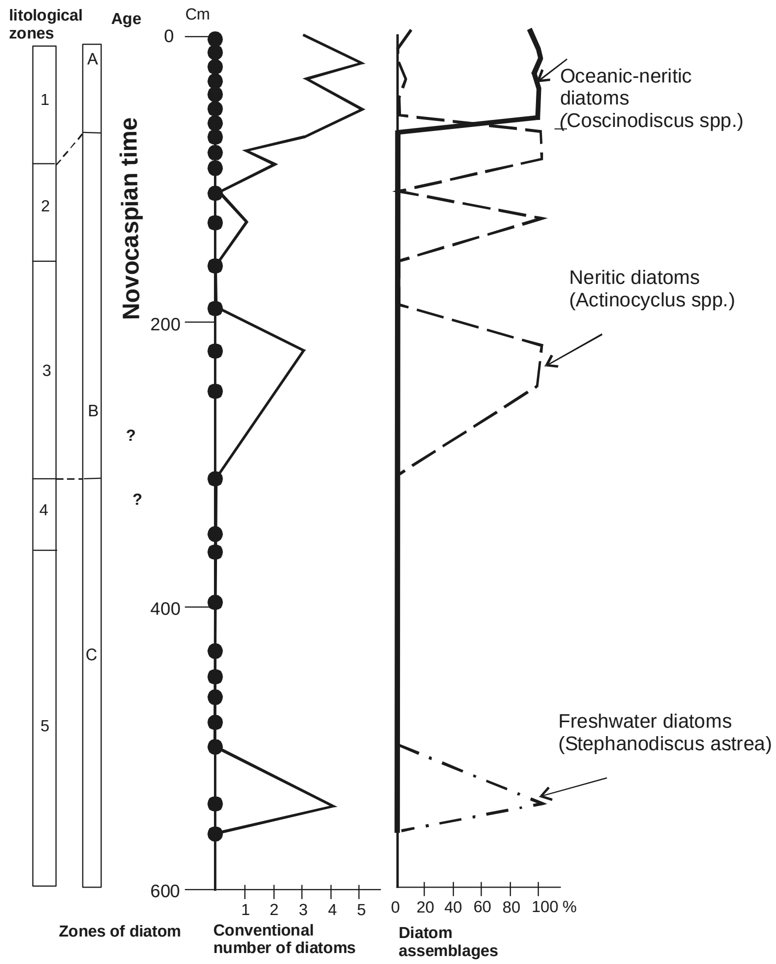

Fig. 2. Litho- and biostratigraphy (based on diatoms) of the core 16 section

Zone C (250–571 cm) is defined conditionally, since, in this interval, the sampling was sparse. No diatoms were found in this zone. Of interest is the only sample (540 cm) saturated with diatom valves ("abundant") with the dominant freshwater halophylic species *Stephanodiscus astrea* Ehr. It is conceivable that this sample represents a fragment of the highly "freshened" zone previously established in the cores from the Middle Caspian Sea [Zakovshchikova T.K. 1974]; its stratigraphic position is unknown.

The data on the diatom assemblages point to temporal changes of the salinity regime in the sedimentation basin. The highly freshened conditions are characterized by a single sample (depth of 540 cm). Changes in the diatom composition in the upper 250 cm of the core indicate relatively rapid replacement of brackish-water and, probably, shallow-water environments (250–70 cm) by a deeper and more saline regime (upper 70 cm). A comparison of our materials with the published data on the stratigraphy of the bottom sediments in the Middle Caspian Sea [Zakovshchikova T.K. 1970, 1974], which are most reliable from our standpoint, allows an assumption that Zone A and some parth of Zone B are Novocaspian in age, i.e., correspond to the Holocene in its recent understanding [Kuprin P. N., 2003], and reflect different phases in the development of the transgressive basin: the initial (Zone B) relatively brackish-water; and, then, (Zone A) probably deeper and more saline. The age of the sediments belonging to Zone C remains unknown.

CONCLUSIONS

Sampling by gravity corers at the foot of the western slope of the Derbent Basin revealed Novocaspian sediments up to 5.7 m thick. Most of the core sections examined comprise five lithological beds with close compositions and thicknesses, which indicates similar sedimentation conditions throughout the study area. The upper parts of all the cores are composed of variegated diatomaceous oozes first identified in the Middle Caspian Sea.

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DISTRIBUTION OF SUSPENDED PARTICULATE MATTER AND CHLOROPHYLL "A" IN THE CASPIAN SEA IN NOVEMBER 2008

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Keywords: suspended particulate matter, chlorophyll, Caspian Sea

INTRODUCTION

The distribution and redistribution of marine SPM are of great importance in interpreting the biological, chemical and geological processes acting in the deep sea. Particulate matter from the productive surface layer descends through the water column slowly by individual particle settling and rapidly by fecal pellet or marine snow transport, providing organic-rich food to the benthic communities. Ultimately, the material in flux to the seafloor may become part of the sedimentary record (Listzin, 1996; Richardson, 1987).

Presently, a primary source of particulate matter to the deep sea is the surface waters. Rivers and, in arid regions, atmospheric input, and, in cold climates, glaciers, deliver high suspended loads of terrigenous material. Primary production of organic matter is the main internal source of oceanic SPM. Phytoplankton and zooplankton detritus and pellets sink, comprising a large fraction of the material in transit through the water column.

The main goal of this work is studying of quantitative distribution, composition, and fluxes of micro- and nanoparticles (suspended particulate matter – SPM) in the Caspian Sea in Autumn.

METHODS

The materials for our investigation were carried out during the 29th cruise of the RV Rift from 7th to 22nd of November 2008 in the Caspian Sea (fig. 1). These works were performed in the framework of the P.P. Shirshov Institute of Oceanology of RAS (IO RAS) Programm "The Caspian Sea System" under the direction of academician A.P. Lisitzin.

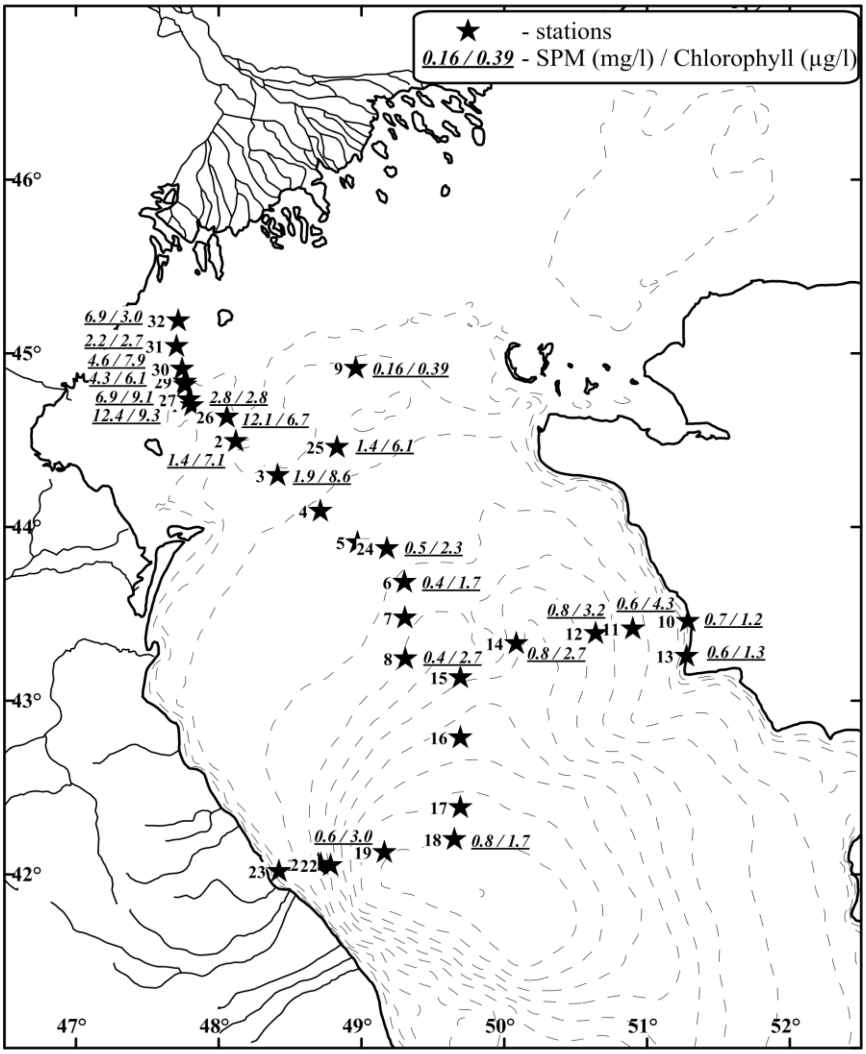

Fig. 1. Locations of samples and SPM and chlorophyll concentrations in the surface layer.
The 29th expedition of the RV Rift, 7–22 of November, 2008

The following tasks were worked out during expedition:

1) Collecting of the samples for determination of quantitative distribution and composition of SPM;
2) Determination of phytoplankton pigments (chlorophyll "a" and pheophytin "a");

The surface water samples were collected by plastic bucket. The deep water samples were collected by 5 l and 10 l Niskin bottles at depth derived from hydrooptic and CTD zonding. In general there were samples from surface, from upper mixed layer, from the pycnocline layer, from underpycnocline layer, from deep clear layer, and from bottom layer. At the deepwater stations (> 200 m) some additional samples were collected from the intermediate deep waters.

For determination of quantitative *distribution and composition of SPM* sea water was filtered with an in-line vacuum filtration system through a preweighed 47 mm diameter nuclepore filter with 0.45 μm pores and glass microfibre filter Whatman GF/F. Main components of SPM composition were obtained in our coastal laboratories: terrigenous lithogenic matter=10×Al (Kuss and Kremling, 1999), POM=2×POC (Krishnaswami and Sarin, 1976), $CaCO_3$ and Opal, as biogenic SiO_2. This data permit us to divide SPM on two main parts – lithogenic and biogenic (POM+$CaCO_3$+Opal). Values of "calculated" SPM concentration (the sum of lithogenic and biogenic SPM) closely replicate original SPM concentrations.

Determination of *phytoplankton pigments* (chlorophyll "a" and pheophytin "a") were carried out by fluorometric method at fluorometer Trilogy TURNER.

RESULTS AND DISCUSSION

Spatial distribution of SPM and phytoplankton pigments in the surface layer of the Caspian Sea in November 2008 was characterized by significant irregularity. Chlorophyll "a" concentration varied from 0.39 to 9.30 μg/l. SPM concentrations varied from 0.08 to 12.4 mg/l. Maximal values were fixed in the marginal filter of the Volga River (fig. 2). Chlorophyll maximum (9.3 μg/l) was detected at salinity limits 4–9 psu, and it was practically coincided with SPM maximum (12.4 mg/l). However, chlorophyll concentration decreases with salinity but SPM concentration decreasing is not such significant. For comparison in July of the same year (27th cruise of the RV Rift) chlorophyll concentration at marginal filter was almost 5 time above. On the contrary in the central part of the sea chlorophyll concentration in November was about 6 times above, than in July.

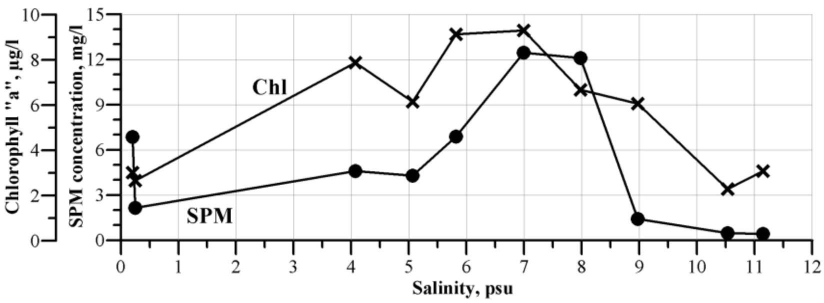

Fig. 2. Distribution of the chlorophyll "a" and SPM at the sea-river section in the marginal filter of the Volga River

Vertical distribution of temperature, salinity, and extinction coefficient was characterized by existence of upper mixed layer for about 40–60 m depth (fig. 3). It is also the layer of the maximal SPM (0.5–0.8 mg/l) and chlorophyll (2–5 μg/l) concentrations. Some stations were distinguished by undersurface layers (10–25 m) of the higher concentrations that can be explained by phytoplankton diurnation. Below pycnocline concentrations was sharply reduced (SPM – 0.1–0.4 mg/l, chlorophyll – 0–0.5 μg/l). Occurrence of near bottom nefeloid layer at some stations says about sediment detachment in slope regions of the sea.

Studying of SPM composition shows that lithogenic matter was the most significant component of Volga River mouth and coastal zones – up to 70 % in Volga Channel. In open sea organic matter prevailed everywhere. The maximal concentration of C_{org} was fixed in the upper mixed layer. But not always the maximum values of C_{org} and chlorophyll concentrations coincided. So the vertical section from the central part of the sea to its eastern coast shows the mirror inversion of distribution of these components in the upper mixed layer (fig. 4). This may be caused by differences in phytoplankton composition and relation between living units and detritus. Close distribution of chlorophyll and biogenic opal permit us to talk about predominance of living silicon-containing species (such as diatoms). And detritus cause C_{org} maximum.

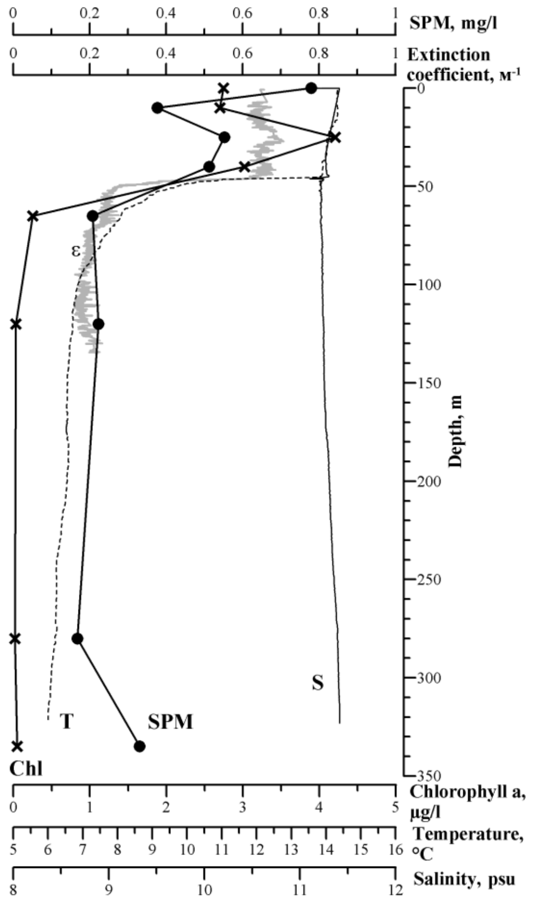

Fig. 3. Typical vertical distributions of SPM, chlorophyll, extinction coefficient, temperature, and salinity in the central part of the Caspian Sea

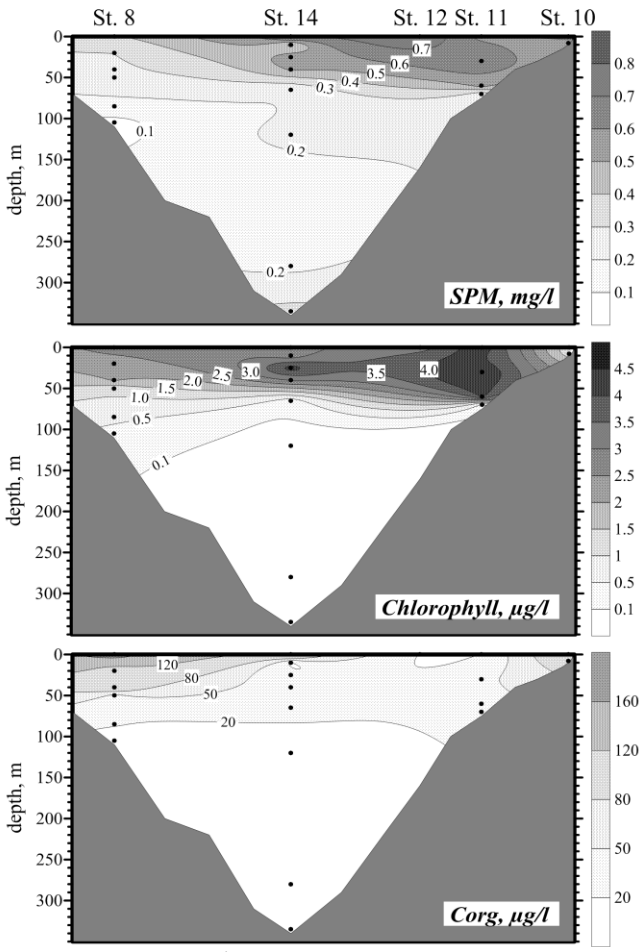

Fig. 4. Distribution of SPM, chlorophyll and C_{org} at the vertical section from the central part of the Caspian Sea to its eastern coast

CONCLUSION

So, the Caspian Sea in November 2008 was characterized by significant space-time variability of biogenous and abiogenous micro- and nanoparticles distribution. The maximal values of all studied parameters are attached to the Northern Caspian Sea. Thus, the quantitative fluctuations of SPM and phytoplankton in this part of the sea depend on Volga River runoff.

ACKNOWLEDGEMENTS

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CASPIAN WATER BALANCE AND CURRENT SEA-LEVEL CHANGES

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Keywords: The Caspian Sea level, atmospheric circulation, water balance, river runoff, precipitation, evaporation

Being the greatest enclosed water basin, the Caspian demonstrates significant long-term level fluctuations which affect not only the processes controlling the sea's natural regime but economic activities within the Caspian region as well. That's why it is the interest to gain an insight into mechanisms of the sea-level changes as well as to make possible the reliable hydrological forecasting for this unique sea.

Most of the Caspian researchers divided factors contributing to the see-level change into geological, hydrometeorological and human-induced ones.

Geological processes taking place in the region of the Caspian result in changes of the sea level through deformation of its bed and shoreline. At the same time, relatively low magnitude of tectonics in Caspian region and opposite trends of the sea bed deformations in various parts of the water basin support opinion of key importance of climate and anthropogenic factor for the sea-level fluctuations. The current vertical deformations of the sea bed and shores are assessed to be as low as several millimeters a year, while the level changes amount to 20 centimeters a year or even higher. Between 1978 and 2004, annual level fluctuations measured up 30-36 centimeters.

In some periods of the Caspian history the human interference played a decisive role in variations of the water balance. In particular, water withdrawals from the Volga and Kama basins, mainly for irrigation and filling the large water reservoirs, peaked in 1950s-60s. Water losses in 1950s were about 200 cubic kilometers which is equal to volume of newly constructed reservoirs.

Overall water consumption in the Caspian basin reached its height in 1980s with a mean annual value of 40 km^3. According to Shikhlomanov et al. (2003), much higher withdrawals were recorded in some years of this period. In 1990s, water consumption dropped to 26-27 km^3 a year. Withdrawal of water from the Volga river decreased more than twice by the end of the 20^{th} century as compared with values of the 1980s.

In the 1956-1975 period, the most part of the water that did not reach the Caspian Sea was used to fill reservoirs. Later, in 1980s-90s, the water withdrawals for irrigation became predominating part of the water resources output within the Caspian catchment area.

Another valuable factor of the Caspian water balance is the Kara-Bogaz-Gol Bay whose water level is few meters below that of the sea. Such a large evaporation pan was isolated from the sea in 1980-1984, and until 1992 the access of Caspian water to the bay was artificially restricted by the dam in the strait. This resulted in see level rise by about 40 cm. After the dam was destroyed, increase in Caspian level became slower. Without human interference, the Caspian water level would be 0.5-0.6 m higher as compared with current values.

Most of studies, observations and models of the Caspian behavior prove out the fact that long-term sea level fluctuations are controlled by climatic changes over both Caspian basin and far out of its bounds. Notably, climatic changes within all the Atlantic-European part of the Northern hemisphere have an impact on the Caspian water balance and, as a consequence, on the sea level.

Caspian level serves as an integrating result of large-scale climatic and hydrological processes. Many researchers discussed a link between Caspian fluctuations and the climatic cycle consisting of two main stages having zonal or meridional types of atmospheric circulation. In 20^{th} century, such stages alternated with each other repeatedly with duration of individual stages falling within the range from several years to three decades.

In parallel with this, distinct changes of both water balance and level of the Caspian Sea were recorded and found to be in correlation with heat-and-moisture exchange over not only European Russia but adjacent areas as well. Atmospheric circulation processes of regional and local scales with shorter cycles complicate the situation along with human activities.

Hydrometeorology of the Caspian region is affected by Atlantic-European system of atmospheric circulation. According to S.N. Rodionov (1989), the Caspian level is closely correlated with large-scale variability of atmospheric circulation over the Northern Hemisphere. General level tendencies toward a decrease or increase were observed in periods of direct opposite climatic situations over the Northern Atlantic region.

The following interpretation based on temperature gradients in tropics and polar regions appears to be appropriate to explain this phenomenon. Rapid climatic warming south of polar latitudes is followed by increase in meridional temperature gradients. Subsequent changes in circulation result in growth of precipitation over the Volga catchment basin and, river's runoff and rise water level of the Caspian Sea.

A key reason of the recent sealevel rise is supposed to be an increased wintertime frequency of North-Atlantic cyclones over the catchment basin during the 1976–1985 period followed by increase in Volga runoff by 25 to 30 per cent as compared with previous years (1970–1977). The rate of evaporation and mean wind velocities tended to decrease in the same period (Nesterov 2000). This researcher studied in detail the atmosphere-ocean relationships (Nesterov 2003) in North Atlantic region for 1957–1996 and analyzed trends of main hydrometeorological characteristics (surface temperature of the ocean, index of North Atlantic oscillation (NAO) and others). He founded that starting from 1970s there was an increase in the frequency of zonal transfere in atmosphere. This was supposedly caused by increase in meridional gradients of surface water temperatures and the index of (NAO).

High gradients of the surface layer temperatures in the North Atlantic result in predomination of zonal circulation patterns with higher cyclonic activity followed by increasing Volga runoff and water level rise in Caspian. During the negative NAO phases meridional circulation processes are most pronounced, the courses of wintertime cyclones move southwards, and the catchment basin of the Volga river suffers from precipitation deficit.

A positive NAO phase that was prevalent in the 1980–1995 period is normally accompanied with significant increase in the frequency of cyclones whose pathways move northwards. Finally, European Russia gains more precipitation, especially in winter. In last century, variations in sealevel were recorded to range between -26 and -29 m.

In the long term, changes of the Caspian level accords well with water balance components. Their values as assessed by R.Ye. Nikonova (1992) with some updates are presented in Table 1. The balance between water inflow from rivers (with Volga contribution being about 80 per cent) and evaporation is of first importance in the context of sea level dynamics.

Precipitation over the Caspian itself as well as water influx into the Kara-Bogaz-Gol Bay are among the factors of secondary significance for the sealevel dynamics, while the groundwater runoff is considered to be insignificant.

The Caspian chronology of the 20th century consists of the following periods distinguished by oppositely directed water level trends. In 1900-1929, the curve of the Caspian level tended to rise with an average of -26.1 m on the background of increasing cyclonic activity. A shift to anticyclonic circulation in 1930s resulted in deficit of precipitation over the Caspian catchment basin. Synchronous increase of evaporation enhanced this effect, and the sea level dropped by 1.8 meters during the 1930 to 1941 interval. In 1950s-1960s, climatic humidity in the Caspian catchment basin somewhat increased, but such a positive tendency gave no rise to the sea level because of multiply increased withdrawal of water to fill newly constructed reservoirs. That is why the Caspian level became more stable, not rising.

In 1970s, climatic conditions of the 1930s came back with eastern form of atmospheric circulation, drop in humidity, growing evaporation and shortage of river water. This brought a sea-level fall of 0.7 m between 1970 and 1977. The lowest for the last few centuries point of the Caspian level was recorded in 1977 (–29 m). Transgression started rapidly in 1978, and by the year of 1995 the Caspian water level rose to -26.6 m. Such a highstand was reached thanks mostly to predominating western form of atmospheric circulation in Atlantic-European sector of the Northern hemisphere. Increased precipitation resulted in growing Volga runoff which even exceeded 300 km^3 in some years. In parallel, the frequency of anticyclones declined, evaporation from the sea surface were recorded to be lower than long-term annual average values. The recent Caspian transgression was also supported by increasing amount of precipitation over the water body, the tendency that was observed since the beginning of the 20th century and became more pronounced after 1940s. The rise of the Caspian level in late 20th century was conditioned not only by climatic changes, but also by temporal cutting off the Kara-Bogaz-Gol Bay from the rest of the Caspian (Kosarev, Nikonova, 2006).

Table 1

Long-term values of the Caspian water balance components for significant periods of the 20-21th centuries

Statistics	Water level	Area	River runoff		Precipitation		Groundwater runoff		Evaporation		Flux of water into the Kara-Bogaz-Gol Bay		ΔQb	ΔHb	ΔHa	ΔHd
	m abs	n·1000 km^2	km^3	cm	km^3	cm	km^3	cm	km^3	cm	km^3	cm	km^3	cm	cm	cm
1900 – 1929																
Mean	-26,1	404,2	332,4	82,3	70,0	17,3	4	1	390,3	96,6	21,8	5,4	-5,8	-1,4	-1,2	-0,2
Max.	-25,7	408,9	459,8	115,2	87,2	21,7	4	1	466,9	114,8	29,7	7,3	110,4	27,6	30,5	8,5
Min.	-26,6	397,8	221,1	55,1	43,8	10,9	4	1	343,3	85,4	12,6	3,2	-180	-44,5	-29,5	-15
1930 – 1941																
Mean	-26,8	394,4	268,6	68,1	72,1	18,3	4	1	397	100,7	12,4	3,1	-64,6	-16,4	-15,6	-0,9
Max.	-26,1	404,3	359,5	89,1	89,5	23,6	4	1,1	413,8	106,3	21,1	5,2	41,9	10,4	10	2,3
Min.	-27,9	379,3	218,7	55,7	57,7	14,4	4	1	378	93,7	6,1	1,6	-119	-30,2	-31,5	-4,5
1942-1977																
Mean	-28,3	369,0	275,3	74,5	70,9	19,3	4	1,1	354,7	96,1	9,8	2,7	-14,5	-3,9	-3,3	-0,6
Max.	-27,8	381,3	373,0	98,0	118,4	32,6	4	1,1	444,7	116,8	15,1	4,0	105,3	29,4	17	18,5
Min.	-29,0	356,2	200,0	55,5	45,0	12,2	4	1	262,3	72,2	5,0	1,4	-116	-30,4	-30,0	-20,4
1978 –1995																
Mean	-27,8	379,1	315,0	83,1	86,1	22,7	4	1,0	348,7	91,9	8,6	2,2	47,8	12,7	13,6	-0,9
Max.	-26,6	397,3	383,0	97,5	106,0	27,6	4	1,1	408,8	102,9	46,4	11,7	110,8	30	36	7
Min.	-28,9	357,0	268,0	70,3	57,8	15,5	4	1	310,2	84,0	0	0	-49,9	-13	-14,5	-10,3
1996-2008																
Mean	-27,0	392,0	292,0	69,0	79,7	20,3	4	1,0	377,3	96,0	19,2	5,0	-20,7	-3,3	-5,2	0,8
Max.	-26,8	394,6	334,8	85,0	119,7	31,0	4	1,1	425,1	108,0	29,1	7,0	84,4	14,0	21,5	14,8
Min.	-27,2	390,2	204,5	52,0	53,6	14,0	4	1	316,3	80,0	15,2	4,0	-158,1	-29,6	-40,2	-16,7

Notes: ΔQb – change in volume of water calculated through water balance methodology, km^3; ΔHb – same value in centimeters of water layer; ΔHa – actual changes of the sea level, centimeters of water layer; ΔHd – a discrepancy between estimated and actual values, ΔHb. and ΔHa.

The short-time drop of the level for the five years after 1996 reached 50 cm and was driven mostly by climatic factors. This was a period of combined climatic situation with domination of zonal (western) and meridional atmospheric circulation patterns. In 1996, the role of western type declined drastically, so the decreasing cyclonic activity over the catchment basin was accompanied by drop in Volga runoff to a value of 180 km^3 a year. Then, however, a tendency of increasing atmospheric humidity arose, and the Caspian water balance started to be filled up annually by at least 40 km^3 in the 2001-2004 period. As a result, the water level grown up to the -27.2 point by the year of 2009.

Forecasting of long-term changes of the Caspian Sea level is an issue whose importance is comparable with complexity. Given the present-day level of scientific understanding and mathematical modeling, a reliable foresight of the Caspian behavior cannot be expected. The first of two main gaps is rather short period of instrumental observations, with the second gap being the absence of theoretical models that would adequately simulate climatic processes in Caspian catchment basin as well as within the whole Atlantic-European sector of the Northern hemisphere. Therefore, current forecasts can be based only on extrapolation of water balance parameters to a period just of several years.

CONCLUSIONS

Fluctuations of the Caspian Sea level are controlled by the large-scale atmospheric processes which are responsible for weather conditions in and out of the catchment basin. Caspian's reaction on climatic changes comes with some delay whose length ranges between a year and several years. The most informative parameters of atmospheric circulation over the Northern hemisphere can serve as predictors of future behavior of the Caspian. Recently some efforts have been made to find links between Caspian level fluctuations and global circulation systems such as ENSO. No statistically significant relationships are found by now. Analysis of hydrometeorological databases and palaeogeographic reconstructions (Rychagov 1997) result in 2 m (and even more) interval of the sealevel fluctuations for the century as the most likely scenario. Corresponding elevation marks of the sea level are -26 and -28 m.

Long-term fluctuations of the Caspian Sea level is a naturally determined phenomenon reflecting the 'breathing' of this large enclosed water body. Both research and economic activities within this region must be planned with an allowance for risk of changing the sea's level.

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INTERANNUAL VARIATIONS OF THE MAIN THERMOHYDRODYNAMIC PARAMETERS OF THE CASPIAN SEA IN RELATION TO THE REGIONAL CLIMATE CHANGE

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Keywords: Caspian Sea, regional climate change, interannual variability, river runoff, sea surface temperature, sea level, salinity.

INTRODUCTION

Regional climate change in the Caspian Sea region together with anthropogenic impact has a strong influence on different physical, chemical and biological parameters of the sea: its sea level, biodiversity and bioresources, freshwater resources, river and groundwater runoff, vegetation cover and desertification in the Caspian Sea region (Kostianoy and Kosarev, 2005). From the other side, desertification itself can exacerbate regional climate change. In this paper we will focus on the interannual variations of the river runoff, sea level, salinity and sea surface temperature of the Caspian Sea.

RIVERS RUNOFF

Climate change will directly affect the water capacity in the Caspian Sea catchment area. Volga runoff constitutes up to 80% of water inflow into the sea, and watershed (including the Oka and Kama River basins) has an area of about 1360 km^2 (Hydrometeorology.., 1992). This catchment area has a considerable length − more than 2000 km from the Caspian Sea to the Valdai Hills. It is located in several climatic zones. Thus, climate change on the watershed significantly affects the Caspian Sea level. The total inflow of fresh water in the Caspian Sea in the period 1880−2001 years was significantly changed, with a little change on average from 1880 to 1930 (with strong interannual variations of 240 km^3/year against the average value of about 300 km^3/year), progressive decrease until 1977 (with a minimum in 1975 – 181 km^3/year) and increase from 1978 to 2001 (with a peak of 387 km^3/year in 1994), and a slight decline in the subsequent years (Frolov, 2003).

SEA LEVEL

Instrumental measurements of the Caspian Sea level and systematic monitoring of its fluctuations began in 1837. The sea level is measured in the Baltic system of heights (BS), adopted in the USSR in 1977. The absolute height of geodetic control points and sea level gauges in meters of the BS is counted from the «zero level» at sea level gauge in Kronstadt, the Baltic Sea. Currently, the BS is used in Russia and in several other CIS countries. Fig. 1 shows interannual variability of the Caspian Sea level according to the sea level gauge data from 1837 to 2006. In the XX century, we can distinguish several characteristic periods: 1900−1929 and 1942−1969 are years of the relative stability or moderate decrease of sea level; 1930−1941 and 1970−1977 are years of a sharp sea level decrease; and the 1978−1995 are years of a sharp sea level increase. Over the past century, the highest water level in the Caspian Sea was registered in 1900 (-25.7 m BS), and the lowest in the last 550 years was recorded in 1977 (-29.0 m BS).

Some measures have been taken to stabilize the sea level, in particular, the separation of the Kara-Bogaz-Gol Bay from the sea by a dam in March 1980. However, by this time (1980−1981) due to natural climatic causes the Caspian Sea level has already risen by 40−50 cm (Terziev and Nikonova, 2003; Abuzyarov, 2003; Kostianoy and Kosarev, 2005; Kosarev, Kostianoy, Zonn, 2009). This has happened as a result of climate change in the Atlantic-European sector dominated by the western form of atmosphere circulation that greatly increased moisture, amounts of precipitation and water content of the rivers. Since 1978, the annual rise in the sea level ranged from 14 to 30 cm. As a result, from 1977 to 1995, the sea level rose by 2.4 m and its absolute value reached -26.6 m BS.

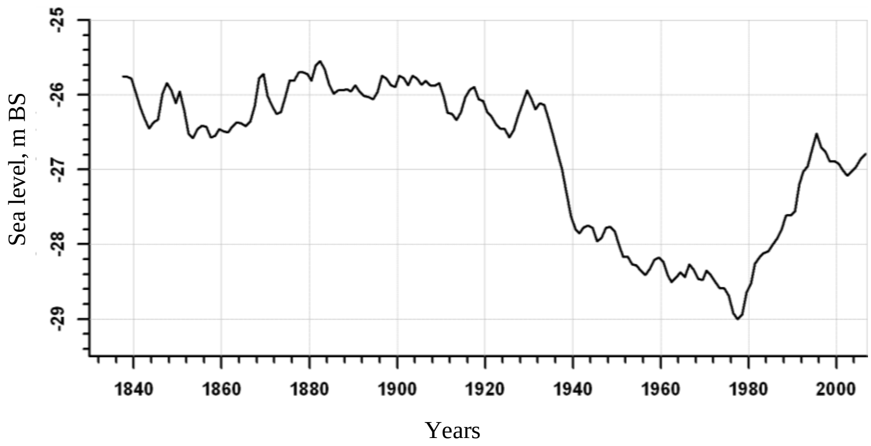

Fig. 1. Interannual variability of the Caspian Sea level (m BS) according to the sea level gauges from 1837 to 2006 (based on data of Russian State Oceanographic Institute, see also (Lebedev and Kostianoy, 2005))

From September 1992 to the present, variability of the Caspian Sea level is well observed by satellite altimetry data (Fig. 2). The results of the calculations showed (Fig. 2) that from the winter of 1992/1993 to the summer of 1995 we observed an increase in the sea level, then there has been its regular decrease until the winter of 2001/2002 (down to the elevation of -27.1 m), and subsequent increase with an average rate of 7.5±1.3 cm/year till summer 2005 (Lebedev and Kostianoy, 2005). Comparison of calculations basing on sea level gauges data and satellite altimetry data showed a good agreement between the results obtained. For the period of 1993−2005, a correlation coefficient ranged from 0.74 to 0.98 (Lebedev and Kostianoy, 2005).

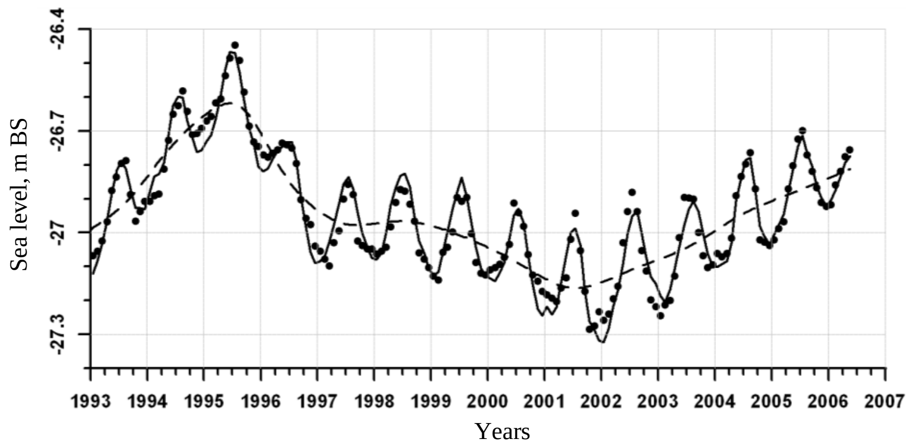

Fig. 2. Seasonal and interannual variability of the Caspian Sea level (m BS) from January 1993 to June 2006 according to the altimeter measurements of satellites TOPEX/Poseidon and Jason-1 (solid line) and data of sea level gauges (markers). Interannual variability is shown by a dashed line (Lebedev, Kostianoy, 2005)

Economic losses, associated with the rise of the Caspian Sea, were estimated by the World Meteorological Organization (WMO) as 15 billion USD (Complex .., 1997). By the same estimates, if in the coming years measures will not be taken to protect coastal structures, the damage could reach 200 billion USD (Complex .., 1997; Abuzyarov, 2003). Fishery, agriculture and water resources in the region were damaged. Sea level rise between 1978 and 1995 destroyed villages and infrastructure in coastal strip 50−70 km wide in Kazakhstan and 5−35 km in Turkmenistan. According to (Transboundary .., 2002), the impact of sea level rise affected 7 million ha of land, where about 600,000 people live. In addition, the wind effects (surges in the shallow Northern Caspian Sea) lead to flooding of the coastal areas. Thus, surges of 2−3 m in height can flood the area of 20−30 km in the coastal zone. On the other hand, according to Caspian Research Institute for Fishery and others, a decrease in the Caspian Sea level can lead to a complete disappearance of valuable species of sturgeon.

Since summer 2005, we observe a slow but steady decrease of the Caspian Sea level with a rate of 7.5 cm/year. During the past winter (2009/2010) the sea level decreased down to the marks (-27.3 m) observed during the intermediate minimum in winter 2001/2002 (see Fig. 2).

SALINITY

Significant long-term changes in salinity are observed mainly in the shallow waters of the Northern Caspian, where they are due, mainly, to changes in the Volga runoff. For more than half a century (1931−1989) annual average salinity of the Northern Caspian varied from 11.7 to 6.4‰ (range of 5.3‰). In a quasi-stationary water-salt balance (1956−1970) this range of variability was significantly less (2.2‰). On the southern border of the Northern Caspian (at hydrological section Chechen Island – Mangyshlak Peninsula) with decreasing of the Volga runoff in 1950−1970 there was an increase in salinity in the surface layer (0−10 m) by 0.5−0.8‰. However, with increasing runoff in the 1980's, salinity was reduced by 0.5-0.6‰ (Hydrometeorology.., 1992).

SEA SURFACE TEMPERATURE (SST)

Analysis of satellite NODS/MCSST data (1982−2000) revealed the positive trends of SST averaged over the Middle and Southern Caspian: 0.05 and 0.10°C per year, respectively (Ginzburg et al., 2004, 2005). There was no way to properly obtain long-term trend for the Northern Caspian SST due to lack of data for the winter season because this region is yearly covered by ice. However, judging by the increase in summer SSTs since 1992, and warm winters (Kouraev et al., 2003), the warming could also occur here in the years 1982−2000. Within this period, however, the warming trend was not monotonic. The most dramatic changes in average SST occurred in 1989−1995: it decreased in 1989−1992 and increased in 1992−1995 (a minimum in 1983 was related to insufficient data) (Fig. 3). The warming of the Middle and Southern Caspian in 1982−2000 occurred in all seasons, with strongest trend (0.06 and 0.09°C/year in the Middle and Southern Caspian, respectively) observed in summer season (July-September), the lowest 0.03°C/year − in autumn (October-December). The mean annual SST in 1982−2000 increased by about 1°C in the Middle and Southern Caspian in comparison with its value before 1952 (Arkhipova, 1955; Arkhipova et al., 1958). The maximum (summer) and minimum (winter) SST markedly increased, but the difference between the maximum summer and minimum winter SST slightly decreased. The positive trend in SST in 1982−2000 was several times higher than that of the preceding period (about 0.01°C/year) (Potaychuk, 1975; Hydrometeorology ..., 1992). The character of SST changes in 1982−2000 in the closely-spaced inland Caspian and Black seas was similar (Ginzburg et al., 2004, 2005, 2008). Close values of the positive SST trends, reduction of SST average values in 1985−1993 and their subsequent increase, the same character of distinct seasonal SST anomalies indicate the decisive role of climatic factors in the interannual and decadal SST variability in both seas. Warming in the 1980's was also recorded in the North-Eeast Atlantic Ocean – an increase by 1°C in 1982−1987 (Djenidi et al., 2000), as well as in several regions of the Mediterranean Sea in 1984−1990 (Santoleri et al., 1994; Kostianoy, 1996).

CONCLUSIONS

Climate change directly affects the water capacity in the Caspian Sea catchment area and the level of the sea. During the last century, the Caspian Sea level varied in the range of 3 m reaching its minimum for the last 550 years in 1977 (-29.0 m BS). From 1977 to 1995, the sea level rose by 2.4 m and its absolute value reached -26.6 m BS. From September 1992 to the present, variability of the Caspian Sea level is well observed by satellite altimetry data. Since summer 2005, we observe a slow but steady decrease of the Caspian Sea level with a rate of 7.5 cm/year. During the past winter (2009/2010), the sea level decreased down to the marks (-27.3 m) observed during the intermediate minimum in winter 2001/2002. Significant long-term changes in salinity are observed mainly in the shallow waters of the Northern Caspian, where they are due, mainly, to changes in the Volga runoff. For more than half a century (1931−1989), annual average salinity of the Northern Caspian varied from 11.7 to 6.4‰. Analysis of satellite data revealed a positive trend of the average for the Middle and Southern Caspian SST in the 1982−2000: 0.05 and 0.10°C per year, respectively. The nature of SST changes in 1982−2000 in the Caspian and Black seas was similar.

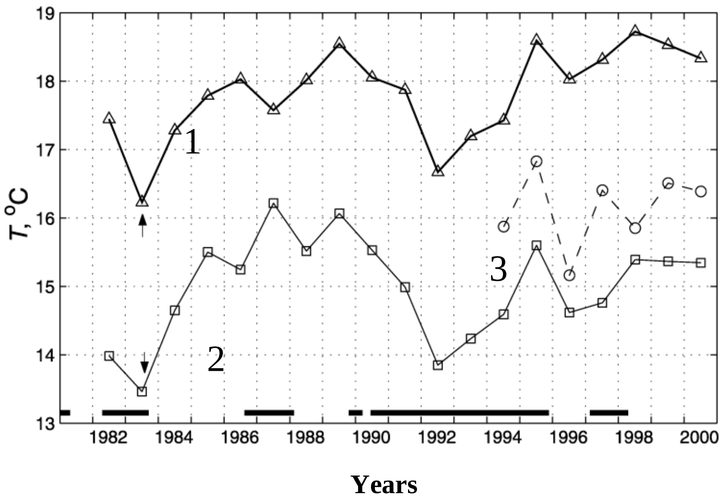

Fig. 3. The mean yearly SST values for different areas of the Caspian Sea in 1982−2000 (Ginzburg et al., 2004). 1 – Southern Caspian 2 – Middle Caspian, 3 – Kara-Bogaz-Gol Bay. The thick segments on the horizontal axis mark the El Niño periods. Arrows indicate low SST values due to a lack of data

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CONTROLS ON SEDIMENT DISTRIBUTION PATTERN IN THE SOUTH CASPIAN SEA, IRAN

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Keywords: Caspian Sea, sedimentology, sediment core, palynology, magnetic susceptibility

INTRODUCTION

The South Caspian Coast in Iran with around 800 km length stretches from Astara in west to Hosseingholi in the east. More than 60 rivers cross the coastline, flowing into the south Caspian Sea. The climate is subtropical with about 2000 mm precipitation in the west, which changes to arid one with 200 mm rainfall in the east. Prevailed coastal and sea current determine the sediment distribution and settlement. During the past decades, the Caspian Sea experiences superimposed changes from anthropogenic and natural sources. They could be retrieved from sedimentary archives of deep sea deposits. A number of studies have focused on the coastal sedimentary processes of the south Caspian Sea (Motamed, 1967, Kazancı et al., 1994, Lahijani et al., 2009), where sediment characteristics of the deeper parts are poorly understood yet. The main goal of this paper is to introduce the sedimentary specifications of the south Caspian Sea under rapid environmental changes.

MATERIAL AND METHOD

A total of 42 cores have been collected from the south Caspian Sea from depth of 20 m down to 450 m using a gravity corer (Fig. 1). The length of cores varies from 50 to 180 cm. The cores are opened and subsampled in the laboratory of the Iranian National Center for Oceanography (INCO) for grain size analysis and determining calcium carbonate as well as organic matter content. Palynology, dating and magnetic susceptibility have been performed on the selected cores at the laboratory of the Brunel University. Also the selected cores were scanned using medical three dimensional X-ray analysis to reveal the main internal structures.

RESULTS AND PRELIMINARY INTERPRETATION

Grain size analysis displays domination of silt and clay fraction in the deeper environments of the sea. The grain size distribution pattern partially reflects the sedimentary environment. However, hydrodynamic condition is a secondary factor that affects the distribution pattern of the sediments as domination of mud appears in the shallower depth of the east part compare to the high-energy environment of the central part. The organic matter of the sediments varies from 2% in the near- shore areas up to 25% in the deeper zones. The quantity of the organic matter increases following the depth of the environment. It seems lower availability of oxygen in the deep water facilitate preservation of the organic matter.

The content of calcium carbonate varies from 10 to 40%. It shows elevated concentration in the eastern part, that can be attributed both to the biogenic and terrigenous sources. The eastern part with relatively gentle slope of the shelf and arid climate is more susceptible for carbonate bearing organisms. Moreover, the rivers of eastern part drain limestones outcropping in the watershed, which provide more carbonate to the Caspian Sea. Also probably an aeolian source and the southward drift on the eastern shore of Iran can provide carbonate sediments. Dating of the cores demonstrate that the south Caspian Sea has high rate of sedimentation that changes between 10 and 25 mm/y. High sedimentation rate occurs in the areas with high sediment supply, both due to riverine sources and coastal and sea drifts. Magnetic susceptibility and its variability in the sediment sequences could be correlated to sea level changes. But the Caspian Sea is a closed basin and its sea level changes and terrigenous sediment supply differs from those in the open ocean. Therefore it should be applied with cautious, considering the Caspian specifications.

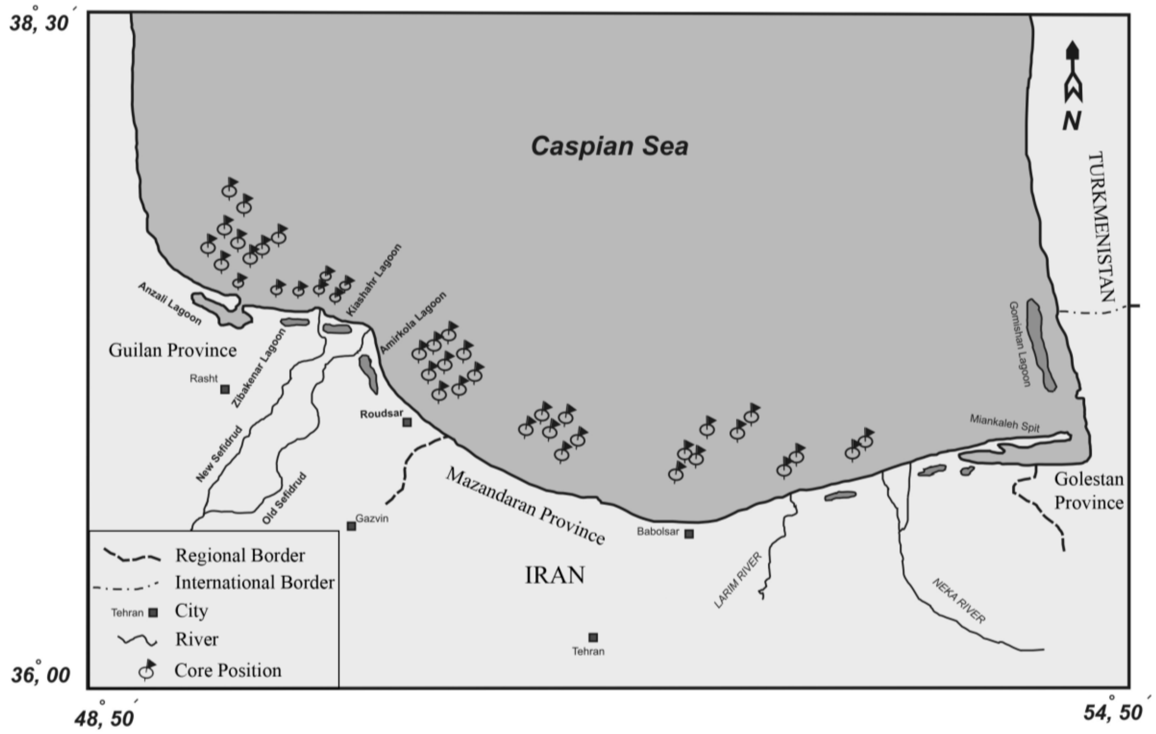

Fig. 1. The sketch map of the south Caspian coasts in Iran showing the position of collected sediment core samples

CONCLUSION

The geology and geomorphology of the South Caspian coastal areas are the main factors that exert primary control on sediment distribution pattern in the basin. Other factors such as hydrodynamics of the sea and variations in biological productivity impose a minor imprint on the dominantly terrigenous basin.

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INTERANNUAL VARIABILITY OF METEOROLOGICAL, HYDROLOGICAL AND HYDRODYNAMIC REGIME OF THE CASPIAN SEA BASED ON SATELLITE ALTIMETRY DATA

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Keywords: Caspian Sea, altimetry, sea level, mean sea surface, wind speed, wave height.

INTRODUCTION

The Caspian Sea is the world's largest isolated water reservoir, with only isolation being its significant dissimilarity from the open seas. The isolation of the Caspian Sea from the ocean and its inland position make the significance of its outer thermohydrodynamic factors, specifically, heat and water fluxes through the sea surface, and river discharge on sea level variability, formation of its 3D thermohaline structure, and water circulation (Kosarev and Yablonskaya, 1994). Over the past half-century, there was the Caspian Sea level regression until 1977 when the sea level lowered to -29 m (Fig. 1). It is obvious that man's impact led to a more than 2.5 m regression of the Caspian Sea level caused by the creation of cascade reservoirs in the Volga and Kama Rivers. This drop is considered to be the deepest for the last 400–500 years (Kostianoy and Kosarev, 2005). In 1978 the water level started to rise rapidly, and now it has stabilized.

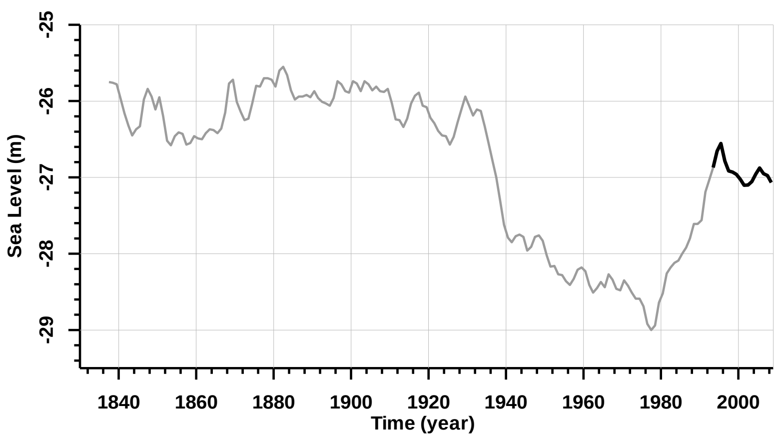


Fig. 1. Interannual variations of the Caspian Sea level measured by sea level gauges (gray line) and satellite altimetry (black line) from 1837 till 2009

Satellite altimetry measures sea surface height (SSH) relative to a reference ellipsoid (or the gravity center) that allows elimination of vertical Earth's crust lift from interannual level variation. It was shown that spatial and temporal resolution of satellite altimetry data allows to investigate seasonal, interannual and space-time variability of the Caspian Sea level (Cazenave et al. 1997; Lebedev and Kostianoy, 2005, 2008; Kouraev et al., 2010).

DATA AND METHODOLOGY

For this investigation altimetric measurements from both the T/P and J1/2 satellites were used for the following reasons. The position of T/P and J1/2 ground tracks (Kosarev and Kostianoy, 2005) is optimal for analysis of sea level variations in the Caspian Sea (Fig. 2). The precision of SSH measurements by T/P and J1/2 to the relative reference ellipsoid is 1.7 cm, which is higher than other altimetry missions. At the same time, accuracy of sea level measurements is of ~4 cm that allows adequate accuracy for specific studies to be conducted. The orbital repeat period (~10 days) enables analysis of interannual and seasonal variability of the sea level. The T/P data represent the longest time-series of satellite altimetry measurements (September 1992 – August 2002) with the possibility of the data extension by J1 data along the same tracks (August 2002 – February 2009) and J2 (July 2008 – December 2009).

Satellite altimetry data processing methods and analysis as well as obtained results on the SSH variations were described in detail in the book by Lebedev and Kostianoy (2005). All necessary corrections from satellite altimetry data-base: microwave radiometer wet tropospheric, smoothed dual-frequency ionosphere and sea state bias are used in the data processing. Maximal tide height for the Caspian Sea is 2 cm in coastal zone so this correction isn't used in the data processing.

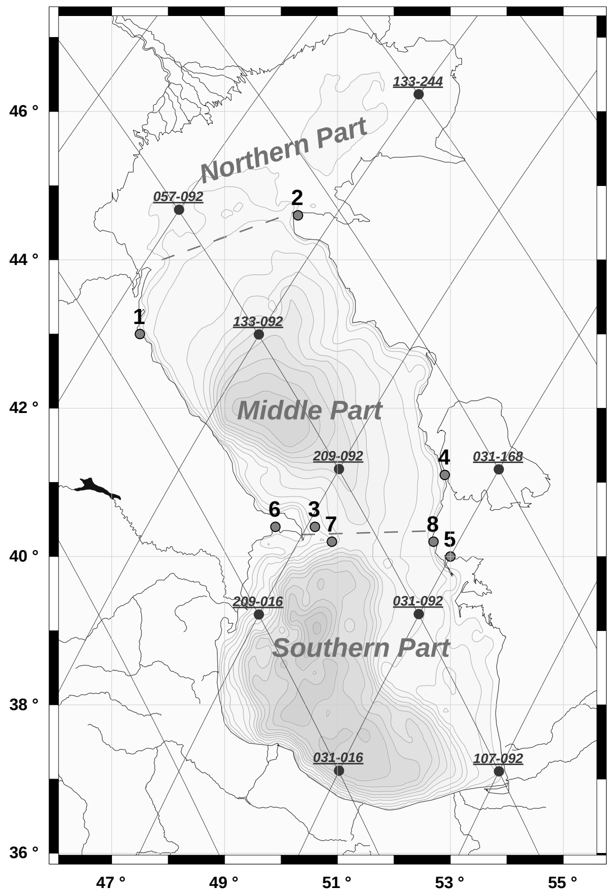


Fig. 2. Map of the Caspian Sea, ground tracks and crossover points of the T/P and J1. Sea level gauges are shown as follows: 1 – Makhachkala, 2 – Fort Shevchenko, 3 – Zhiloy Island, 4 – Kara-Bogaz-Gol, 5 – Turkmenbashi, 6 – Baku, 7 – Neftyanye Kamni, 8 – Kuuli Mayak

Regional MSS model of the Caspian Sea (GCRAS09 MSS) was calculated according to the following scheme. For satellite altimetry data processing dry tropospheric correction was calculated on atmospheric pressure from nearest weather stations located along the Caspian Sea costal line. From the T/P and J1/2 satellite altimetry data, the SSH synoptic and seasonal variations for all passes of each repeat cycle were eliminated. In last phase, the GCRAS09 MSS was constructed as a SSH function of latitude, longitude, and time with correction on climatic dynamic topography. For specified time interval SSH was interpolated on grid by radial basis function method.

Dynamic topography (DT) was constructed on the basis of the superposition of the SLA (calculated relative to the GSRAS09 MSS model) distribution over the climatic dynamic topography (or hydrodynamic level), which was calculated on the base of a three-dimensional baroclinic model.

RESULTS

The wind regime of the Caspian Sea is defined by three principal factors: regional atmospheric activity, topography of the coasts (orography) and local circulation induced by the thermal difference between the land and the sea. Comparison of wind speed data from meteorological stations and results of calculations of satellite altimetry data have shown that in-situ data and remote sensing measurements coincide within the limits of accuracy for satellite altimetry methods. The coefficient of correlation between these types of data was 0.819. In general wind speed is 1.5 times higher in winter than in summer with a maximum in the Middle Caspian. Seasonal variability of significant wave height shows that in general in the Middle Caspian wave heights are two times higher in winter than in summer and 1.5 times higher than in the Southern Caspian.

Investigation of the Caspian Sea level variation was based on the analysis of SSH variability in 7 crossover points (2 – in the Northern Caspian, 2 – in the Middle Caspian and 3 – in the Southern Caspian (Fig.2)). Integrated interannual variability of the Caspian Sea level is shown in Fig. 1 (black line). Comparison of SSH variations in 7 crossover points with data of 8 sea level gauges has shown that a maximal value of the correlation coefficient 0.967 was observed between the station in Baku and nearest crossover point (Fig. 3). For the sea level time variability of the whole sea, which is traditionally calculated basing on the sea level gauges in Makhachkala, Baku, Fort Shevchenko and Krasnovodsk (nowadays Turkmenbashi), the correlation coefficient for all crossover points is higher than 0.94.

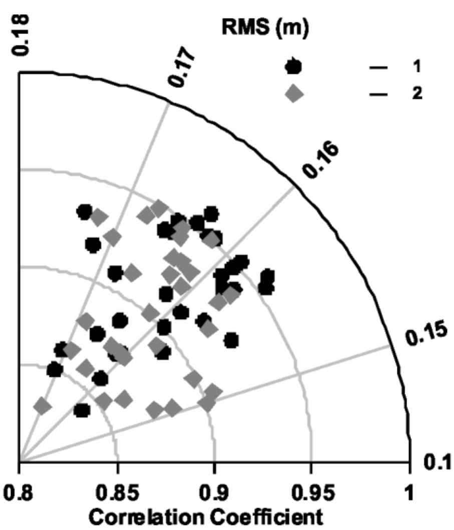


Fig. 3. Correlation coefficients and RMS between average monthly data of sea level gauge measurements and SSH derived from satellite altimetry data. Black circle markers (1) show correlation between data in the Middle Caspian Sea and gray diamond markers (2) – in the Southern Caspian Sea

According to variation of the interannual Caspian Sea level change (Lebedev and Kostianoy, 2008; Kouraev et al., 2010) we determine five time periods: strong rise (1993–1995) with rate +19.9 cm/yr, strong drop (1995–1997) with rate -22.2 cm/yr, slow rise (2002–2006) with rate +9.9 cm/yr, slow drop (1997–2002 and 2006–2009) with rate -5.9 cm/yr and -7.9 cm/yr respectively (Fig.4). For investigation of spatial variability we constructed an annual MSS for each year from 1993 to 2009 with using the GCRAS09 MSS Model data and interpolation on regular grid by radial basis function method. Map of rate of the interannual Caspian Sea level change are calculated as difference between two annual MSS maps (Fig.5). For time period of strong sea level rise (1993–1995) mean value of the sea level change rate is 9.2 cm/yr. Maximum value (more than 12 cm/yr) was located in the Middle and Southern Caspian and correlated with depths. Near the Kara-Bogaz-Gol Bay rate of sea level rise of 8.1 cm/yr was less then the mean value. In next time period (1995–1997) of strong sea level drop a maximum value (more than 15 cm/yr) was observed in the Northern Caspian and minimum (less than 3 cm/yr) are located near southwestern coast of the Southern Caspian. Similar regime of slow sea level drop holded since 1997 till 2002. Mean value of the sea level change rate was -4.8 cm/yr. In the time periods of slow drop (1997–2002) and slow rise (2002–2006) a rate of sea level change was well correlated with gravity anomaly field. Extreme variation of it is observed in the Middle and Southern Caspian near the Apsheron Ridge.

The process of refilling of the Kara-Bogaz-Gol Bay and its acquisition to a climatic regime is well traced in the SA data of the T/P and J1/2. Fortunately, the start of the T/P mission successfully coincided with the beginning of the filling of the bay and the area of the bay is crossed by two tracks of the above-mentioned satellites. By the mid-1996, the rapid filling of the bay with the Caspian Sea water had caused a rate of the bay level rise of about 168 cm/yr (Fig. 6a) (Lebedev and Kostianoy, 2005, 2008). Then, the level rise stopped and its variations started to reflect seasonal changes well correlated with the seasonal level changes in the Caspian Sea. Thus, the rate of the level fall (until winter 2001/2002) in both basins was approximately -6.3 cm/yr. For the time period 2002–2006 the bay level has been rising again with the rate +6.8 cm/yr. Since 2006 till present the level of the bay is falling with a rate of 8.9 cm/yr (Fig. 6b). Integrally the Kara-Bogaz-Gol Bay level oscillations are near an absolute mark of -27.5 m.

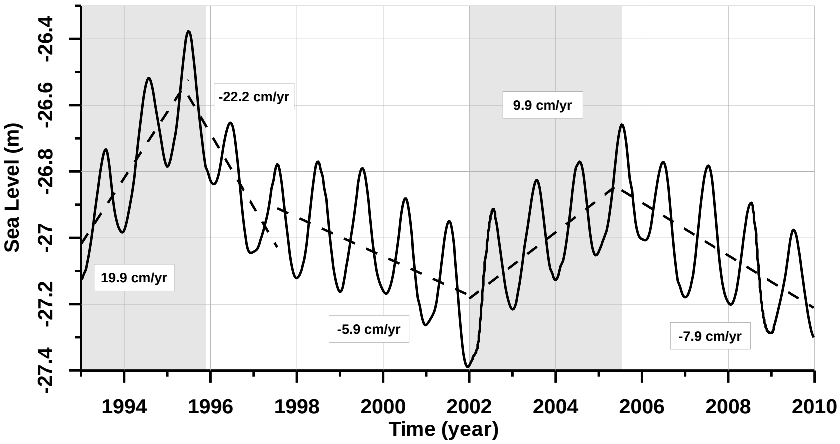
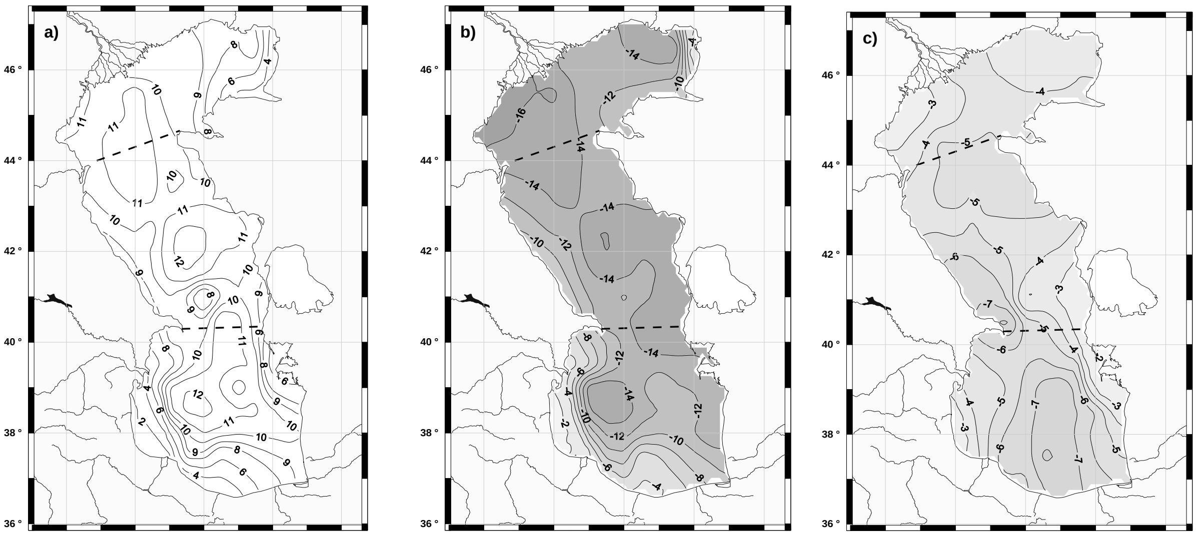


Fig. 4. Interannual and seasonal variability of the Caspian Sea Level (m) at 7 crossover points (see Fig.2) in September 1992 – December 2009. Gray area show temporal interval where the sea level rises



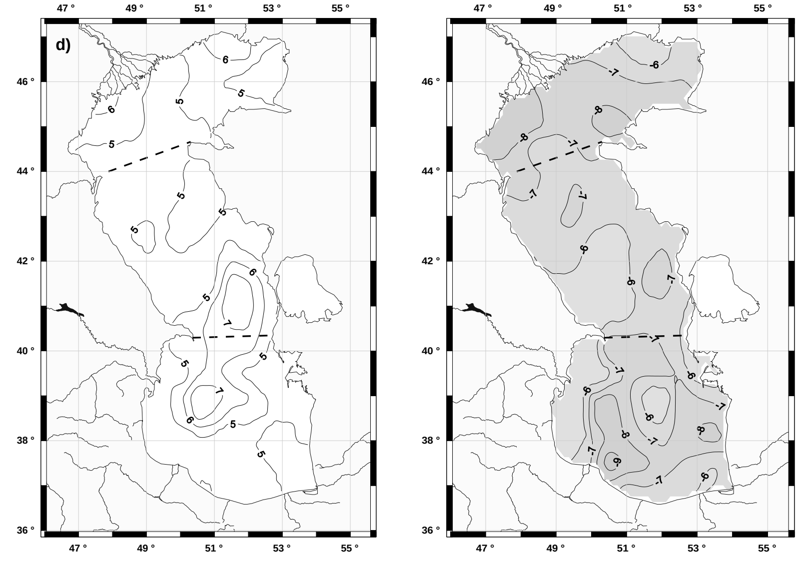


Fig. 5. Map of rate of the interannual Caspian Sea level change (cm/yr) for five time period:
(a) – strong rise (1993–1995),
(b) – strong drop (1995–1997),
(c) – slow drop (1997–2002),
(d) – slow rise (2002–2006),
(e) – slow drop (2006–2008).
Shades of gray correspond to negative values. Dashed lines show borders between the Northern and Middle, and Middle and Southern parts of the Caspian Sea.

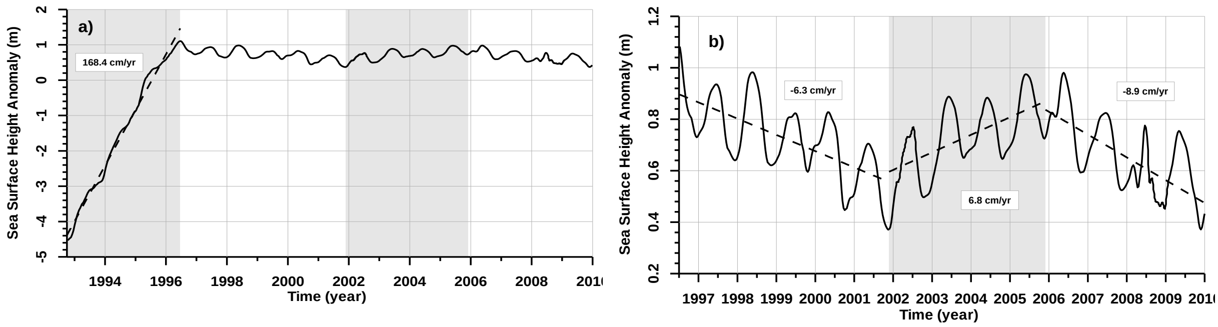


Fig. 6. Interannual and seasonal variability of SSH (m) in the Kara-Bogaz-Gol Bay at crossover point of 031 pass and 168 pass in (a) September 1992 – December 2009 and (b) July 1996 – December 2009. Gray area show temporal interval where the bay level rises

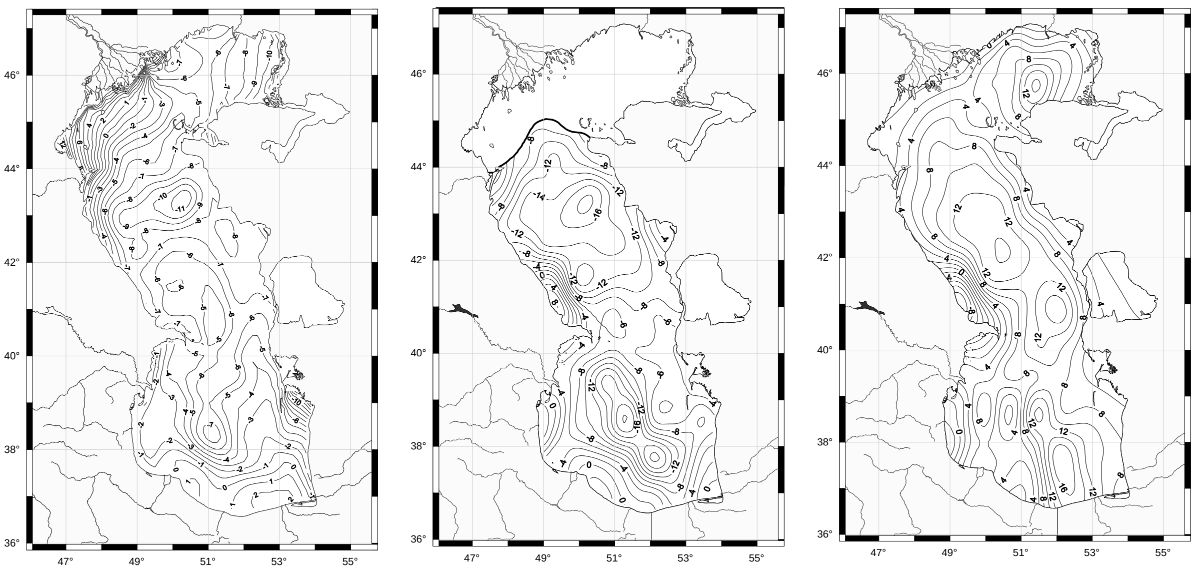


Fig. 7. The climatic or mean dynamic topography (a) (cm) from numerical hydrodynamic Hydrometeorological Research Center (HRC) of Russian Federation model (Popov, 2004).
The seasonal dynamic topography (cm) for January (b) and July (c) for September 1992 – December 2009 on the base of satellite altimetry data of T/P and J1/2 and results of hydrodynamic simulation on the base of the HRC model.
Bold line shows mean boundary of the sea ice in the Northern Caspian.

Analysis of seasonal DT shows existence of a gyre in the Middle Caspian (Fig. 7), which changes its direction of rotation from a cyclonic one in winter months to an anticyclonic one in summer months.

This transformation seems to be conditioned by seasonal variability of theVolga River dischage and wind conditions over the Caspian Sea. Dynamics of the Southern Caspian Sea have a pronounced vortical nature; wind variability is a cause of this phenomenon.

ACKNOWLEDGEMENTS

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MATHEMATICAL MODELING OF THE SHELF ECOSYSTEM OF THE CASPIAN SEA

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Keywords: Caspian Sea, shelf, ecosystem, modelling

Mathematical modeling of the shelf ecosystem of the Caspian Sea is based on the method of aggregation and averaging with the subsequent hierarchic decomposition. This approach includes a step-by-step comparison of the modeling results with the data of observations. Forecast of the condition of the marine ecological medium based on the characteristics of the optical fields [1, 2] (absorption coefficient, backscattering coefficient, and coefficient of diffuse light reflection), which depend on the condition of the components of the ecological system, should be specially emphasized among the problems solved on the basis of mathematical modeling. The regularities of the formation of spatiotemporal inhomogeneities of the hydrooptical characteristics reflect the complexity and multicomponent property of the ecosystem composition and take into account the interrelations between the processes of different nature occurring in the ecosystem: physical, chemical, biological, or geological. On the other hand, the signal of the upgoing radiation is well determined by remote observations from aerospace carriers. This provides conditions for calibration of the model based on the data of remote and sea truth experiments [1, 2].

This stage of research is related to detailed development of the universal model of a marine system with respect to the established relations between the processes of different nature (physical, chemical, biological, and geological) to include it into the system of monitoring of the shelf in the northern region of the Caspian Sea. In this study, we solved the problems of calculating the annual and spectral evolution of the absorption coefficient, the backscattering coefficient, and the coefficient of diffuse light reflection, as well as the problem of performing a comparative analysis of the results obtained with the data of the field and remote observations available. The model has a block structure of three levels. At the first level of modeling, individual processes are taken into account. Most frequently, they are established empirically. These are relations for the laws of hydromechanics, optics, thermodynamics, regularities of chemical reactions, photosynthesis, and the increase in the biomass of organisms [1].

The interaction between the processes is presented by the models of the second level: the hydrothermodynamical block (HTD), hydrobiological block (HB), and hydrochemical block (HC). It is possible to model the ecological processes only using the models of the third level, which unites the models of the second level into a closed system. A real object is not described by a model of any level but by a hierarchic sequence of models describing a real system with increasing degree of approximation to its properties [1, 2]. Tuning of the mathematical model for the ecosystem of the shelf in the northern part of the Caspian Sea was performed with respect to significant components, processes, parameters, and components of the model. The tuning of the model is also determined by the objectives of the forecasting. It is quite difficult to obtain a sufficiently reliable forecast of the sequences of individual anthropogenic impacts on the condition of the ecological system of the Caspian Sea shelf only on the basis of its individual components. It is necessary to consider the ecosystem and its response to the anthropogenic pollution as a whole. As was mentioned above, in this case, hydrooptical characteristics can become good indicators of the condition of the ecological system.

At the first stage of solving the multidisciplinary problem of forecasting the anthropogenic impact effect, we modeled the main aggregated components of the ecological system on the shelf of the northern part of the Caspian Sea. These components included the following: the biomasses of phytoplankton (*X*1), zooplankton(*X*3), macrophyte algae (*X*2), and fish (*X*7); theconcentrations of nutrients: compounds of nitrogen andphosphorus (*X*4,*X*5); and the concentration of particulate and dissolved organic matter (*X*6). The formulationof the modeling problem of the ecological system of the shelf was given in [3,4]. Below, we present the results of the earlier modelling of the intra-annual evolution of the phytoplankton and organic of the northern part of the Caspian Sea (Fig. 1).

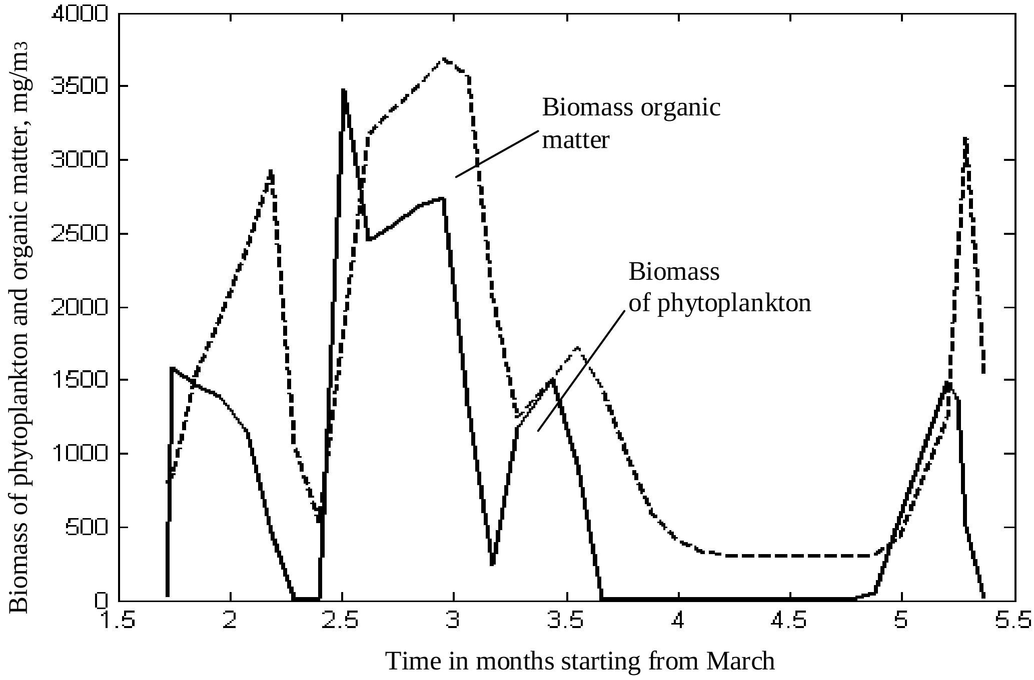

Fig. 1. Model calculation of the annual evolution of the phytoplankton organic matter biomass in the region of the northwestern shelf of the Caspian Sea (box model).

The relation between the distribution of the ecosystem components responsible for the absorption and light scattering processes in the marine environment and the spectral composition of the returning light energy gives us a possibility to estimate the biological condition of the marine environment using the modern methods of remote sensing. Unlike other methods of field observations, remote data give us a concept about continuous and simultaneous variations in the parameters of the ecosystem [1]. The experience of calculating the annual evolution of the optical characteristics performed for the northwestern shelf of the Black Sea [2] was applied to the shelf basin of the northern part of the Caspian Sea [5-7].

According to the known models of sea optics use the following relation for the absorption coefficients:

$$\chi(\lambda) = \chi_{в}(\lambda) + \chi_{п}^{уд}(\lambda)c_{п} + \chi_{ж}^{уд}(\lambda)c_{ж} \tag{1}$$

where $c_п$ and $c_ж$ are the concentrations of phytoplankton pigments (mg/m3) and yellow substance (in dimensionless units); $\chi_в(\lambda)$ is the absorption index of molecules of pure water; and are the specific indices of absorption by the pigments of phytoplankton and yellow substance; and $\chi_{п}^{уд}$ and $\chi_{ж}^{уд}$ is the wavelength of the spectrum. The backscattering coefficient $\beta(\lambda)$ is determined from the:

$$\beta(\lambda) = \frac{\sigma_в(\lambda)}{2} + \frac{\sigma_r^{уд}(\lambda) c_r}{Q+1} \tag{2}$$

where $\sigma_в(\lambda)$ is the scattering coefficient by molecules of pure water; is the specific scattering coefficient by suspended particles; c_r is the total concentration of particulate matter with respect to dry substance (g/m^3); and Q is the asymmetry coefficient of the indicatrix of scattering by particulate matter.

The coefficient of diffuse reflection is calculated from relation:

$$R(\lambda) = \frac{\beta(\lambda)}{3\chi(\lambda)} \tag{3}$$

The following relations were accepted to estimate the values of c_n, $c_{ж}$, and c_r from the concentrations of phytoplankton X_1 and suspended and dissolved organic matter X_6 [1, 2]:

$$c_n = a_{11} a_{21} a_{31} X_1$$

$$c_{ж} = a_{16} a_{26} a_{36} a_{46} в_1 X_6$$

$$c_r = a_{16} b_2 X_6 \cdot 10^{-3} + a_{11} X_1 \cdot 10^{-3} + c_{rr} \tag{4}$$

where a_{1i} is the ratio of dry phytoplankton and detritus biomass to wet biomass; a_{2i} is the share of organic matter in its dry biomass; a_{3i} is the ratio of the light absorbing matter to the amount of organic matter (for phytoplankton i = 1 and for dead organic matter i = 6); a_{46} is the transition coefficient from dimensional (mg/m3) to dimensionless concentration of yellow matter; $b1$ and $b2$ are proportions of the particulate and dissolved parts of dead organic matter; and c_{rr} is the value of c_r at X_1, and X_6 = 0 [2, 4].

The model presented here was applied as a part of the optical model block of the ecological system of the shelf in the northern part of the Caspian Sea. Preliminary results of numerical experiments reflect the spectral dependences of the absorption coefficient, backscattering coefficient, and coefficient of diffuse light reflection for all the seasons of the year and for the period of field and remote measurements (August–September). Figure 2 shows the results of the calculations of the coefficient of diffuse light reflection spectra by months and seasons of the year.

It was found during a comparison of the results of the calculations with the data of the optical observations in July 2003 and August–September 2004 from R/V *Tantal* and the SeaWiFS sea color scanner [5-7] that the agreement between them is not only qualitative but also quantitative to an order of magnitude. This was most clearly manifested for the values of the coefficient of diffuse light reflection (Fig. 2). In a comparison of the radiance coefficient spectra measured by a floating radiometer in different regions of the Caspian Sea, it was found that the measurements in the southern part of the study region (Figs. 2a, 2г) are the closest to the results of the model calculations (Fig. 2 д). Here, the spectra of the radiance coefficient have wide maximums near 510–550 nm and a minimum near 675 nm (corresponding to the “red” maximum of chlorophyll *a* absorption).

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The absolute values of the radiance coefficient are not high, which points to relatively low concentrations of particulate matter. In the model calculations of the values of the phytoplankton biomass and particulate and dissolved organic matter, we also obtained low values for this period of the year (Fig. 1, 2). No sharp decrease in the values of the radiance coefficient was found in the shortwave range of the spectrum, which indicates that the content of colored organic matter (yellow substance) is also low. This agrees well with the results of the calculations [8].

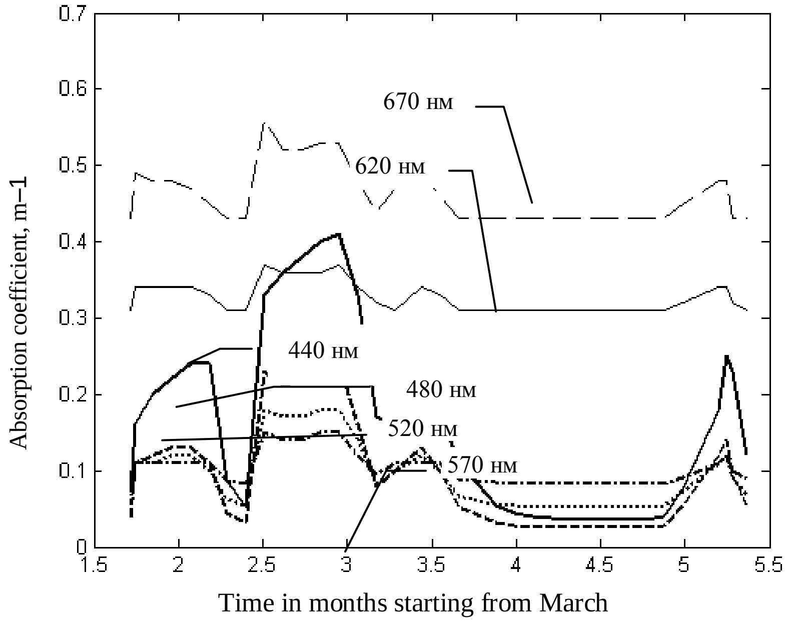

Fig. 2. Model calculation of the annual evolution of the absorption coefficient in the visible spectral range (440-670 nm)

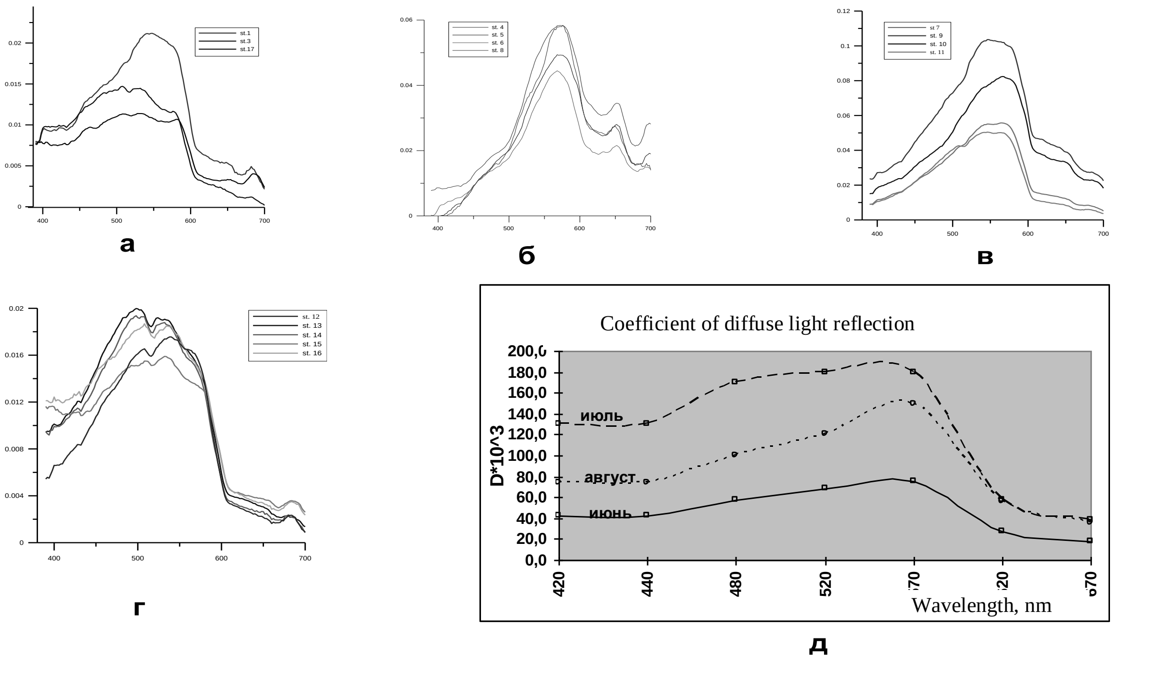

Fig. 3. Comparison of the results of (а-г) the measurements of spectra of the radiance coefficient by a floating spectral radiometer in different regions of the Caspian Sea and (д) the model calculations of the coefficient of diffuse light reflection

A joint application of mathematical modeling and the data of remote and contact methods within a general monitoring system will make it possible not only to carry out high quality calibration of the model but will open possibilities for solving the problems of diagnosis and further justified forecast of the condition of the main components of the ecological system based on the optical characteristics. At the same time, a joint application of different methods of modeling opens the capability to provide risk management [9] and becomes actual in the economical aspect of the problems we solve.

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THE VARIABILITY OF THE CO_2 SYSTEM AND DISSOLVED OXYGEN IN DEEP WATERS OF THE MIDDLE CASPIAN IN THE PERIOD OF THE LATEST 70 YEARS

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Keywords: Carbonate system, oxygen, river discharge

INTRODUCTION

The interannual variability of the hydrological and hydrochemical regimes of the Caspian Sea one can follow from the 30-ties years of the previous century till now days. In this period hydrological and hydrochemical observations were carried out regularity. The level of the Caspian Sea has a direct relation with its salinity and the downsurge level on 1 meter brings to the grooving of salinity of the upper layer approximately on 0.26 psu and vice versa (Bruevich, 1937). Undoubtedly the maintenance of the hydrochemical factors of intermediate and deep waters will change. Bruevich, (1937) noted that every change of the sea level is accompanied with the change of the chemical exchange between the upper and deep waters.

RESULTS

To carry out of the change of the chemical composition was chosen the area in the northern part of the Middle Caspian which is supplied with the archive and modern hydrochemical data (fig.1).

To analyze the long term changeability of the chemical components of waters the data was used the results was got in the expeditions of IO RAS from 1983 to 2008, the archive database "Hydrochemical of the World Ocean", the date of the river run-off given by the chair of the Hydrology of department of Geography of the Moscow State University and others sources. Based on this data the average maintenances were got for the standard depth for the 10-ytars period. To analyze the changes the chemical composition the data for the layer deeper 300 meters was used because this waters less influenced by the seasonal changeability. There were no considerable changes of temperature in column of water in the period from the 30-ties years of the XX century to 2008. The temperature changes range in deep waters (deeper 300 meters) for this period is 1°C (the average temperature on the deep of 300 meters is 5°C). For salinity such comparison is difficult to carry out. Mainly it is connected with the fact that in the 70-ties years of XX century methods of salinity measurements was absolutely changed. That's why it is difficult to interpret the changes of salinity for the period from 60-ties to 80-ties years of the XX century. Hydrochemical parameters in contrast to temperature experienced very strong changes.

Fig. 1. Location of the area which is used for the investigation of the interannual variability of the CO_2-system and dissolved oxigen

In the 30-ties years of XX century the sea level was close to the modern state, the pH data in deep waters was mach lower than in following period of the lower state of sea level. Lower than 300 meters the pH data very quickly went down from 8.0 to 7.8 un. NBS. In the period from 50-ties to 80-ties years of the XX centuries the pH was very high (8.2 – 8.3 un. NBS) practically everywhere. In 2000-ies when the sea level went up and stabilized, the pH distribution again comes nearer the data which was observed in the first half of the XX century.

The similar dynamics was observed and in the distribution dissolved oxygen. According to the archive data of the 30-ties years of the XX centuries to the latest expeditions (from 2004 to 2008), the value of the dissolved oxygen is lover, than in the period of 50–80 years of XX centuries. It must be mentioned that the oxygen concentration in deep waters in 2000-ties years was lover, than was observed in 30-ties years. The maintenance of the dissolved oxygen in near-bottom waters got in latest expeditions is 0,2–0,3 ml/l. In the 30-ties years the average maintenance of dissolved oxygen in near-bottom waters of the Middle Caspian didn't go down lower than 2 ml/l. It can de connected firstly with the improving of the methods of measurement and sampling of the dissolved O_2. Secondly, the data in 30-ties years was got on the primary stage at the loving of the sea level. The third reason is that after regulated Volga's stream in 40 – 50-ties years there was an increase the maintenance of dissolved organic matter in river run-off.

In the period of the lover sea level (50 – 70 ties years) the average maintenance of dissolved oxygen in deep waters went up to 4 – 5 ml/l. It was connected with the decrease of the oxygen demand to oxidation of the organic matter, coming to sea as the result of the lowing of the river discharge and more developed processes of the vertical mixture of the sea waters.

The figure 2 presents the correlation between the maintenance of dissolved oxygen, total dissolved inorganic carbon (C_{tot}) and pH in the layer 300 – 500 meters and the sea level. But for the total alkalinity (Alk) there is no such dependence. The lowest data of Alk were observed in 30-ties years and the highest in the 2000-ties. It was connected with the fact that when the level of the sea went up the wide littoral areas was covered by waters.

That is the creation of tandem reservoir system led to the rapid increasing of the organic substance into the sea. One can suppose that the maintenance of the dissolved organic matter in the Caspian Sea increased in comparison with the 30-ties years to 30 – 40 %. For the latest 10 years in the Caspian Sea the concentration of the dissolved organic matter increased from 2 – 3 to 6 – 9 mg C/l (Sapozhnikov et.al., 2008).

So strong increased of the dissolved organic substance, without any doubt mast reflect on the amount of the Alk. It can be one of the possible reasons of the rapid increasing Alk in 2000-ies years. The changing of the maintenance of the dissolved organic matter from 5 to 10 mgC/l can cause the increasing of the Alk from 0.2 – 0.5 mg-eq/l. If take into consideration Alk-component connected with the organic acids the (Alk – $A_{org.}$) dependence from the sea level becomes the same as for the other analyzed parameters.

The connection of the average data of the maintenance C_{tot}, O_2, pH and Alk in the laer of 300 – 500 meters with the average for decennial annual volume of the Volga river flow similar to the dependence of this data from the sea level. The exception is the data of the 30-ties years (fig.3). Most likely the consequences regulated run-off of the river Volga and the change the composition of the chemical flow storage. Possibly it is the consequence of the difference, used the methods of the hydrochemical analyses.

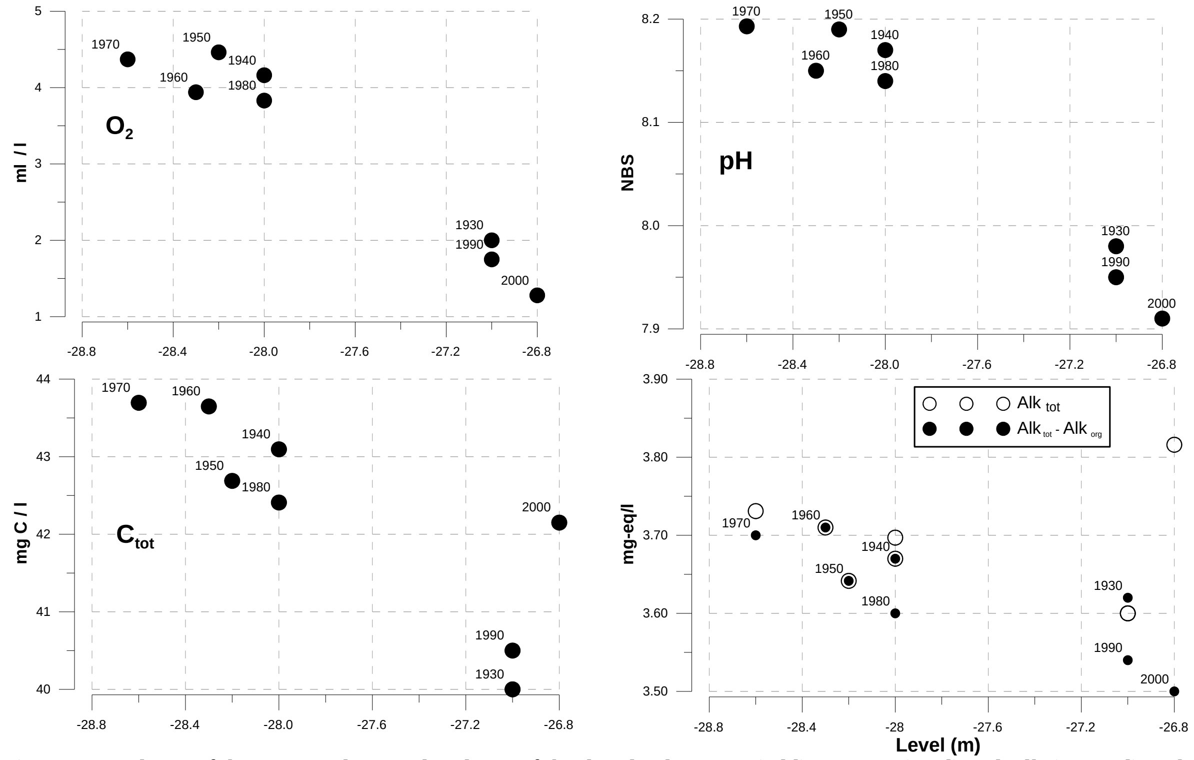

Fig. 2. Dependence of the average decennial volume of the dissolved oxygen (ml/l), pH, C_{tot} (mg/l) and Alk (mg-eq/l) in the 300–500 meters layer from Caspian sea level

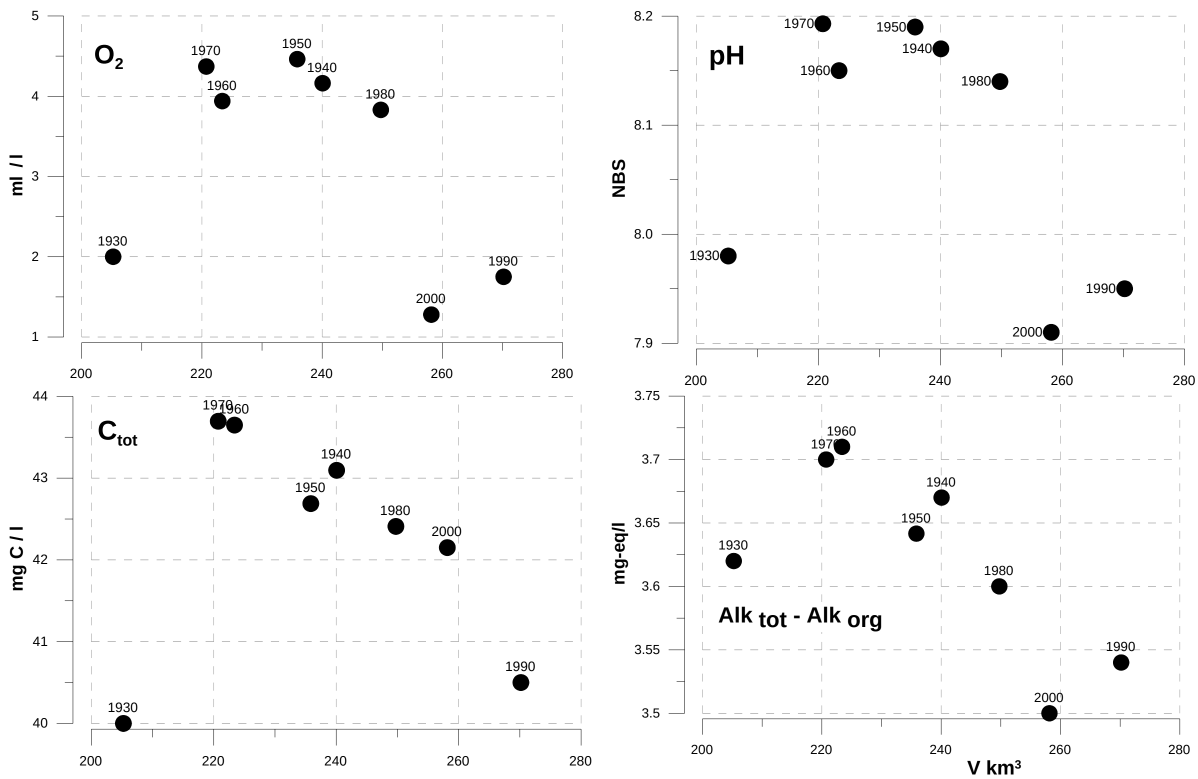

Fig. 3. Dependence of the average average decennial volume of the dissolved oxygen (ml/l), pH, C_{tot} (mg/l) and Alk (mg-eq/l) in the 300-500 meters layer from the Volga's run-off (km^3 in year)

With the sea level changes the character of the vertical distribution of the Alk. In the period of the high standing of the sea level with the depth occurs the lessening of its data. When the level of the sea is low the vertical Alk distribution has a more “normal” view – it increases with the depth. It is connected with the fact that the waters of the upper layer (to 150 – 200 meters) are under the strong influence of the river flow storage. The increasing of the volume of the chemical flow and the weakening of the exchange between upper layer and deep waters leads to the fact that the Alk greatly increases in the upper layer waters.

CONCLUSION

One can single out two main types of the vertical distribution of the dissolved oxygen, pH, Alk and C_{tot}, which are typical for the certain sea level. When the sea is high (the 30-ties years and from 80-ties to nowdays) the maintenance of the dissolved oxygen, pH, Alk and C_{tot} is well lower than in the period of the low standing of the sea level (from 50-ties to 70-ties years XX century).

The character of the carbonate system years change allows to come to the conclution that the main reasons of the changing of the hydrochemical regime, at least, in the Middle Caspian is the change of the volume of the river flow storage and the intense of the vertical water exchange.

One can mention that the maintenance of dissolved inorganic carbon as well as the others hydrochemical components in the Caspian Sea changes from the surface to bottom during all the period of the observations.

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POKMARKS AND MUD VOLCANOS OF CENTRAL CASPIAN

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Keywords: Central Caspian, pockmarks, mud volcanos, Pleistocene, Holocene

It have been believed that in Caspian Sea mud volcanism is occurring in Southern Basin only, while the most intensive gas saturation of bottom sediments is registered in the shallow shelf plains in the north and on Apsheron threshold. Nevertheless, anomalies of fluid nature have been discovered in Central Caspian during recent cruises of R/V Rift (P.P.Shirshov Oceanology Inst., RAS). In south-eastern part of Derbent (Central) depression the seismoacoustic profile (parametric SES-2000standard) shows dome-shaped hill, 5m in height. Underneath the hill wave field has chaotic pattern which is of great contrast with well-stratified sediments nearby (Fig.1). We interpret this dome as underwater mud volcano. Investigation of its morphology and age is not finished yet, although it must be very young due to high sediment rates in this area in late pleistoncene-holocene.

In North Caspian shelf plains gas-saturated sediments occur as horizontal layers and bright spots. Contrary, in Central Caspian depression, areas of sediments with huge gas saturation have shape of narrow vertical zones (from bottom surface to hundreds of meters underneath) with chaotic seismic field (Fig.2). Such difference in shape depends on nature of saturation process. In the north gas has mainly autochthonic nature, it has been extracted while diagenetic transformation of organic material from Volga and Ural rivers.

In Central Caspian depression gas is probably migrating from gas-saturated horizons down below. In this case such marks on the bottom surface are evidences of hydrocarbon fields or/and systems of tectonic failures above such fields. One more difference between Central Casian and areas in North Caspian and Apsheron threshold are pockmarks (Fig.3), which are widespread in Central depression.

Pockmark absence in north plains and Apsheron area is probably connected with too coarse sediments and active hydrodynamic pattern.

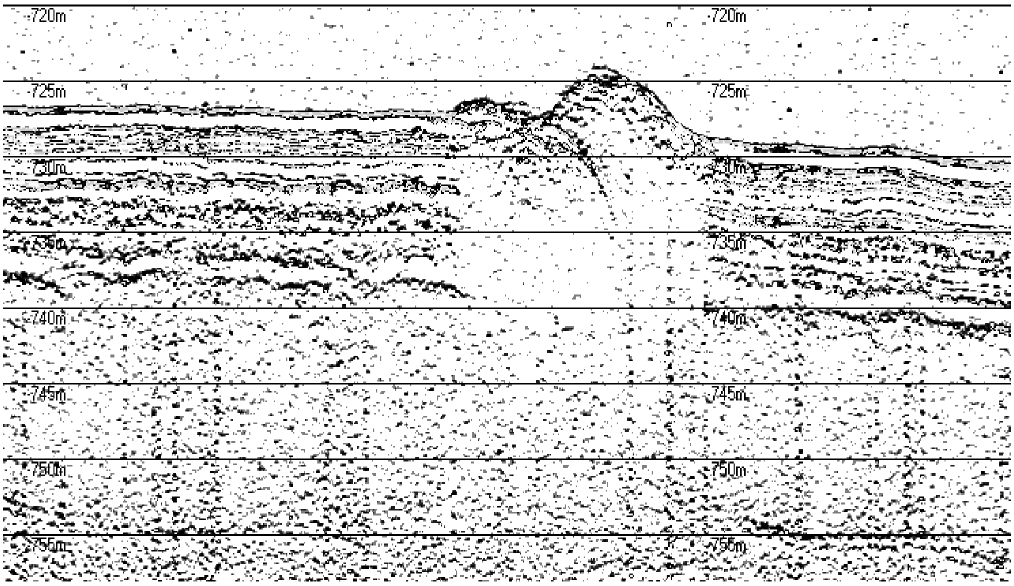

Fig. 1. Seismoacoustic profile across mud volcano in Derbent (Central) depression (SES-2000 standard, 10kHz)

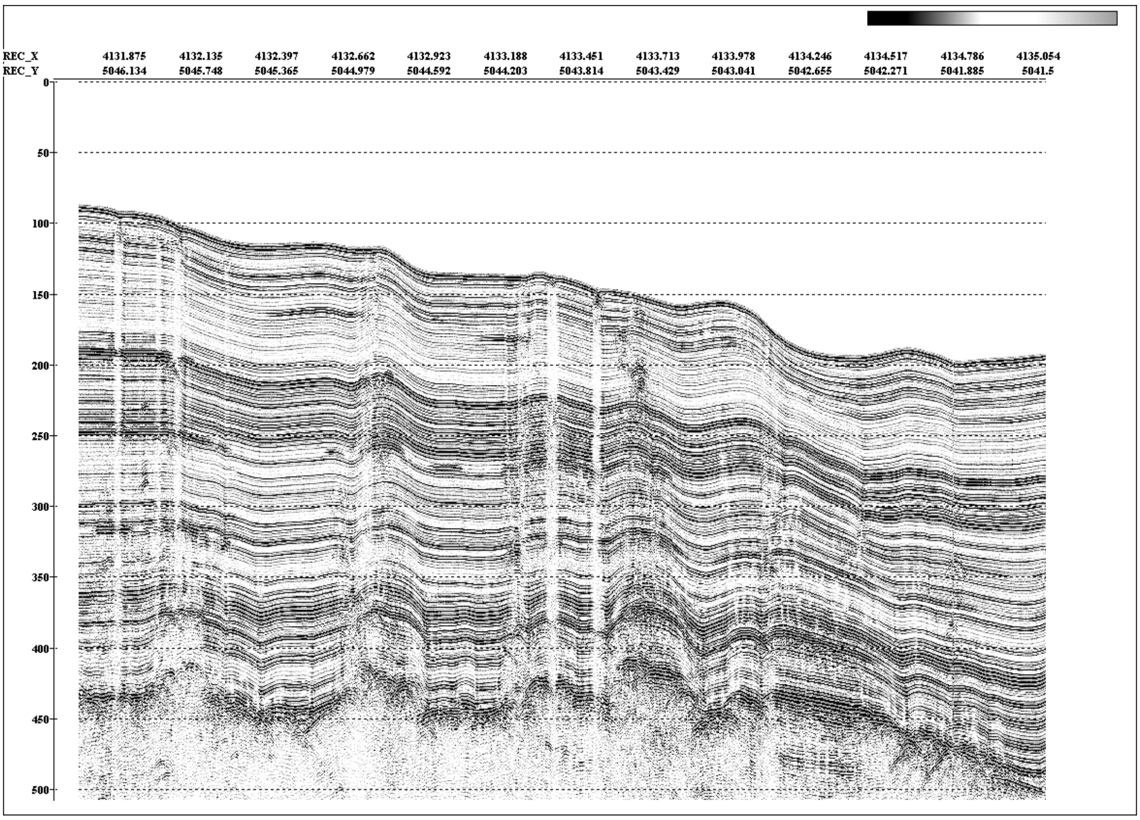

Fig. 2. Channels of vertical gas migration in bottom sediements of Derbent (Central) depression with pockmarks on the bommom surface (Sparker, 200-700Hz)

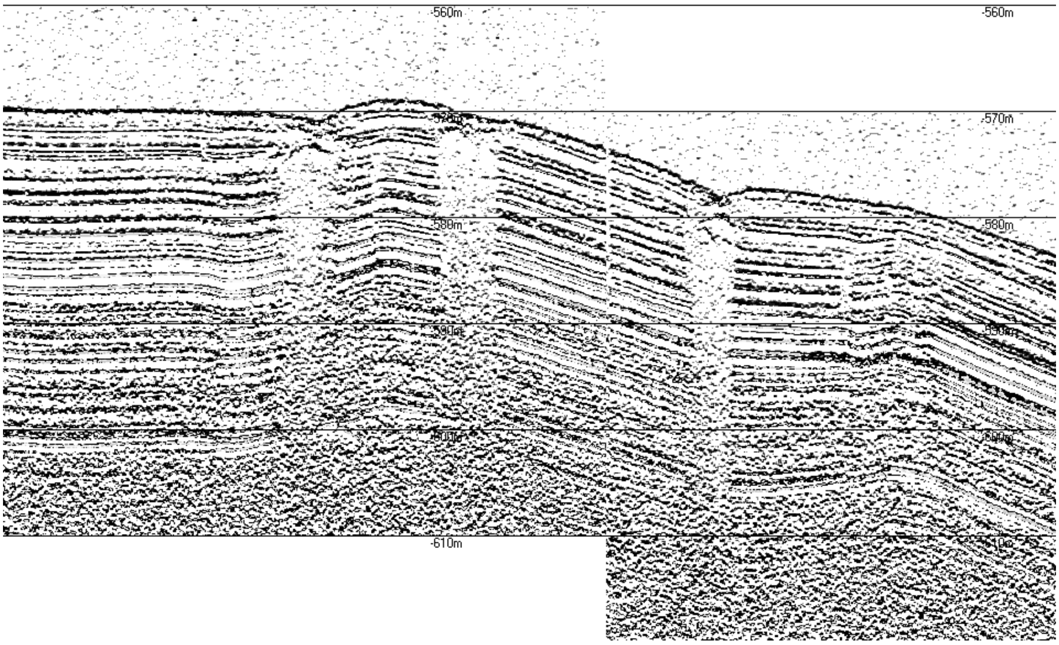

Fig. 3. Pockmarcks in Derbent 9Central) depression of Central Caspian (SES-2000standetd, 10kHz)

THE RELATIONSHIP BETWEEN PHYTOPLANKTON DIVERSITY AND TROPHIC STATUS OF CASPIAN SEA WATERS

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Keywords: Phytoplankton diversity; Trophic status; Caspian Sea; Iran

INTRODUCTION

The Caspian Sea (hereafter referred to as CS) is unique in its size and characteristics. It has a surface area of about 386,400 km2 and water volume of about 78,700 km3.It is the world's largest inland body of water, located in a large continental depression about 27 m below sea level. The Caspian Sea is noted for its production of sturgeon, and its oil and gas resources (Peeters *et al.*, 2000). Development of industrial areas, particularly on the northern coast of the CS has been extensive. Effluent discharges from these industries pollute the ecosystem, causing a shift in water quality level from a natural trophic status to an eutrophic condition. Vollenweider *et al.*, (1992) clearly documented the destructive and harmful effects of eutrophication level on the coastal environment. The situation in the southern Caspian Sea near the Iranian coast is quite different. The input nutrients are very much limited to biotransformation and vertical transport (Leonov & Stygar, 2001). Ecological Aquatic Center of the Caspian Sea (1996) and Caspian Scientific Network (2003) reported that advection transport of rich nutrient water from the north by water current is minimal because water circulation in this area is formed in the deep zone and is not able to affect the inshore zone as in this study.

Many authors have asserted that the introduction of alien species into a marine environment may result in various negative impacts including decline in water quality and fisheries (Vinogradov *et al.*, 1992). Recently, the ctenophore *Mnemiopsis leidyi* has been reported to be present in the Caspian Sea (Shiganova *et* *al.*, 2001). Shiganova *et al.*, (2003) and Kideys & Moghim (2003) and Nasrollahzadeh (2008) suggested that the trophic status of the Caspian Sea has changed since after the introduction of the ctenophore *M. leidyi* in late 1999.

Species diversity, one of the important characteristics of a natural community, has long attracted the interest of many researchers. For aquatic communities, the relation between phytoplankton diversity and trophic status of water has been discussed by several investigators (Ogawa & Ichimura, 1984). Therefore, the purpose of this study is to correlate between trophic status and several indicators of eutrophic condition that have been established such as phytoplankton community and species diversity of the southern Caspian Sea – Iranian coast.

MATERIALS AND METHODS

Study area and sampling

The Hydrology and Hydrobiology study of the CS was carried out in 1996–1997 and 2005. Four cruises were carried out on board the *R/V Gilan* in the representative months of the four seasons. During Phase I (representing before the introduction of an alien species) and during Phase II (representing after the introduction of an alien species), samples were taken in spring, summer, autumn and winter. A Parallel Study (as supplementary data) from 16 smaller scale sampling at shallower sites was also included in the discussion (1994–2005 on 18 transects). The data used in this study were collected from the coastal areas along the southern region of the CS (920 km), by the Ecological Aquatic Center of the Caspian Sea (EACCS) and the Fishery Research Center of the Gilan Province. Stations were identified along 9 and 6 transects during Phase I and Phase II, respectively (Fig. 1).

Along each transect four stations were located at depths of 10, 20, 50 and 100 m. Surface water samples (at 30–50cm depth) were collected with a 2 litter Ruttner sampler. The samples were kept in 1 litter polyethylene bottles and placed on ice. In the laboratory the samples were kept in the dark and frozen (-20 °C) until they were analyzed.

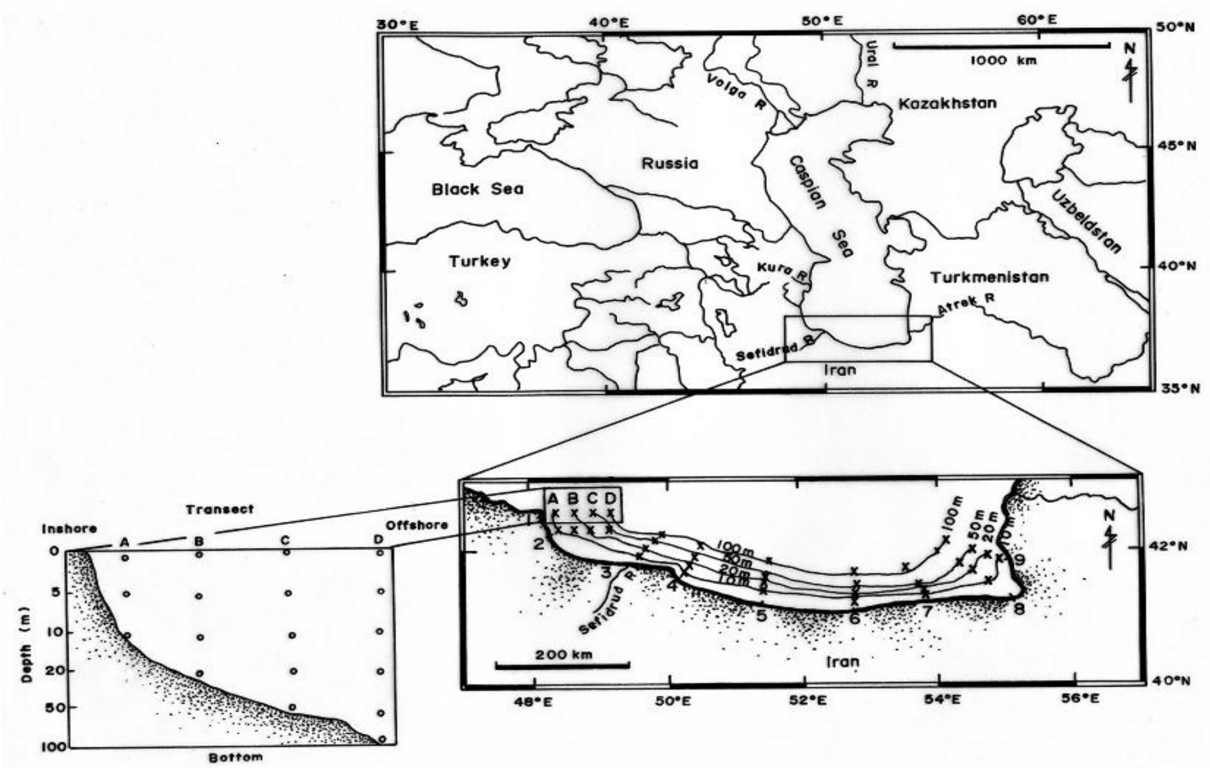


Fig. 1: Map of the southern Caspian Sea showing locations of sampling along 9 (1-9) transects (Labeled ×) and shows different depths of sampling points

Phytoplankton

Phytoplankton samples were collected from surface water (at 30–50cm depth) using a Van Dorn sampler (Vollenweider, 1974). The samples were kept in 0.5 liter bottles and preserved using buffered formaldehyde to yield a final concentration of 2%. The samples were let to settle for at least 10 days following which the water was siphoned off from the top layer to a volume of approximately 250 ml. The samples were then centrifuged at 1000 g for 20 minute and further siphoning off to a volume of 30 ml (Salmanov, 1987). Phytoplankton present in a subsample of 0.1ml was enumerated using a Sedgewick–Rafter cell under a binocular microscope (cover slip 24-24mm and with magnifications of 100, 200 and 400) (Vollenweider, 1974; Newell & Newell, 1977; Sournia, 1978, APHA, 2005). Phytoplankton taxonomic classification was carried out based on Zabelina *et al.*, (1951), Prescott (1962), Proshkina-Lavrenko & Makarova (1968), Tiffany & Britton (1971) and Habit & Pankow (1976). Phytoplankton diversity was calculated by the Shannon–Weaver diversity index (H') function (Sournia, 1978; Washington, 1984). The Caspian Sea TRIX will be identified as TRIXCS which was adopted by Nasrollahzadeh (2008).

RESULTS

TRIXCS value

The mean of TRIXCS varied seasonally in spring: 4.71; summer: 4.11; autumn: 4.20; winter: 3.95 during Phase I. Seasonal variations in the TRIXCS values during Phase I was found to be significant ($p<0.01$), with a minimum and maximum average recorded in winter and spring. During Phase II, the mean of TRIXCS varied seasonally in spring: 5.85; summer: 5.98; autumn: 5.92; winter 5.11. The mean annual TRIXCS value during Phase II (5.80) was higher compared to Phase I (4.48).

On the basis of the TRIX trophic classification scale, 56% of the stations surveyed during Phase I were found to be high quality status (TRIXCS units less than 4.00) (Penna *et al.*, 2004), 39% were good (TRIXCS value between 4 and 5) and 5% were moderate (TRIXCS between 5 and 6). During Phase II the water quality status was found to be excellent for 4% of the stations and good for 17% while 79% of the stations were found to have moderate water quality status.

The mean annual TRIXCS data set showed that during Phase I, 33% of the samples have high water quality status and 67% were good. During Phase II the results indicated that the water quality status was moderate. The long-term study showed that 75% of the stations recorded high and good water quality status before the introduction of the ctenophore, after which the TRIXCS dropped to 17%. Overall, the water quality status in the southern Caspian Sea shifted from oligotrophic to meso-eutrophic after the introduction of the ctenophore and the situation was repeated when the long-term sudy data was examined (Fig. 2).

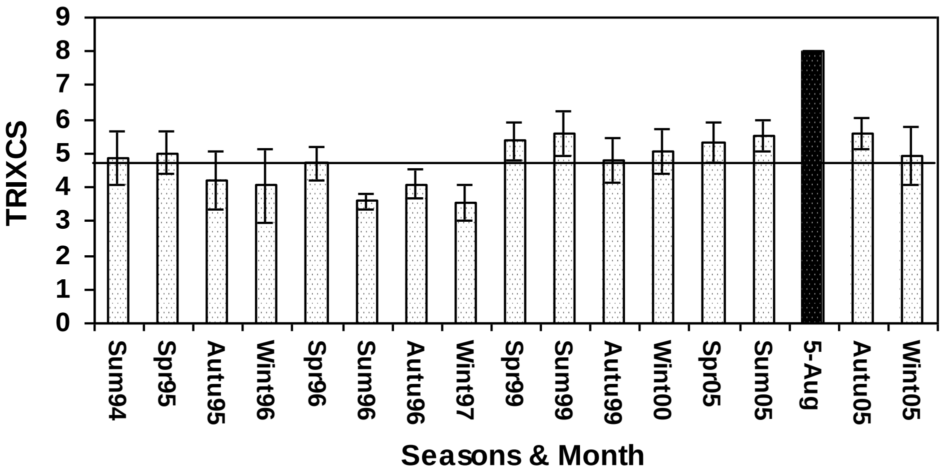


Fig. 2: Long-term (Parallel Study) changes in the trophic index in the southern Caspian Sea- Iranian coast based on TRIXCS values. The data for August 2005 was adopted from Soloviev (2005). Note the high peak of TRIXCS in August 2005 when one species of Cyanophyta bloomed in the area.

Phytoplankton composition, abundance and ecological index

The comparative analysis of the seasonal dynamics for both periods reveals substantial differences in the phytoplankton taxonomic dominance and number of species attained. During Phase II, the number of microalgae species (96 species) was about 32% higher than what was recorded during Phase I (50 species). The average annual abundance was also found to increase from Phase I to Phase II. In terms of number of species and abundance, both sets of data showed that the Bacillariophyta (diatoms) were dominant during all seasons during Phase I and the year from 1994 to 1999 (Ecological Aquatic Center of the Caspian Sea, 1996 and 1998; Laloei *et al.*, 2002). During Phase II, the Bacillariophyta (diatoms) were still the dominant group in terms of number of species, but the Cyanophyta recorded higher abundance (especially during summer and autumn).

During Phase I, the annual Shannon-Weaver diversity index (H´) and Evenness (E) were calculated as 1.25 bits/cell and 0.61 respectively, and 1.89 bits/cell and 0.65 during Phase II. However, the variability of the diversity indices was quite different with values of 1.01–1.41 bits/cell for Phase I and 1.45–2.41 bits/cell for Phase II. During Phase I, the highest Shannon-Weaver index was recorded in autumn (35 species), and the lowest was in winter (29 species).

During Phase II, the highest index was recorded in spring (50 species) while the lowest was in autumn (32 species). On the basis of Parallel Study (1994–2005, N = 870 samples), the Shannon-Weaver index calculated varied from 0.97 to 2.00 bits/cell for 25% to 75% percentile with a median of 1.46 bits/cell (Figure 3). It was also found that before the introduction of the ctenophore the index was always lower than the mean value but always higher afterward. Similarly, the Shannon-Weaver index was found to be lower during Phase I and higher during Phase II.

Correlation between Shannon-Weaver and TRIXCS

The plot of Shannon-Weaver diversity index against TRIXCS during Phase I and Phase II are shown in Figure 4. The correlation coefficients (r) between these two indices were calculated to be 0.23 and 0.43 during Phase I and Phase II, respectively ($p<0.05$). The results indicate that there is no significant correlation between TRIXCS and the Evenness during the two periods ($p>0.05$). However, relatively high correlation between TRIXCS and number of species (species richness) with $r = 0.36$ and $r = 0.49$ during Phase I and Phase II, respectively is observed ($p<0.05$).

DISCUSSION

Several explanations have been proposed to explain the relation between phytoplankton diversity and the trophic status of water. Based on the information theory, Ogawa & Ichimura (1984) proposed that a low diversity phytoplankton community (made up of more than 90% of one species) developed in hyper-or oligotrophic waters, and a phytoplankton community with high diversity occurred in meso-or eutrophic waters. The calculations coincided well with patterns obtained in field surveys. For instance, during 2005 period, one species of Cyanophyta (Nodelaria sp.) bloomed in the south CS which the water contain low Shannon-Weaver index (0.25-0.50 bits/cell) (Fig. 2 in August).

Another explanation in which nutrient ratios variation can cause changes to the phytoplankton community structure (Schollhorn & Graneli, 1996; Hung *et al.*, 2008). Justic *et al.*, (1995) reported that in the Baltic Sea, Kattegate, Dutch Waden Sea, North Sea, and the Black Sea, significant bloom of non-siliceous algae was observed during periods of decline in Si/P ratios. It is assumed that with decreasing Si/N and/or Si/P ratios, more N and P remain available for the growth of non-diatom biomass because silicate sets the limit for diatoms growth (Sommer, 1994).

During the long-term observation for this study, with decreasing of Si/P ratios (From 25 to 11) abundance of the non-siliceous algae (Cyanophyta and Chlorophyta) increased as similarly reported by Sommer (1994) and Justic *et al.,* (1995).

Giovanardi & Vollenweider (2004) defined the TRIX values exceeding 6.00 as typical of high productive coastal waters. Values lower than 4.00 TRIX units reflect scarcely productive coastal waters, while values lower than 3.00 are usually found in the open ocean where the productivity is low. In the case of the southern Caspian Sea during summer 2005, the TRIXCS value exceeding 6.9 (corresponding to high bloom of *M. leidyi*) strongly reveals an external factor influencing the productivity of the area. Kideys & Moghim (2003) reported that changes in phytoplankton species abundance and biomass can be associated with increase in abundance of the ctenophore. In present study, changes in taxonomic composition of phytoplankton coinciding with high TRIXCS values were also observed during Phase II.

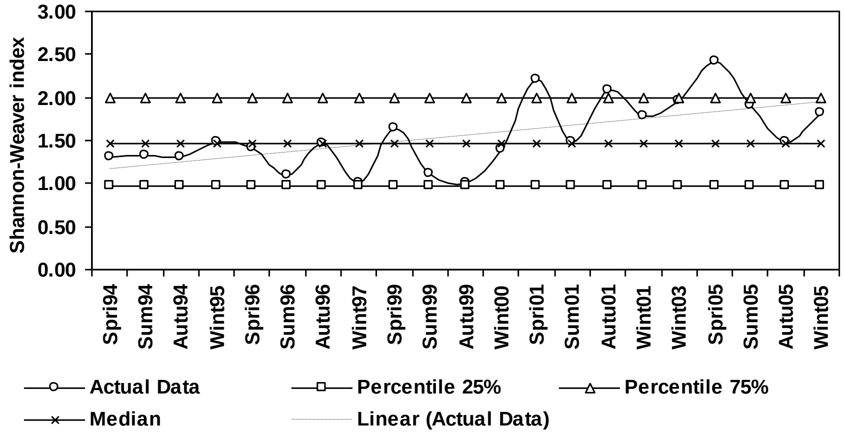
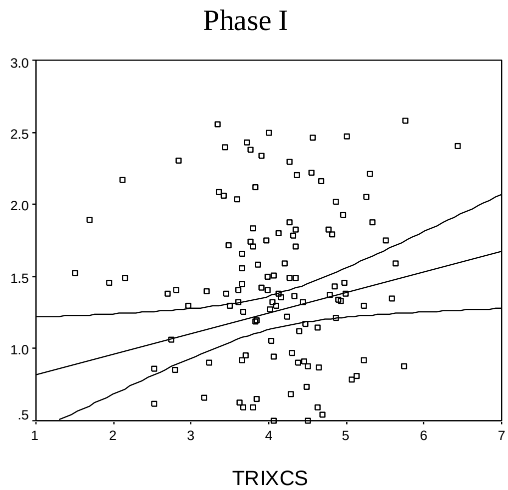


Fig. 3: Parallel Study (1994–2005), the Shannon-Weaver index calculated for 25% to 75% percentile and median in the southern of Caspian Sea – Iranian coast



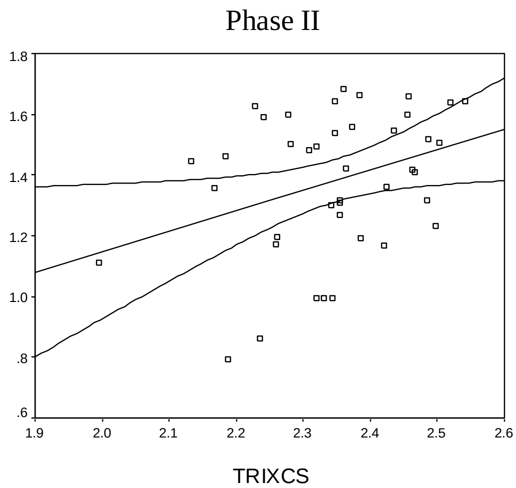


Fig. 4: Plot of Shannon-Weaver index against the corresponding TRIXCS values in the southern Caspian Sea-Iranian coast during Phase I (1997-97) and Phase II (2005). The data from Phase II were transformed by square root but not so for data from Phase I

The higher nutrient concentrations during Phase II could, to a certain extent, explain the blooms and maximum phytoplankton densities attained in comparison to the before introduction of the ctenophore (Phase I). The significant difference in the various parameters between the two periods provide further evidence that the gradient in the level of trophic status is a pertinent factor for the difference in phytoplankton bloom responses. Moncheva *et al.*, (2001) also reported that smaller size phytoplankton are normally dominant in sites with high TRIX. During Phase II, the small species seem to increase in dominance with increasing the TRIXCS values and the proportion of Bacillariophyta in the total community progressively decreased, while the other non-diatom groups increased.

Shiganova *et al.*, (2003) reported that the indices of the phytoplankton species diversity are higher at locations where mass aggregation of ctenophore *M. leidyi* occurs (2.99–3.76), as opposed to stations where the amount of ctenophore *M. leidyi* is small (2.0–2.79). The same trend was observed in present study where we found higher Shannon-Weaver index (1.45–2.41 bits/cell) during after introduction of ctenophore (after the introduction of an alien species) as compared to the before introduction of ctenophore (1.01–1.41 bits/cell).

Phytoplankton diversity is normally low in very oligotrophic waters. It increase as the trophic status moved to a mesotrophic condition, and high values of more than 2.0 bits/cell are obtained in both mesotrophic and slightly eutrophic waters (Ogawa & Ichimura, 1984; Moncheva *et al.*, 2001). In present study, the Shannon-Weaver diversity index and Evenness for the before introduction of ctenophore (good condition) and after introduction of ctenophore (moderate condition) are reasonably consistent with the above suggestion. Low diversity generally corresponds to low species richness or with the bloom of the dominant species. The diversity index reveals minimum values during the bloom periods of the dominant species (Coelho *et al.*, 2007). During autumn of after introduction of ctenophore, an impressive increase in the abundance of *Spirulina laxissma* (Cyanophyta) was mainly responsible for the peak in the phytoplankton abundance, coinciding with the minimum Shannon-Weaver diversity and Evenness indices. The calculated and observed values of diversity coincide fairly well.

A correlation between the TRIX and several indicators of eutrophic condition has been established such as phytoplankton community, evenness and species diversity (Moncheva *et al.*, 2002; Yurga *et al.*, 2005). In present study, the correlation between the TRIXCS and the Shannon-Weaver diversity index and number of species is reasonably consistent with the above suggestion.

ACKNOWLEDGMENTS

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DISTRIBUTION AND COMPOSITION OF ATMOSFERIC AEROSOLS IN THE MARINE BOUNDARY LAYER OF THE CASPIAN SEA

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Keywords: atmospheric aerosols, suspended particulate matter, Caspian Sea

INTRODUCTION

Atmosphere is one of the main agents of transportation of pollutants that can be in a gaseous phase or included to the aerosol composition (Shevchenko, 2003). The Caspian Region has a special importance for development and implementation of marine oil-and-gas projects. And now, we can see a great activity in development of new deposits due to increasing demand to the Caspian oil and the Caspian gas (Geography…, 2006). The researches of the atmosphere conditions above the Caspian Sea including the Russian sector before starting of aggressive mine workings are necessary for determination of the background regime. Knowledge of background environmental conditions allow us to estimate the influence of oil-producing industry. And knowledge of production volumes and therefore of emission volumes gives opportunity to forecast the situation continuation and to estimate the risk level for environment. The annual and seasonal expedition researches are necessary for reliable estimation of the background atmosphere conditions of the Caspian Sea Region. So, we can estimate variability of atmosphere within different time scales (from one day to several years), get main statistic characteristics of different pollutants, determine pollution sources non-connected with marine oil extraction and a degree of their influence on the atmosphere conditions in the research area.

METHODS

Aerosol studies were carried out during expedition aboard RV Rift in the middle of the winter (24th of January to 2nd of February 2005) in the Russian sector of the Caspian Sea. The main aim was to collect of materials for estimation of background atmospheric conditions in relation to heavy metals in aerosols. The following tasks were worked out during expedition:

– Collection of aerosols by nylon meshes (mesh method)

– Collection of aerosols by direct filtration through Petryanov cellulose acetate filters AFA-HA-20 (filtering method).

Mesh method consists in catching of aerosol particles by nylon meshes at the expense of electrostatic charging in incoming air flow. Five nylon meshes with 1m^2 area each with 0.3 mm cells inserted to the special frame were hung out at the bow of a vessel at the 3–8 m above a deck (8–13 m above sea level). The sampling was realized only under headwind with its deviation from a vessel course for excluding of pollution from the vessel.

After sampling the meshes were removed from the frame and washed twice in distilled water. For determination of quantitative distribution and composition of aerosols this water was filtered with an in-line vacuum filtration system through a preweighed 110 mm diameter nuclepore filter with 0.45 μm pores. Filters were dried in drying cabinet with a temperature 50–60°C. In the coastal laboratory filters were reweighed for determination of dry aerosol sample weight. Knowing the air volume passed through meshes we can determine concentration of atmospheric aerosols in the surface layer. Material and elemental composition of meshed aerosols were obtained by colorimetric analysis, instrumental neutron activation analysis (INAA) and atomic absorption spectrometry.

Filtering method consists in direct pumping of studied air through Petryanov cellulose acetate filters AFA-HA-20. This method allows to collect all aerosol particles including soluble matter (marine salt and other). The shortcoming of this method is the small quantity of collected matter that limits analyzing. Determination of microelements (and heavy metals) was carried out by both INAA and atomic absorption spectrometry. Atomic absorption spectrometry used because it is the most accurate and sensible method for determination of some heavy metals. Also it allows determining toxic elements undetermined by INAA.

Terrigenous lithogenic matter was calculated from Al×10 (Kuss and Kremling, 1999).

RESULTS AND DISCUSSION

For detection of aerosol source-regions we used back trajectories of air masses calculated with Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model – a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The intial development was a result of a joint effort between NOAA and Australia's Bureau of Meteorology (Draxler, Rolph, 2003).

We used 5-days trajectories for altitudes 10, 50, and 100 m above sea level (fig. 1). Trajectories were calculated for starting and finishing of each sampling.

So we can see that during our expedition (aerosol collecting) air masses came from sparsely populated steppes and semideserts of Central Asia with undeveloped industry. Thus under these circumstances we have not to expect high level pollution by detrimental gases and heavy metals.

Our data shows that collected aerosols were mainly lithogenic. From Si/Al ratio we can see that the main mineral of Caspian aerosols was quartz. It is prevailed in soils of the Central Asia (Khrustalev, 1978).

At figure 2 we can see concentrations of main heavy metal and dust concentration against Threshold Limit Value (TLV) for atmosphere (Collection …, 1986). It is shown that values of all received elements is much less than TLV. There is only one sample with dust concentration close to TLV. It is associated with strong winds and intensive removal of Aeolian material from steppes and semideserts of Central Asia (Khrustalev, 1978).

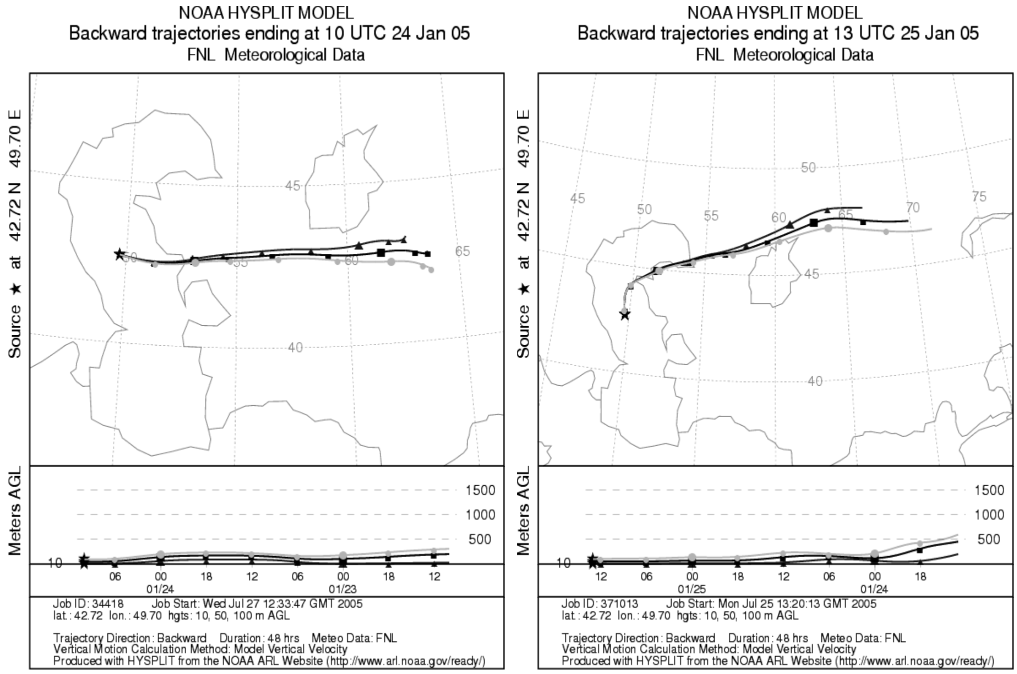

Fig. 1. The most representative back trajectories of air masses calculated using HYSPLIT model (Draxler, Rolph, 2003) for altitudes 10, 50, and 100 m above sea level for starting and finishing of each sampling

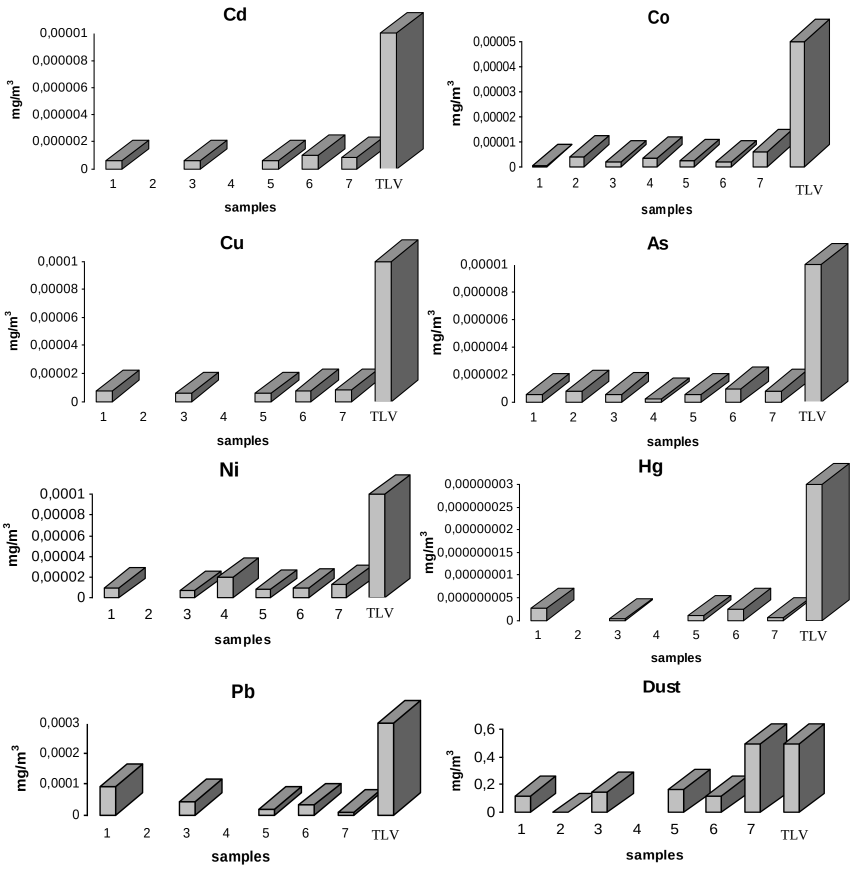

Fig. 2. Heavy metal and dust concentrations in the surface layer of atmosphere of Caspian Region

CONCLUSIONS

Concentrations of detrimental gases and heavy metals in surface layer of atmosphere in the Caspian Region are significantly lower that TLV.

There is no any industrial pollution in researched areas in the time of aerosol input from the North, North-East and East. All observed concentrations are background.

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CASPIAN SEA BOTTOM SCOURING BY HUMMOCKY ICE FLOES

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Keywords: Caspian Sea, ice floe, hummock, stamukhi, ice gouging, geotechnical safety, impact on pipelines

Forms of ice gouging were documented for the first time at 3 to 12 m depth in the North Caspian Sea. Gouges and systems of scouring gouges formed by drifting hummocky bodies frozen in ice floes have been discovered as a result of simultaneous hydrolocation survey and echosounding. The length of the largest and most well-defined gouges exceeds a few kilometers; the width of individual gouges is up to 5 m, and the width of gouge systems is up to 200 m. Apart from linear forms, local pits remaining from stamukhas sitting at the bottom have been discovered.

Work on development of the existing hydrocarbon reserves in the North Caspian Sea has become active in the last 20 years; this work is supported by engineering and construction of stationary platforms, underwater pipelines, and other oil and gas infrastructure. For this reason estimation of the intensity of the ice impact that belongs to the category of hazardous natural processes is the key to geotechnical safety of the oil and gas infrastructure and environmental safety of the water areas.

The Caspian Sea belongs to partially freezing seas. The ice conditions of the Caspian Sea are very complex and variable. Its northern part, which is shallow, freezes every year, in the central portion ice appears along the coast during severe winters only, while in the southern portion there is no ice at all (Bolgov et al. 2007). The ice season in the North Caspian Sea lasts from November through March. Complete freezing and formation of fast ice usually take place north of the line from Chechen' Island to Kulaly Island (Fig. 1). During cold and extremely cold winters, fast ice can settle down to the 20 m isobath.

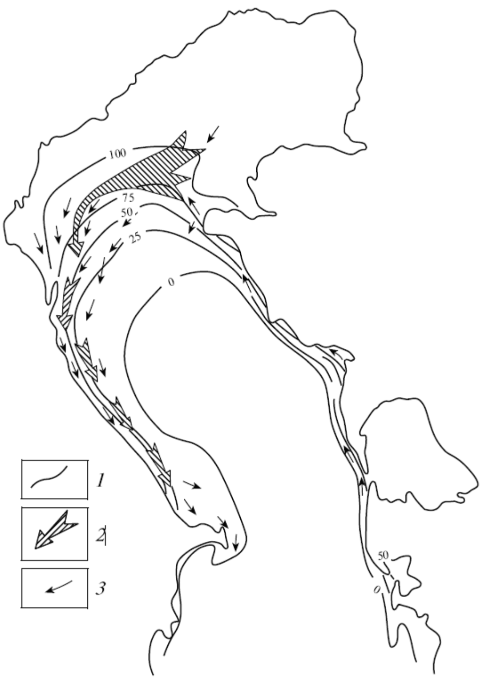

Fig. 1. Probability of ice formation and ice drift (Hydrometeorology… 1992): (1) probability isoline (%); (2) general drift direction; (3) prevailing drift direction

Unlike the seas in the Arctic Region and the Far East, ice formation in the North Caspian Sea at a typical water salinity of 2 to 11‰ takes place at the freezing point of –0.2 to –0.6°C (Zhigarev 2007). The density of the sea ice with no impurities is lower than in the Arctic Region and is ~920 kg/m (Luk'yanova 1965). The ice temperature conditions strongly depend on the ambient air temperature. In typical conditions, the ice temperature is –1 to –2°C with homoeothermic distribution, while during long periods of –20°C frosts, the temperature in the ice layer coming in contact with water can drop down to –4 to –8°C with a significant distribution gradient (Hydrometeorology… 1992).

The maximum thickness of flat ice in the North Caspian Sea even during very severe winters does not exceed 60–70 cm (Bolgov et al. 2007), while the maximum thickness of fast ice is no more than 90–120 cm (Hydrometeorology… 1992). However, a significant proportion of the water surface can be covered by so-called rafted ice (Borodachev et al. 1994). Ice rafting in the Caspian Sea is observed almost every year as a result of ice ride up. Young ice less than 30 cm thick is normally involved in ice rafting. The maximum thickness of rafted ice can be up to 3 m (Bolgov et al. 2007).

The specific features of the ice conditions of the North Caspian Sea are relatively thin and "warm" ice and a short (as compared with the Arctic Region) period of ice formation; these specific features are responsible for the relatively low strength of the flat ice and, therefore, the particularly favorable conditions for ice fracturing and hummocking against the background of strong winds. Wind hummocking is most typical of the North Caspian Sea; currents and fluctuations of the surging level also promote this process. The hummocking processes are heavily influenced by the shallowness, sinuosity of the coastline, and quite complex bottom configuration with a large number of submarine banks and spits.

The maximum number of hummocks per unit area for all types of winter is observed in the zone of contact between fast ice and drifting ice. Since the position of the fast ice edge changes continuously during the cold spell, the zone of active hummocking occupies large areas. A consequence of hummocking is the establishment of hummocked ice ridges perpendicular to the direction of the wind, which causes hummocking at the boundary of steady fast ice and in the zone of unsteady fast ice. The formation of both hummocks and stamukhas (grounded ice hummocks) is typical of active hummocking.

In the North Caspian Sea, autumnal and winter stamukhas are distinguished (Bolgov et al. 2007). Autumnal stamukhas form in November and December from nilas and gray ice having a thickness of 5–15 cm. They are normally small in diameter and have a height of 1–3 m above the surface of flat ice. Such stamukhas form everywhere in the maritime belt down to 2 m depth. Winter stamukhas usually form from gray-white ice and white ice having a thickness of 20–70 cm. They can be up to 100–300 m, occasionally 500 m in diameter and have a height of up to 10–15 m. The maximum recorded height of the sail of a stamukha was 20 m. The maximum depth at which the formation of stamukhas was documented in the Caspian Sea is 12 m.

Analysis of the number of hummocked ice ridges and stamukhas in the North Caspian Sea revealed the following pattern (Fig. 2): the maximum number of hummocks per unit area is observed during years with moderate ice coverage during the cold spell; during severe winters, the majority of the water surface is covered by steady fast ice that prevents active hummocking; during years with mild winters, hummocking is also limited due to the incomplete ice coverage of the water surface and the small thickness of the ice. Level fluctuations of the Caspian Sea, which reached a 3 m amplitude in the 20th century (Klige 1997), in the general case, have a noticeable influence on the configuration of shallow waters (Ignatov and Ogorodov 1998) and a significant impact on the number of hummocks per unit area in the North Caspian Sea (Bolgov et al. 2007).

Apart from stamukhas, so-called ice pileups are also widespread in the North Caspian Sea; these ice pileups bury under themselves a few islands and banks that are above and below the current sea level. The origin of ice pileups is similar to that of stamukhas. In spring, after the water surface becomes free of ice, they can be preserved for quite a long time in the seabed topography.

The first person to pay attention to "activity traces of drift ice" on the surface of the bottom of the North Caspian Sea and publish a pioneering article on this subject was B.I. Koshechkin, an eminent Soviet geographer and geologist, and later also ethnologist and writer (Koshechkin 1958). His conclusions and results were undoubtedly of interest at that time and contributed significantly to the theory of geomorphology and shore dynamics that was actively developing, so they were immediately included in the textbooks (Leont'ev 1961).

During an airborne geological survey over the eastern coast of the Caspian Sea using aerial photography and visual observations, a specific pattern of the surface of the sea bottom was noticed (Koshechkin 1958). This pattern includes light colored intercrossing gouges and scratches situated with no regularity at all at first sight, against the background of the darker surface of the bottom. There are sometimes even a few series of such gouges being strictly parallel to each other and looking like a "comb" in plan view. This pattern is normally observed in shallow areas of the water surface, which are covered with ice in winter. It is most typical and well-defined in the shallow zone of the Mangyshlak gulf down to depths confined to the 3 m isobath.

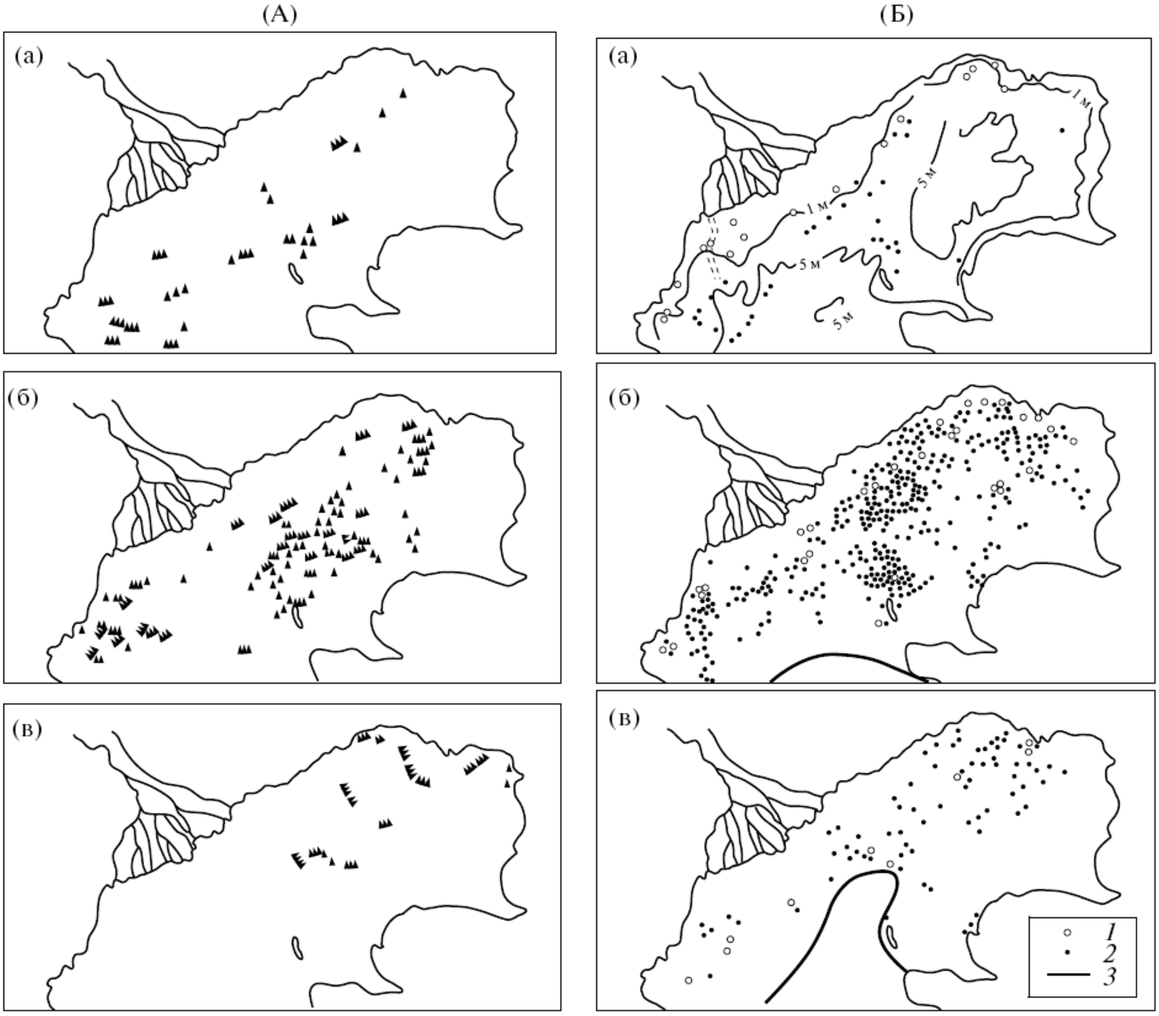

Fig. 2. Position of hummocked ice ridges (A) and stamukhas (B) in the North Caspian Sea during severe (a), moderate (b), and mild (c) winters; 1, 2 are autumnal and winter stamukhas, respectively, and 3 is the maximum position of the ice edge (Valler 1980, Valler and Egorov 1980)

It was assumed (Koshechkin 1958) that the formation of gouges and scratches is associated with wedge work of ice during the period of spring advances of ice. Blocks of ice break away from the edge of the ice field and move in the direction of the prevailing wind currents. With that they strip off the surface layer of silt and algae and form behind themselves "scouring scratches", which can be up to 2–3 km long. As a block of ice melts, its weight and, therefore, its capability to mechanically affect the ground decrease, and finally the block of ice rises to the water surface. This process is reflected in the morphology of the strips. Each gouge has a well-defined beginning – a sharp boundary where the ice floe broke away from the edge of the stationary ice field. The farther the ice floe is from the ice field, the smaller the width of the gouge; it gradually contracts and finally wedges out. Analysis of the distribution of the principal directions of the scratches and a comparison of these directions with the direction of the prevailing winds indicated that the movement of piled-up ice masses complies with the direction of the prevailing winds and currents caused by them.

Later, in the course of an echosounder and diving survey of the Kulaly Bank (near the Filanovskiy and Korchagin deposits), V.V. Andreev et al. (1971) discovered "several series of submarine bars and gouges stretched southeastwards," while they chose not to determine the genesis of these bars and gouges definitively. The relative altitude of the bars was 40–60 cm greater than that of the gouges; the bars were traced to the 15–16 m depth and were most clear at the 11–12 m depth. Now that the concept of bottom scouring and preservation of forms of ice gouging has advanced considerably (Ogorodov 2003), the latter circumstance can be well explained by the fact that at depths of less than 7–8 m forms of ice gouging formed during the previous cold spell were significantly reworked by waves, while at depths of more than 15–16 m such forms cannot form at all in the Caspian Sea, since the keels of drifting hummocky bodies are not large enough to reach such a great depth.

When designing underwater pipelines and telecommunication cables in the Arctic and other freezing seas, one needs reliable estimates of the impact of hummocky ice bodies on the bottom and the depth of penetration of these bodies in the ground. Underestimation of bottom scouring can lead to damage to the engineering structures, while unnecessary deepening of the infrastructure greatly increases the construction cost. All other things being equal, the maximum intensity and depth of bottom scouring are observed in the region of drifting ice gravitating towards the fast ice edge, where hummocking takes place during the entire cold spell and along which edge ice floes drift with frozen-in hummocky bodies, the latter reaching the bottom. Having frozen in drifting ice floes, these hummocky bodies make the deepest and longest scouring gouges (Fig. 3).

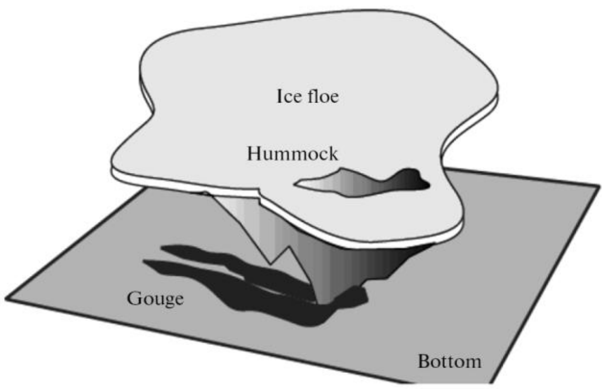

Fig. 3. Bottom scouring by hummock frozen in a drifting ice floe (Marchenko et al. 2007)

Although monitoring of the ice conditions in the Caspian Sea is conducted continuously, there have been almost no special studies aimed at discovery of forms of ice gouging. A number of attempts made to document microforms of ice gouging using seismoa-coustic profilographs, echosounders, and side scan sonars (SSSs) were not successful. The main reason was that the surveys were carried out in summer, i.e., a few months after the time of the formation of scouring gouges; that period also included spring months, which are characterized by both intense undulation and a high content of suspended material in the water of the Volga River. During that period, the majority of the gouges were leveled and silted with bed load material, which is relatively mobile there. However, ice piling on the shores, stamukhas that definitely sit at the bottom, and traces of bottom scouring at small depths (less than 3 m) were documented during direct observation by various subdivisions of the Federal Service for Hydrometeorology and Environmental Monitoring. In virtue of the limited transparency of the seawater in the North Caspian Sea and the almost permanent undulation during the transition season of the year, forms of ice gouging were not documented at great depths.

In March 2008, a hydrolocation survey (SSS) and echosounding were carried out in parallel as part of a joint expedition of the State Oceanographic Institute and Moscow State University along the pipeline route running from the Filanovskiy and Korchagin deposits immediately after the water surface became free of ice.

The results of processing of SSS data and sounding graphs indicated the presence of gouges and systems of scouring gouges (Fig.4) formed by one-keeled and many-keeled drifting hummocky bodies frozen in ice floes; these gouges and systems of scouring gouges were clearly marked in the bottom configuration, including the deep water area (down to 12 m depth).

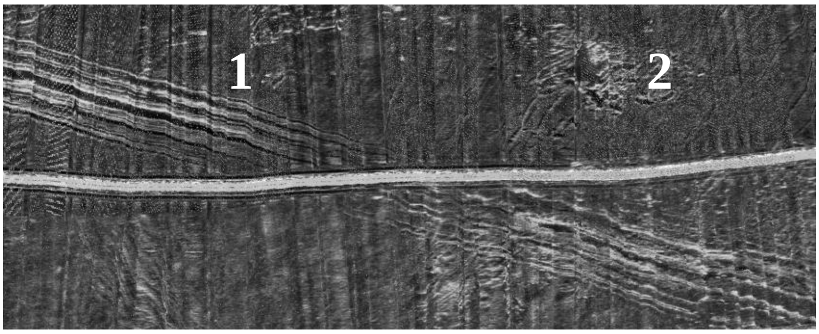

Fig. 4. Fragment of an SSS pattern (0.25 x 0.7 km) with a well-defined system of ice gouges (1) and a local pit with traces of the formation of stamukhas (2); sea depth is ~10 m

A total of 238 gouges and systems were identified on the pipeline route. The length of the largest and most well-defined of the gouges discovered appears to exceed a few kilometers (the majority of the gouges cross the survey area and end outside it); the width of individual gouges is up to 5 m, and the width of systems of gouges is up to 200 m; it was impossible to determine the exact depth of the gouges due to continuous undulation, but, based on the SSS data and sounding graphs, it reaches 1 m. Apart from linear forms, local pits remaining from stamukhas sitting at the bottom were discovered. Thus, forms of ice gouging were documented for the first time at 3 to 12 m depth in the North Caspian Sea.

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WATER BALANCE OF NORTHERN CASPIAN SEA AND THE SEA LEWEL CHANGING

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Keywords: Northern Caspian Sea, Volga River, water balance, sea level, inflow, outflow, accumulation, precipitation, evaporation

INTRODUCTION

The basic receipts component in water balance of Caspian Sea is a drain of the Volga River. The basic expense component is evaporation. Their parity defines seasonal and long-term change of volume and a water level in Caspian Sea. The drain of Volga River makes 80 – 85 % of a total river drain of water and about 65 % of receipts parts of water balance of Caspian Sea (Hydrometeorology and hydrochemistry of the seas. Volume V, release 1, 1992). He plays a dominating role in changes of water balance of Caspian Sea and especially of Northern Caspian Sea (NC). For the present the problem of estimation of inter-annual and intra-annual dynamics of Volga water volumes redistribution in NC and its receipts to Average Caspian Sea taking into account losses on visible evaporation is little developed. Water-balance model of NC is developed for the decision of this problem and with its help the changes of basic components of its water balance are calculated under various typical scenarios (characteristic years). The laws of redistribution in Northern Caspian Sea of water volumes under the influence of a river drain and water losses on evaporation taking into account changes of a hydrological mode of the Volga River, background level of Caspian Sea and meteorological conditions are achieved.

WATER-BALANCE MODEL OF NORTHERN CASPEAN SEA

As northern border of NC the sea edge of Volga delta (SED) serves. The border between NC and Middle Caspian Sea passes on a line connecting island Chechen with cape Tjub-Karagan (fig. 1). Area of NC at a level mark -27 m BS makes 104.6 thousand km^2, at a mark -28 m BS makes 90.1 thousand km^2 and at a mark -29 m BS makes 71.9 thousand km^2 (Bolgov M. V, Krasnozhon G. F, Ljubushin A.A., 2007). The water area of NC is subdivided on two large parts: western (WP) and east (EP). Abroad between them the line from Dzhambajsko-Novinsky islands in the north (to the east of SED) to northern extremity of island Kulaly, on island Kulaly, from its southern extremity to cape Tjub-Karagan is accepted. In the western part of NC the basic volume of a drain of Volga arrives, therefore practically all its water area represents offing off shore of Volga (Polonsky V. F, Mihajlov V. N, Kirjanov S.V., etc., 1998). Off shore width lengthways of SED makes 175 km, and on its southern border makes about 215 km. The Volga offing off shore includes extensive shallow zone (SZ) adjoining to SED. Its area makes nearby 10000 km^2. Its extent from SED to depths on isoplaster -30 m BS makes 35 – 60 km. The part of water area of NC located to the south from this isoplaster, adjoining in the east with east part of NC we will define the term “A deep-water zone of western part NC” (DWZ). Its southern border coincides with southern border NC. This part includes deep zone of Volga offing off shore. Thus, the total area of western part NC develops of area of SZ in the north and area of DWZ in the south. For water-balance calculations area of NC has been divided into three parts allocated with the account morphological and hydro-meteorological features (fig. 1): 1) SZ – its area makes 0.1 from total area of NC, average depth makes in the modern condition 1.5 – 2.0 m; 2) DWZ – its area makes 0.38 from total area of NC, average depth makes 6-8 m; 3) EP – its area makes 0.52 from total area of NC, average depth makes 4 – 5 m.

The water-balance model allows to count components of water balance for separate parts of nc and solves the equation of water balance (1) concerning water-balance outflow from concrete part of nc:

$$W_{OT} = W_{П} + W_{OC} - W_{ИC} - \Delta W \ , \qquad (1)$$

where W_{OT} – volume of outflow of water from corresponding part of nc, $W_{П}$ – volume of inflow of water in corresponding part of nc, W_{OC} – volume of precipitation on a surface of concrete part of nc, $W_{ИC}$ – water losses on evaporation from a surface of concrete part of nc, ΔW – change of water volume in concrete part of nc. All components of water balance are resulted in km^3.

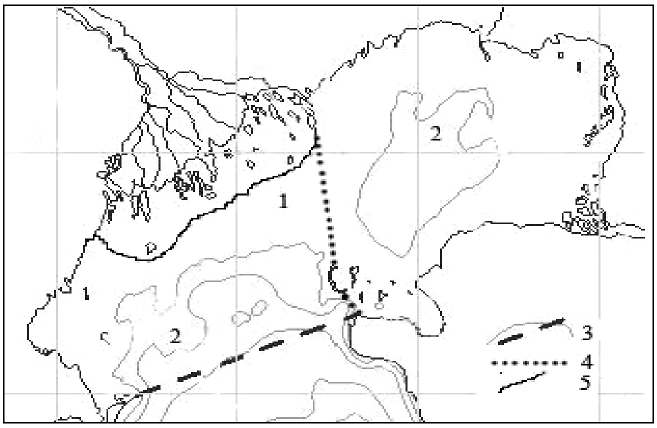

Fig. 1. The scheme of Northern Caspian Sea with the allocated areas of different depth and borders of separate parts: 1 – average depth of 2-4 m, 2 – average depth is more white 6 m, 3 – border of NC, 4 – border of east part NC, 5 – border of shallow zone of Volga offing off shore

Inflow (outflow) of underground waters is not included in the equation (1) because of a weak hydrogeological level of scrutiny of area and the small importance of this size in comparison with other components of water balance of parts of nc. According to supervision the volume of inflow of Volga river water to dwz is set. It is set develops of volume of inflow to top of delta minus volume of total losses of water on visible evaporation (W_{HC}-W_{OC}) in all areas of delta (Polonsky, Ostroumova, 2005). Also the volume of inflow of water of the Ural river to ep is set. The water balance pays off for monthly intervals of time.

The careful analysis of the given of Russian and Kazakh sea hydrological posts has shown that with the greatest reliability the average level of Northern Caspian sea can be calculated as an average arithmetic of indications of posts of an island Tjuleniy, Lagan and Fort Shevchenko. The area of all Northern Caspian sea paid off on dependence of the areas on a sea level, received by R.V. Nikolaeva (Bolgov, Krasnozhon, Ljubushin, 2007), approximated by us as polynom functions.

Change of volume of water in each of parts of NC within a month pays off as a result of multiplication of average monthly value of the area of a corresponding part (taking into account its share from total area of NC) on a difference of background water levels on the end and on the beginning of month. The background water level on the beginning of current month is defined as average of water average levels last and flowing months. The background water level on the end of current month is defined as average of water average levels next and flowing months. Average monthly water levels for an estimation of changes of volumes of water in SZ undertook on post – island Iskusstvenniy, in EP – on post – Fort Shevchenko, in DWZ – on post – island Tjuleniy. For an estimation of component of water balance W_{OC} the monthly layers of precipitation measured at meteorological station – Zelenga are used. For component W_{HC} estimation on monthly values of meteorological elements of station – Zelenga and mophometric characteristics of allocated parts of NC monthly layers of evaporation from a water table (Ostroumova, 2004) pay off.

All calculations are carried out in spreadsheets EXCEL. For alternative calculations of water balance of NC taking into account its division into districts we had been selected 4 years which display a wide spectrum of conditions of formation of water balance of NC (fig. 2). On a phase of the beginning of sharp lifting of Caspian Sea level that is shallow 1977 (volume of an annual drain in Volga delta top make 198 km^3) and 1979 abounding in water (volume of an annual drain of 319 km^3). On a phase of modern high standing of Caspian Sea level that is shallow 2006 (volume of an annual drain of 205 km^3) and 2005 abounding in water (volume of an annual drain of 289 km^3. Layers of evaporation of water from a surface of Northern Caspian Sea for a year in 1977, 1979 and in 2005, 2006 differ slightly and make 870 mm, 886 mm and 878 mm, 893 mm accordingly. In a year monthly layers of evaporation change: from zero to several mm in the winter and to 140-160 mm in the summer. Distinction of volumes of losses of water on evaporation in these couples of years are caused, basically, distinction of the areas of water table of NC and make 65 km^3, 73 km^3, and 92 km^3, 94 km^3 accordingly. Results of calculation of water balance of different parts CK are presented in drawings 3-4.

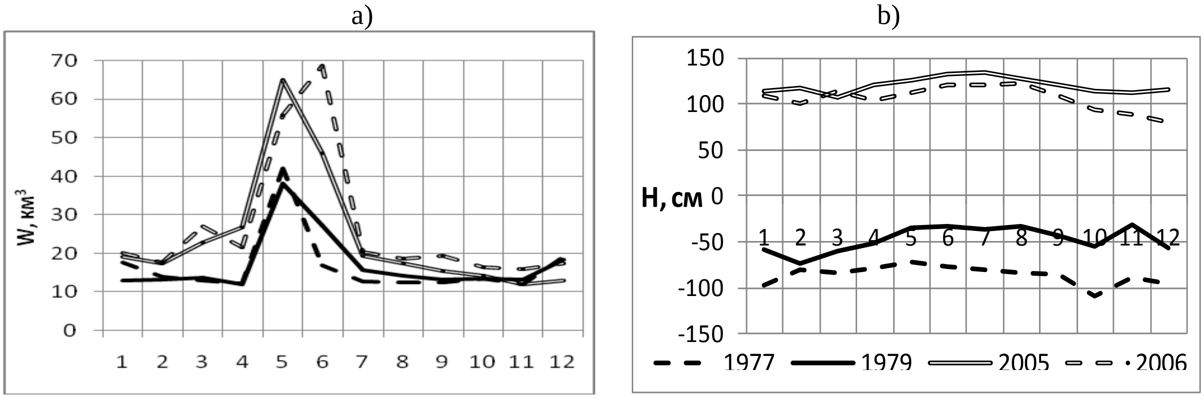

Fig. 2. The basic characteristics of the chosen scenarios for calculation of water balance of Northern Caspian Sea at various marks of a sea level: a) monthly volumes of Volga River drain (W, km^3), b) average levels of Northern Caspian Sea (H, sm over zero of posts -28, m BS)

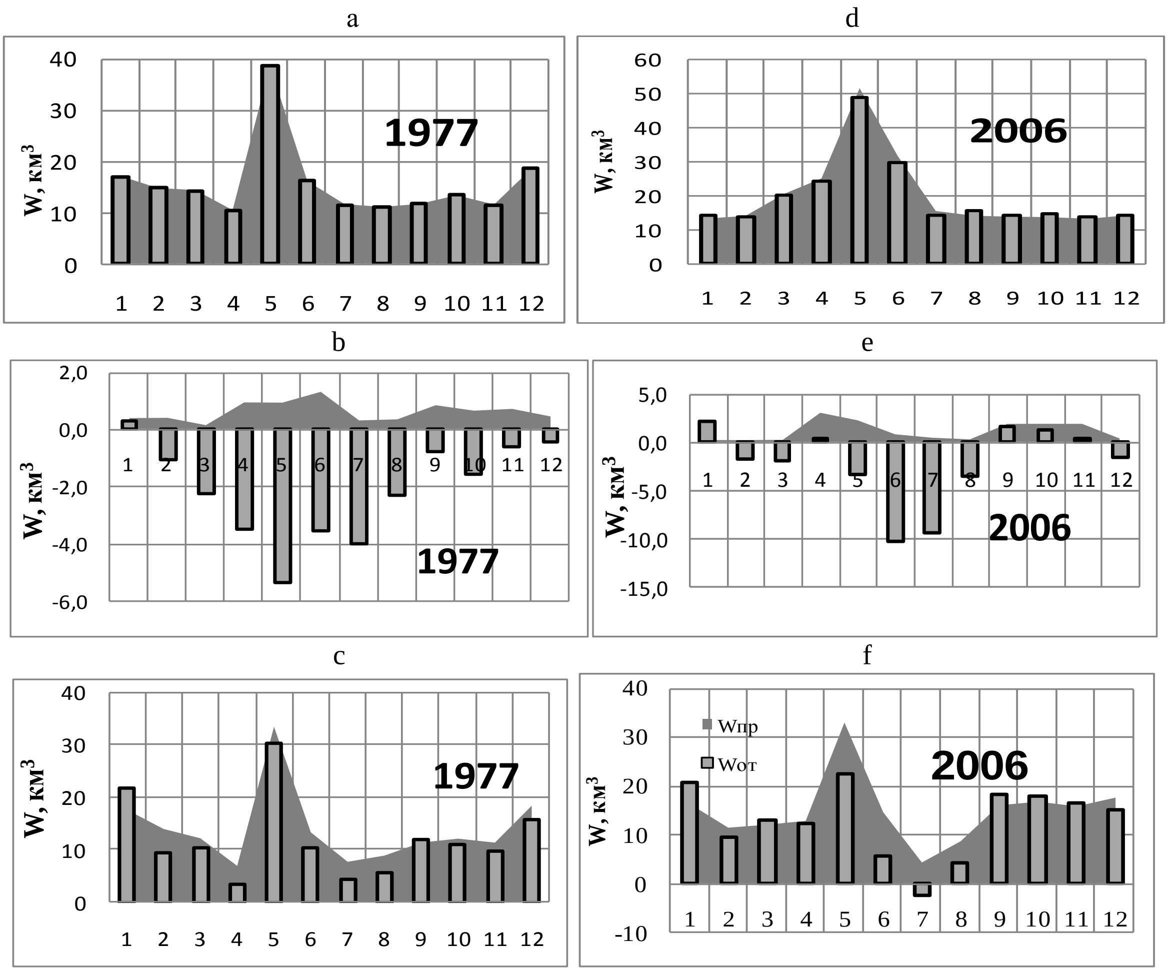

Fig. 3. Change of incoming component ($W_{ПР}= W_{П} + W_{ОС}$) and outflow ($W_{ОТ}$) in various parts of Northern Caspian Sea in shallow 1977 and 2006: a, d – shallow zone; b, e – east part of NC; c, f – deep-water zone of western part of NC

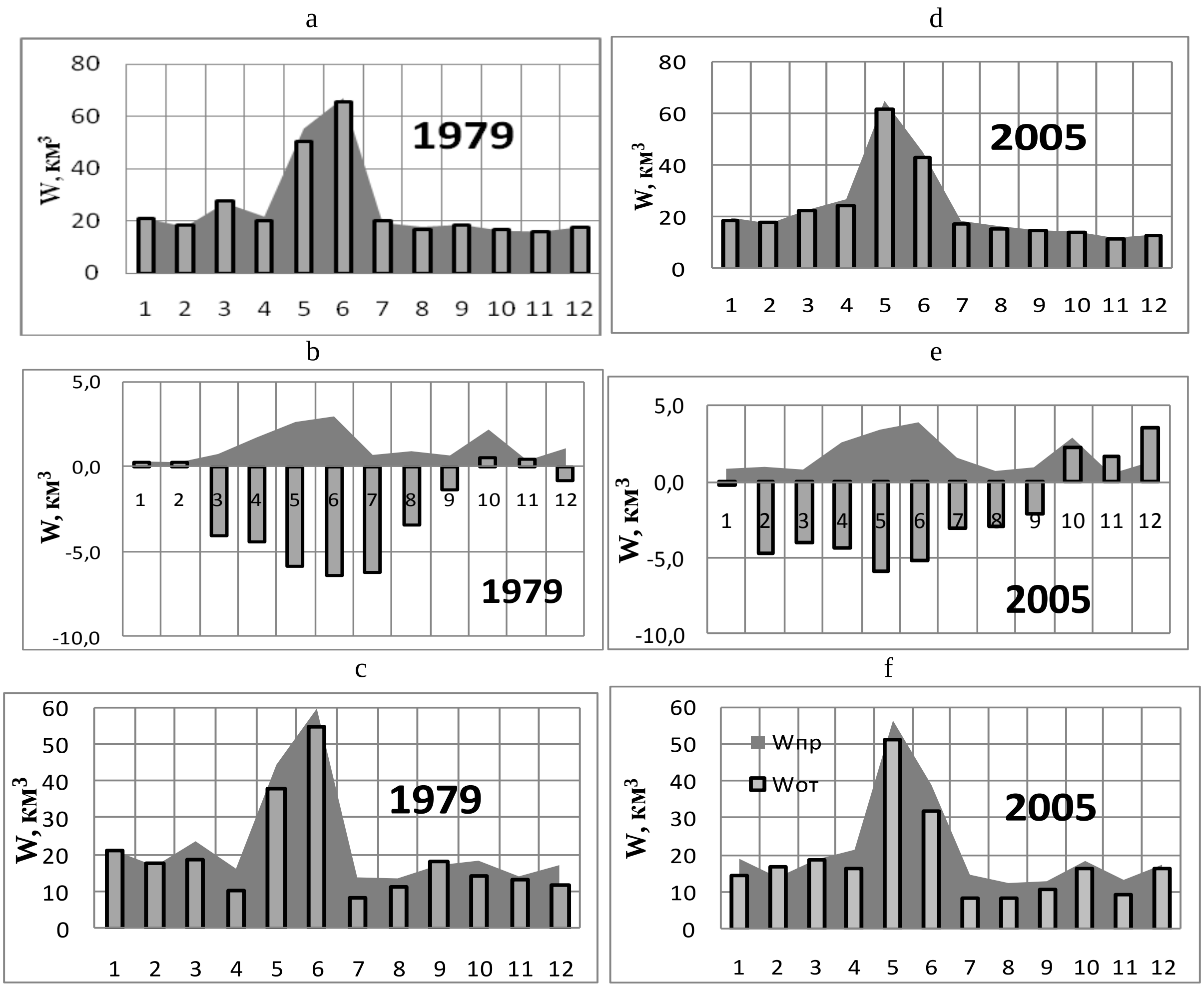

Fig. 4. Change of incoming component ($W_{ПР}= W_{П} + W_{ОС}$) and outflow ($W_{ОТ}$) in various parts of Northern Caspian Sea in abounding in water 1979 and 2005: a, d – shallow zone; b, e – east part of NC; c, f – deep-water zone of western part of NC

CONCLUSION

The general feature for all parts of Northern Caspian Sea in all years is water accumulation in a high water and degrease of water volume after a high water in the raised evaporation. The important feature of water balance of east part of Northern Caspian Sea is what because of deficiency of a drain of the Ural River the water-balance overflow in east part from the western part occurs incoming component an overwhelming part of year. In our scheme of water exchange for a positive direction of outflow of water from east part of Northern Caspian Sea the direction towards the western part of Northern Caspian Sea originally was accepted. Calculation has shown, what in practice this size, as a rule, is negative – water arrives in the opposite direction. In shallow zone of Volga offing off shore transit of the Volga water always dominates – outflow slightly differs from inflow.

In a deep-water zone of western part of Northern Caspian Sea within all year transit of the Volga waters to Average Caspian Sea dominates, and in shallow years in months with the raised evaporation and the lowered drain water outflow can come nearer to zero value. In the conditions of the lowered level of Caspian Sea (about -29, m BS) even in the conditions of shallow 1977 at annual losses of water on evaporation on the Northern Caspian Sea of 66 km^3 there was an equilibrium state concerning long-term changes of level of Caspian Sea. In 1979 abounding in water at annual losses of water on evaporation on the Northern Caspian Sea of 74 km^3 that balance was sharply broke – background level of Caspian Sea has started to raise. Thus water inflow from Northern to Average Caspian Sea has increased with 145 km^3 in 1977 to 238 km^3

in 1979. At modern high standing of Caspian Sea level (about -27, m BS) in an existing range of drain in Volga delta top (261 km^3 a year for 1999–2008) the quasi-equilibrium condition of background level of Caspian Sea remains. Inter annual fluctuations of a sea level within 0.2 m can be caused such distinctions in annual water inflow from Northern to Average Caspian Sea, as 212 km^3 in 2005 (at annual losses of water on evaporation on the Northern Caspian Sea of 94 km^3) and 154 km^3 in 2006 (at annual losses 92 km^3).

ACKNOWLEDGEMENT

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SEA LEVEL RISE AND CHANGES IN THE ECOSYSTEM OF THE MIDDLE AND SOUTHERN CASPIAN SEA IN PAST 30 YEARS

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Keywords: the Caspian Sea, the sea level, ecosystem, reservoirs, dissolved oxygen, hydrogen sulphide, nutrients, organic matter, phytoplankton.

INTRODUCTION

In past 30 years, hydrochemical studies in the Middle and Southern Caspian Sea have shown that this period was marked by significant changes in the Caspian Sea ecosystem connected with a sharp rise of the sea level up to -26.5 m and changes in freshwater and chemical discharge as a result of development of numerous reservoirs in all large rivers of the Caspian Sea watershed. The Caspian Sea ecosystem has not restored to the state of 1933-34 when the sea level was at -26.5 m. Causes of the Caspian Sea ecosystem changes after the beginning of the sea level rise in 1978 are analyzed.

In 1983, when the Caspian Sea level attained -27.8 m (Fig. 1), the Institute of Oceanology (RAS) organized an expedition with participation of the VNIRO experts. In the Middle Caspian Sea basin, the oxygen saturation in deep waters (below 300 m) was still large and ranged from 3.6 – 4.8 ml/L, while in the Southern Caspian Sea basin (horizons below 400 m), the oxygen concentration dropped below 2.5 ml/L. In the Middle Caspian Sea, concentrations of silicates and phosphates attained 128 μM and 1.0 μM, respectively, i.e. they did not significantly differ from the respective values registered in 1971-1976, but were slightly lower than in 1933 (the sea level of -26.5 m), when the silicate and phosphate concentrations were round 140 μM and 1.6 μM, respectively.

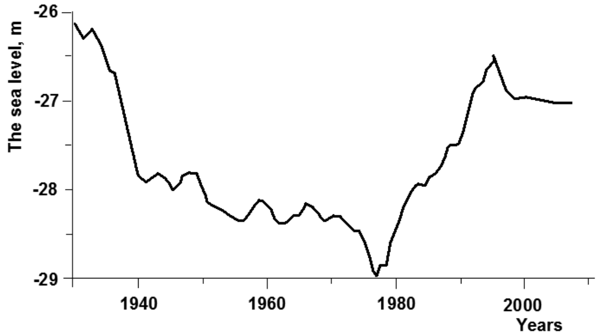

Fig.1 Variations in the Caspian Sea level, 1930-2008

In deep waters of the Southern Caspian Sea, the silicate concentration increased up to 130 µM, this is higher than in 1933 (100 µM), the content of phosphates attained 1.2 µM (compared to 1.02 µM in 1971). Distribution of nitrates returned to the level on 1933 (data cited by Bruevich, 1937), i.e. the nitrate maximum was found in the layer of 200-400 m and attained 12 µM, but, the most interesting fact was that the nitrate concentration decreased down to the bottom very slightly totaling a bit less than 10 µM in the bottom waters, whereas in 1933 such decrease was zero.

After 1995, the Caspian Sea level attained -26.5 m, and then dropped down to -27.1 in 1997, it has not changed till now (Fig. 1). Experts from the VNIRO Laboratory of marine ecology in collaboration with the CaspNIRKh started annual ecosystem surveys of the basin.

Such monitoring was necessitated by the fact that the sea level of -26.5 m coincided with the sea level in 1933–1934, when Bruevich made his classical research (1937), and we got a chance to compare results and see whether the ecosystem reversed to its previous state or not.

The performed hydrochemical, biochemical, and hydrobiological studies showed that the ecosystem had not reversed to its state of 1933–1934 because of several causes. Firstly, during the period since 1933 till 1995–2000, there were built a lot of reservoirs in all large rivers of the Caspian Sea watershed (e.g. 11 reservoirs in the Volga-Kama river system, 3 reservoirs in the Terek River, 2 reservoirs in the Sulak River and the Samur River each, 4 reservoirs in the Kura River, etc. Moreover, if we count dams in the minor affluents, the number of reservoirs in the Volga River system will total 120. Besides, numerous small reservoirs appeared near summer settlements, villages, etc. which dammed streams, built new ponds or gutter trenches in lows, etc.. The number of such reservoirs in the Volga River system attains 700,000. All these ponds and reservoirs produce the same negative effects on the river system: they accumulate particulate matter; silicates precipitate into the bottom deposits of the reservoirs (as silicates are mainly transported in the form of particulate and colloid matter); phytoplankton blooms consume phosphates and nitrates; the downstream discharge contains organic compounds of phosphorus and nitrogen, ammonium, urea, and large stocks of the allochthonous organic matter. All these together with the sea level rise and development of the stable stratification have led to depletion of nutrients from the surface layer and accumulation of silicates and phosphates in deep waters of the Middle and Southern Caspian Sea.

As it was mentioned above, in the 1970s-80s, the content of phosphates and silicates in the deep waters of the Southern Caspian Sea slightly decreased, however, in the 1990s and later it again grew up to the level of the 1930s: phosphates – >1.8 µM and silicates – >110 µM (Fig. 2).

In the 1930s, the nitrate concentrations dropped down to zero in deep waters, revealing processes of the nitrate-reduction and even thiodenitrification, while at present they only fall down to 8 µM. In the 1930s, the maximum nitrate concentrations (11.4 µM) were registered in the layer of 200-400 m, while today the maximum layer is 200-500 m with the value of 15-16.5 µM.

Due to the "biological pump" in the narrow bottom water layer, which is actually depleted of oxygen and even shows trace concentrations of hydrogen sulphide, the silicate concentrations total 217 µM, i.e. twice higher than those registered by Bruevich. This could be a result of winter high waters and blooms of rhyzosolenia. No organisms consume this diatom species in winter, and it sinks to the bottom to decay.

Studies of 1995 showed that in deep waters of the Middle Caspian Sea, hypoxic conditions started to develop and the oxygen content did not exceed 0.4 ml/L.

Our annual surveys in the Middle and Southern Caspian Sea allowed to identify a continuous decrease in concentrations of dissolved oxygen (down to values round 0.2 ml/L) in deep waters of the basins. Here we should note that these values were registered with an oxymeter secured on a Neil Brown sounder, and later, after 1995, with a flow sensor of dissolved oxygen (SBE-43) fixed on an SBE-25 CTD-sounder. Additionaly, we measured absolute values with the Winkler method, which allowed us to calibrate the oxymeter data.

The pattern of the vertical distribution of dissolved oxygen which had developed in deep water basins of the Middle Caspian Sea and Southern Caspian Sea by 2001 showed that in the latter the oxygen values in the bottom waters were round 1.4 ml/L (880 m), while in the former they did not exceed 0.7 ml/L (700 m).

In 2002, concentrations of dissolved oxygen in the Derbent deep remained constant, while in the Southern Caspian Sea basin they decreased by 1 ml/L and only totaled 0.35-0.4 ml/L. Obviously, the winter vertical circulation did not reached the bottom layers of the Southern Caspian Sea.

Thus, the presented pattern shows that the complete depletion of oxygen and appearance of hydrogen sulphide in the Middle and Southern Caspian Sea could be caused by anomalous conditions which occurrence is very rare. This apparently explains low concentrations of hydrogen sulphide in all cases of its detection.

a

b

c

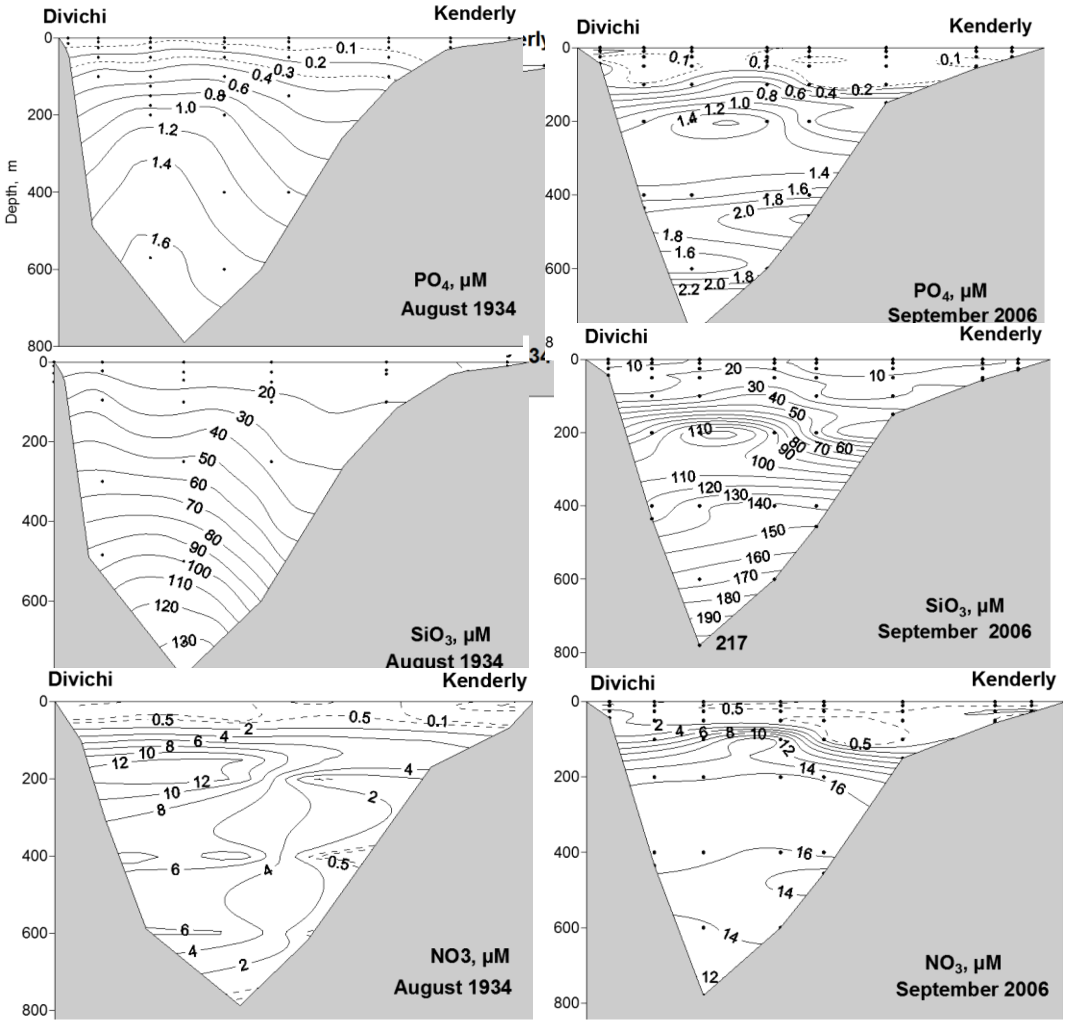

Fig. 2 Distribution of phosphates, μM (a), silicates, μM (b), and nitrates, μM (c) at the Divichi-Kenderly section in the Middle Caspian Sea, August 1934 and September 2006

Presence of hydrogen sulphide in the deep water basin of the Southern Caspian Sea (Kurinsky Kamen'-Ogurchinsky Island section, 2006) (Fig. 3), resulted in an almost complete depletion of nitrates (0.6 μM) from the bottom waters (990 m), though even at the depth of 800 m, the nitrate concentration was rather low (1.6 μM) which reveals impact of the thiodenitrification processes even 200 m above the bottom. Naturally, in the hydrogen sulphide layer of the bottom waters, concentrations of phosphates increased up to 3.0 μM immediately.

For comparison purposes it would be interesting to compare our surveys with similar sections made by Bruevich in 1933-1934 (Fig. 3). The vertical distribution patterns of oxygen and hydrogen sulphide in the Southern Caspian Sea in 2006 and in 1933 are very similar.

The phytocenosis composition has also dramatically changed in the Caspian Sea. Now the abundance of peridinia exceeds that of diatoms four times. The Caspian Sea ecosystem functioning is supported by the detritus 'microbial' loop, i.e. decomposition of the allochthonous organic matter. The spring bloom of diatoms is weak because in winter the surface layer receives small influxes of nutrients and the 'new' primary production is very small. In summer, when concentrations of nitrates, phosphates, and silicates in the euphotic layer are actually zero, all primary production is developed on recycling and, consequently, does not go to higher trophic layers.

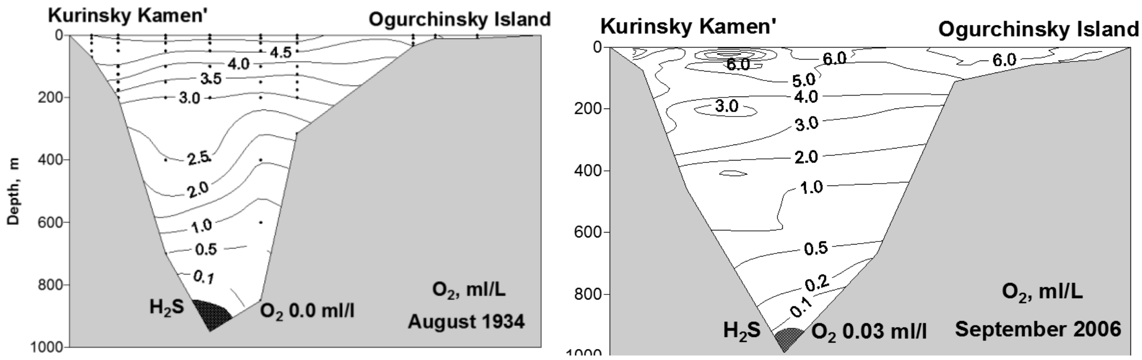

Fig. 3 Distribution of dissolved oxygen (ml/L) in the Caspian Sea, Kurinsky Kamen'- Ogurchinsky Island section, 1934 (Bruevich) and 2006 (VNIRO).

Such pattern of production and decomposition processes explains the poor state of pelagic fish, but suggests improving in the state of benthic fish species (due to increase in the organic matter flux into the bottom sediments), and fish species consuming detritus. However, it is difficult to see any improvements in the state of the benthic fish stocks (e.g. sturgeons) due to horrible poaching, whereas improving in the state of the detritus cunsumers (e.g. mullets) is obvious as fish catches off Kalmykia coasts have grown.

CONCLUSIONS

Long-year observations of the hydrochemical and hydrobiological conditions in the Caspian Sea show that recently (2006-2009) ecosystem of the Middle and Southern Caspian Sea has not reversed to its previous state in 1933-34 when the sea level was similar. At present hypoxia is less vivid, anaerobic conditions and hydrogen sulphide are only identified in a narrow bottom water layer (10-20 m above the bottom). Nitrates do not drop down to zero in the bottom layer and show the maximum values (14-16 μM) in the layer of 200-400 m. In deep waters, concentrations of silicates and phosphates total 178 μM, and 1.8 μM, respectively, and even attain 217 and 3.1 μM, respectively near bottom. In summer, the surface layer reveals actually analytical zero of phosphates, silicates, and nitrates. All primary production is developed on recycling. Spring bloom of alga is weak and the 'new' primary production is very small. The observed large amounts of organic matter (up to 7-8 mgC/L) and considerable flux of OM into bottom sediments improve the feeding stocks of sturgeons and mullets with parallel deterioration in the state of pelagic fish species.

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DECADAL VARIABILITY OF THE CASPIAN SEA THERMOHALINE STRUCTURE IN RESPONSE TO EXTERNAL FORCING: AN ANALYSIS OF IN-SITU DATA

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Keywords: The Caspian Sea, thermohaline structure; decadal variability, external forcing

INTRODUCTION

Investigation of different aspects of inter-annual and decadal variability of the World Ocean waters state is one of the focal point in modern oceanography. Along with global quasi-cycling changes like the El-Nino – Southern Oscillation or the North Atlantic Oscillation (Harrisson et al., 1998, Kaplan et al., 1998), recently several transitional variations in the water state have been revealed in the World Ocean, which were interpreted as so called "regime shifts" – transition processes between relatively stable regimes (Yasunaka, Hanawa, 2005). The most known of such kind of oceanic processes is a blocking of the Atlantic meridional water circulation in the Labrador Sea in the surface (Houghton, Visbeck, 2002) and intermediate (Dobrolyubov et al., 2002) layers under high production of freshened water masses. This process is related to the passive phase of the North Atlantic Oscillation, but has its own development dynamics and is not fully periodical.

The analysis of long-term records of met ocean characteristics in the enclosed seas shows that besides cycle-type inter-annual variations there are transitional changes of the sea waters in the form of trends of different duration. So, in the beginning of 1990s in the Eastern Mediterranean Sea an important change in the deep water formation process occurred which resulted in the appearance of a new region of deep water formation northward of Crete (the Crete Sea) instead of the Adriatic Sea (Klein et al., 1999, 2000; Theocharis et al., 1999). This led to the significant reconstruction of the thermohaline structure and circulation in the deep and intermediate layers at the most part of the Mediterranean Sea (Malanotte-Rizzoli et al., 1999, Wu et al., 2000, Blankart, Pinardi, 2001).

Recently, another important transition process was revealed in the Japan Sea (Gamo et al., 2001, Kim et al., 2001). In mid-1990s in the deep basins of the Japan Sea the physical and chemical evidences of blocking of the deep-water autumn-winter ventilation have been obtained. During ventilation the surface waters reached intermediate layers only (200 – 1500 m), which resulted in the disappearance of well-known intermediate minimum of oxygen. The main reason for this was long-term warming of surface waters in winter. The process was recognized to be similar to the above mentioned blocking in the Labrador Sea.

In the Caspian Sea the river run-off and winter severity index were found to be the key variables determining changes in thermohaline pattern. The most significant shift in its decadal mean values was between 1968 – 1977 and 1978 – 1987 intervals (Tuzhilkin, Kosarev, 2004). For these two decades, respectively, annual volume of the river run-off was 240±13 km^3 and 306±11 km^3, annual index of winter severity was −154±48 °C and −90±16 °C, index of summer longitudinal air transport (calculated as atmospheric pressure difference between western and eastern shores) was 0.01±0.11 GPa and −0.39±0.15 GPa. Thus the 1978 – 1987 decade exhibited considerable increase in river inflows, decrease in winter severity and enhancement of atmospheric forcing of the upwelling along the Caspian eastern shore.

DATA AND METHOD

To analyze decadal variability of the Caspian hydrological regime, the most complete data set of 55,000 shipboard temperature (T) and salinity (S) profile measurements for the 1950 – 2000 period has been used (Tuzhilkin, Kosarev, 2005). In addition, data on atmospheric pressure, winds, air temperature, and river run-off, for the same period at main coastal met ocean stations have been employed. These data were processed and analyzed according to world-wide known methodology (Boyer, Levitus, 1994).

RESULTS

The above described decadal variations of the external factors were also reflected in distribution of the Caspian hydrology parameters (Kosarev et al., 2004).

Mean February temperature of the surface water layer was 0.5 – 2.0 °C higher in the 1978 – 1987 period compared with the previous decade. Along the eastern shore, decrease of water temperature by 0.8 – 1.2 °C was observed in summer, with enhanced upwelling being considered as a main reason. At the same time, within the north-western part of the sea mean temperatures for the later decade were higher (by 1 °C near the Volga delta) as compared with the 1968 – 1977 period. It appeared to be an effect of effective warming of large volume of riverine freshwaters. In 1978 – 1987, both winter and summer values of surface salinity were much lower than those of the previous decade. This decadal difference varied from 0.2 – 0.3 ‰ in the Southern Caspian to 1.0 – 1.5 ‰ in the Northern Caspian.

Vertical thermohaline structure of the Caspian waters underwent pronounced changes too, as clearly demonstrated by quasi-meridional vertical *S* sections (Fig. 1) based on shipboard observations during August-September 1976 and September 1995 (Kosarev, Tuzhilkin, 1995; Data Report IAEA research, 1995; Tuzhilkin, Kosarev, 2004).

The 1976 sections reflect conditions of relatively long period when water loss dominated over water inflow. Among the major consequences of this situation was almost uniform vertical distribution of salinity within the Caspian deepwater basin (see Fig. 1a).

In winter, the absence of sustainable haline stratification in turn stimulated intense convective mixing, especially in the case of the so-called haline inversions when high-salinity surface waters overlaid summer thermocline. Subsequent cooling resulted in rapid destroying of the thermocline and sinking the high-salinity surface waters to deeper layers. In response to this, all the Caspian water column below the thermocline was characterized by uniform distribution of temperature and salinity.

The 1995 sections characterize conditions at the end of nearly 20-year period of the Caspian Sea when the entry of freshwaters dominated over the water loss. It is not surprising that the salinity tended to decrease along the whole water column and became stably vertically stratified (see Fig. 1b).

Profound changes were also recorded in vertical thermal structure of the Caspian waters. Owing to uplift of lower boundary of the seasonal thermocline, its thickness was more than two times less in 1995 than it was in 1976 (Fig. 2).

At the same time, vertical temperature and density gradients of the seasonal thermocline increased by a factor of 2 and 1.5, respectively. The most significant drop of temperatures (more than by 1°C) and salinity (by 0.1–0.6‰) was registered within intermediate layer (50–200 m). Potential density of both intermediate and deep waters markedly dropped by 0.2–0.3 kg m^{-3}. All the described changes in mean values are statistically significant with probability of 90 %.

DISCUSSION AND CONCLUSION

The undertaken research suggests that the Caspian thermohaline structure responds clearly to decadal changes in large-scale external forcing, such as heat and water fluxes through the sea surface and river run-off. Fundamental transformations of the Caspian hydrological parameters inevitably reflect on functioning of marine ecosystems.

The analysis of decadal alterations in Caspian's hydrology and interrelations within the system of external thermo- and hydrodynamic factors and thermohaline structure enabled to recognize two main states of this system.

During the first one reduced river run-off coupled with relatively high winter severity results in strengthened ventilation. This has an effect of water salinity increase and vertical salinity distribution homogenizing. In parallel with vertical expanding of seasonal thermocline, its temperature gradient becomes lower, whereas deep waters become colder. The other state corresponds to the opposite combination of the external factors (i.e., increased river run-off and milder winters) and is attended with stable vertical salinity stratification which impedes vertical diffusion exchanges of heat and salt and distorts regular ventilation of near-bottom layers. The lower boundary of the actively ventilated zone is located at 200 – 300 m level. In winter, intermediate layers are intensively fed by colder surface waters. Coupled with a decrease of vertical turbulent diffusion, it results in a drop of water temperatures within the lower part of the thermocline. The thermocline itself becomes thinner, while its gradients become higher.

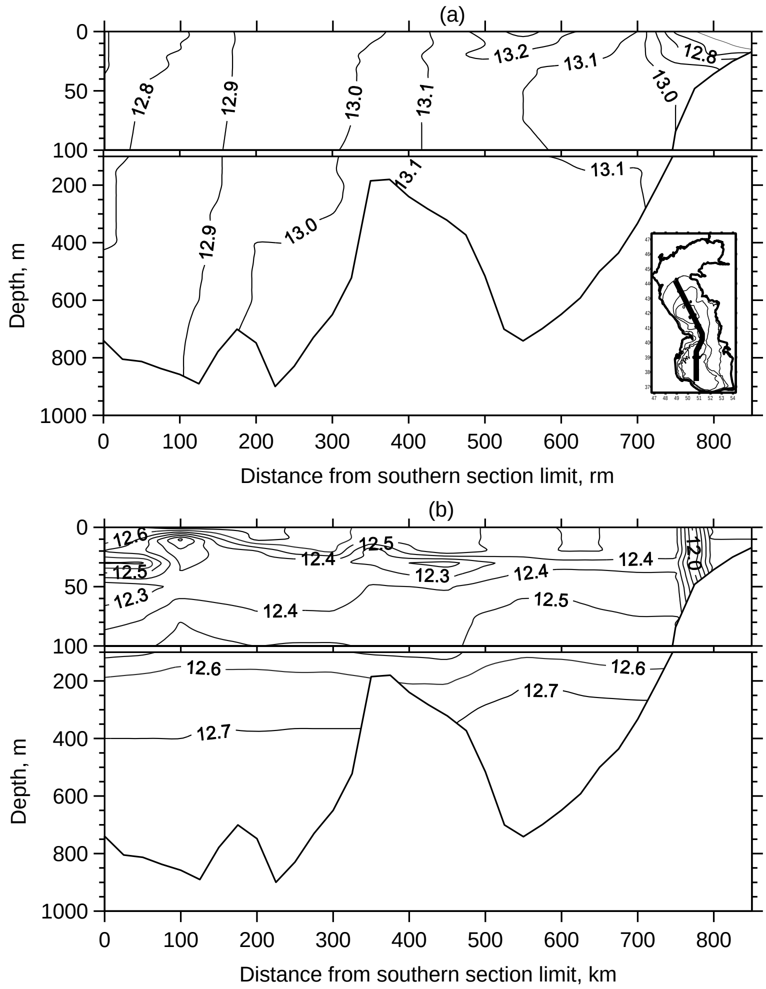

Fig. 1 Quasi-meridional vertical sections of the water salinity (‰) in the Caspian Sea in (a) August-September 1976 and (b) September 1995. See inset in Figure 1a for the location of the section

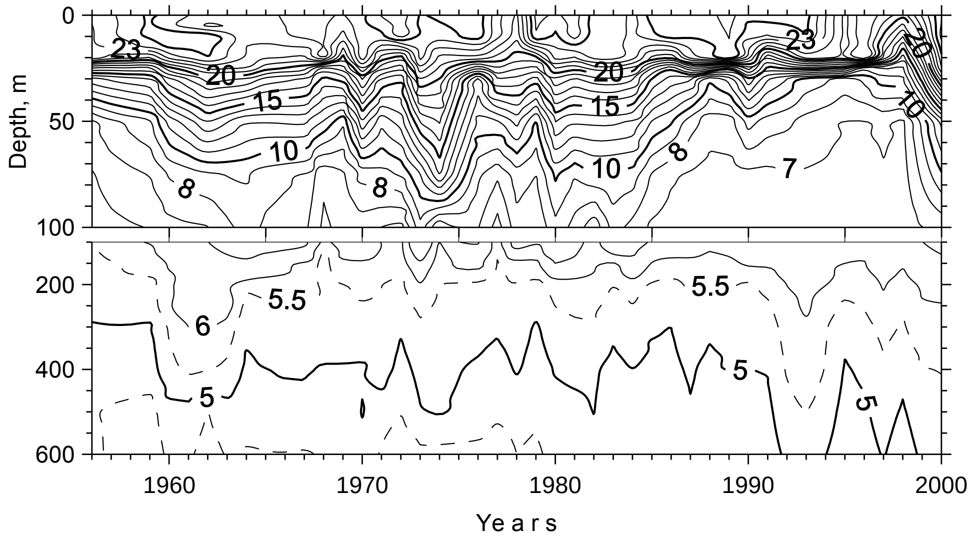

Fig. 2 Long-term variability of water temperature (°C) vertical structure in August according to the ship observations in the deep-water area of the Middle Caspian basin

The two states lasted different periods of the Caspian history. While the first state was observed during 10 years from late 1960s to late 1970s, the followed second state persisted through 1995 (i.e., during 17 years). The duration of these states is likely to be controlled by macro-circulation processes (such as North-Atlantic Oscillation) within the World ocean –Global atmosphere system (Rodionov, 1994; Nesterov, 2001). The latter of two states appears to be less favorable for the Caspian ecosystem, because the increase of vertical water density stratification is normally accompanied by a drop of dissolved oxygen concentrations in deep waters along with weakening of turbulence-induced supply of the surface euphotic layer with nutrients (Tuzhilkin et al., 2005). The processes such as diminishing of autumn-winter ventilation, decrease in thickness of the upper quasi-uniform layer and sharpening of summer thermocline contribute to concentration of pollutants in surface waters. This poses a serious hazard to the sensitive Caspian biota. Analysis of rapid and dramatic changes in the Caspian hydrological regime highlights the need for complex environmental monitoring and adequate environmental protection system.

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SESSION V.

THE CASPIAN REGION: ENVIRONMENTAL PROBLEMS AND MANAGEMENT

ENVIRONMENTAL PROTECTION AND MANAGEMENT WITHIN THE CASPIAN SEA OIL AND GAS FIELDS

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Keywords: oil and gas fields, industrial accidents, present-day geodynamics, environmental disaster

Oil and gas fields are discovered in all parts of the Caspian Sea. Northern Caspian offshore plays were first discovered in 2000-2005 and their oil and gas production is only beginning. However, multiple onshore fields are in production for several decades in Kalmyk and Kazakh sector.

The negative impact of oil and gas production on the environment is exacerbated by natural exogenous and tectonic processes, sometimes rapidly developing within the Caspian Sea. The main processes capable of leading to accidents in oil and gas facilities, are abnormal changes in sea level, wind-surges, drift and hummock of ice, and of course, the modern tectonic movements of the crust. It is known, that the Caspian region, including the territory of Caspian Sea, is characterized by high activity of modern tectonic movements. In Southern and Middle Caspian Sea areas the highest activity is localized in the western part (Azerbaijan and Dagestan sectors), within the Northern Caspian Sea – in the eastern part (Kazakh sector).

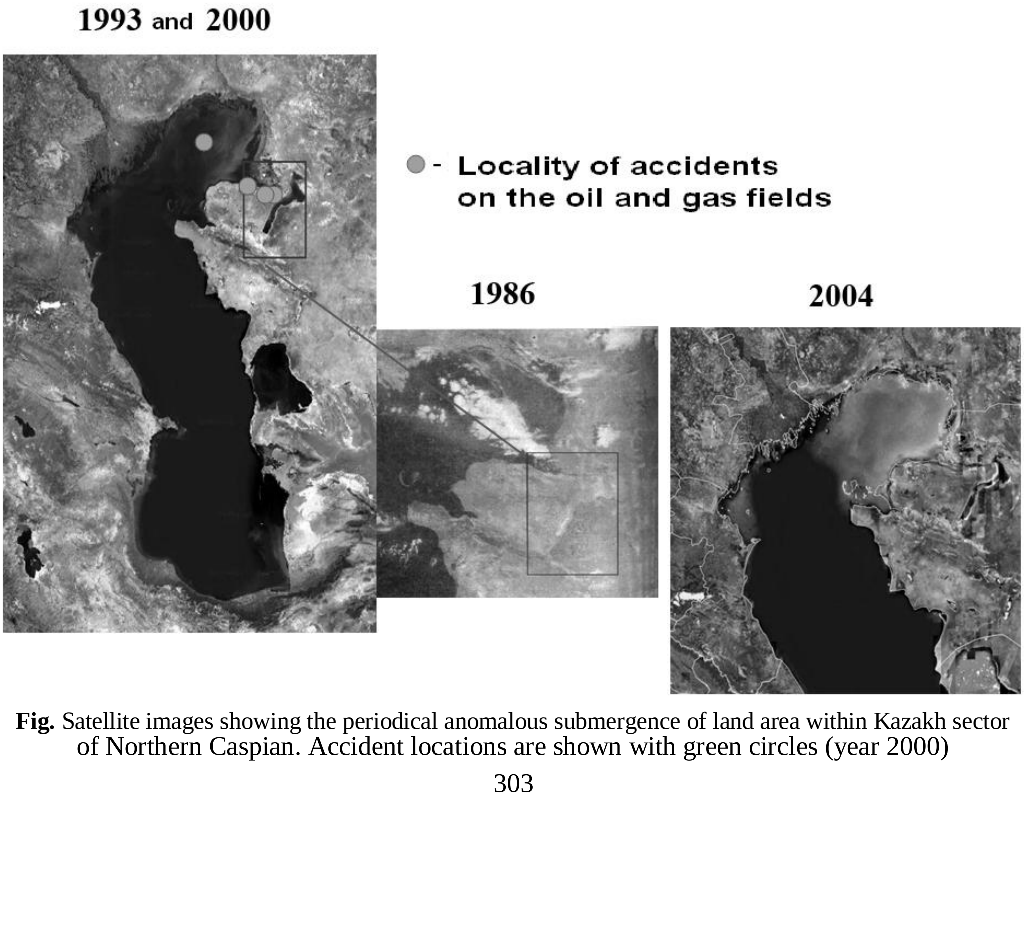

Fig. Satellite images showing the periodical anomalous submergence of land area within Kazakh sector of Northern Caspian. Accident locations are shown with green circles (year 2000)

All major accidents, that occurred in the Caspian oil and gas industry and had serious environmental consequences, have always had a connection with the development of anomalous modern geodynamic processes in terms of time and location. Over the past 10 years, such event has happened in March-April 2000. Major breakdown of the entire Caspian ecosystem started in the north-eastern part of the sea. Two explosions occurred almost simultaneously: at the "Sunkar" well on marine Kashagan filed and at well 37-Tengiz (Tengiz field). The explosions were followed with major fires.

At the same time Caspian waters flooded a huge area in Buzachi Peninsula, where several producing fields are located (Kalamkas, Karazhanbas etc.). This flooding was so fast, that workers did not manage to stop the producing wells. Hundreds of thousands of tons of oil were flowing into the Caspian Sea for a few days. It should be noted that the flooding was local. Immediate ecological disaster was intensified by particularly environmentally-harmful fluid composition. It contained sour oil and large amounts of hydrogen sulfide. As a result over 50,000 seals died – 1/5 of the entire Caspian seal population. Mass mortality of fish and birds was inevitable.

Similar environmental catastrophes had happened several times before, in the areas of producing fields in the Southern Caspian.

The periodicity of accidents at oil and gas facilities can be observed, while their location stays the same. For example, the explosion at the well 37-Tengiz has also happened in 1986. Back then the fire could not be extinguished for more than a year. The flooding of northern part of Buzachi Peninsula has cyclic character too and is not connected with the general rise in sea level. It is associated with activisation of fault system, which periodically leads to rapid surface subsidence, hence flooding the area with Caspian waters. The following Figure shows satellite images taken in different years, which show a periodic (every 5-6 years) inundation of narrow (5-8 km) and linearly extended (up to 70-100 km) area, where producing fields are located.

In order to improve industrial and environmental safety in the oil and gas industry it is absolutely necessary to implement mandatory forecasts for the development of natural and anthropogenic tectonic processes. The geodynamic monitoring must be organized to avoid emergency situations and preserve the ecosystem of the Caspian Sea. Such works were carried out for offshore fields located within the Russian sector of the North Caspian, utilizing the latest scientific and practical achievements in this field.

The problem of reducing the environmental and economic risks is highly actual today for all countries located in the Caspian Sea region. The recently developed study of spatiotemporal laws of both natural and anthropogenic present-day geo-deformational processes is the key to ensure environmental safety within oil and gas industry. Such study allows companies to understand how these processes can influence the technical condition of industry's objects and structures.

The environmental protection of the Caspian Sea during the growth of its oil and gas exploration should be the subject of international scientific and practical cooperation among various interested institutions.

ACTIVATION OF ANTHROPOGENIC PROCESSES AT THE CASPIAN OIL REGION

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Keywords: anthropogenic factor, anthropogenic processes, deflation, salinization, road erosion, gullying, flooding, technogenesis, activation of processes, saline soil, sors, stratal water

INTRODUCTION

Three groups of processes are widely developed in natural habitant are available to change the environment in general and the relief in particular. Natural process develops independently of human activity. Anthropogenic processes which are appeared exclusively as a result of human activity, are not peculiar to any ground, but artificially created. The anthropogenic processes are those, which were significantly weak before the human activity or led to a significant modification of certain natural processes: deflation, salinity, road erosion, gully formation, flooding. Both process groups are particularly various on the areas of intensive development of natural resources, for example at the West Kazakhstan oil and gas regions.

The West Kazakhstan region is entirely located on the desert and semi-desert zones, where is a very delicate balance between climate change and natural geomorphological processes. Therefore, almost any kind of technological impacts leads to a serious transformation of exogenous relief. The most common form for such intervention is the construction and maintenance of roads, pipeline laying.

MAIN CONTENT

The most common process in this area is the eolian process. It is strongly activates as a result of terrain disturbance in the area of oil and gas production. A striking example is the area around the Komsomolsk and Kosshagyl fields, where loose sand dunes are developed, are not typical for this area. The terrain disturbance during industrial development and raw materials export intensified eolian processes which are created 200-1000 metres and more positive arenaceous form of ridges. The ridge height not exceed 1,5 metres. Construction of new and maintenance of existing transport network passing through cohesionless soil with thinned vegetation contributes the activation of the eolian process as well. Anthropogenic damage of soil and active deflation of sand is strikingly observed in the Kulsary Village and among it. This is the largest settlement in the region with 36,4 thousand population, which is involved in to industrial production.

All settlements in this area are connected with each other by many network of the pipelines, roads (mostly earth road), which are multiply increase human impacts on soil and vegetative ground cover and sharply activated development of the eolian process. The deflation centre is often developed along the Kulsary – Emba, Kulsary – Kosshagyl, Turgyzba – Tasshagyl, Shokpartorgay – Koisary dirt roads. Such deflation areas are observed along the Karaton – Sarkamys, Makat – Kulsary – Oporniy track.

Thus, the eolian process activates dramatically as a result of increased anthropogenic load, as it good seen on aero photographs and space images – the most clarified some white areas.They pass along the railway and car roads (dirt and ground), particularly at their crossing, constructing of communication lines, along the oil and gas pipelines and other engineering structures. The process of intense deflation continues, and the eolian move occurs on the western and eastern areas if judging by the wind rose of the Oporni and Kulsary weather stations.

A salinization process is typical for the oil-fields of the West Kazakhstan with extremely continental climate, which is also occurring everywhere. The development of this process often relates with lifting of groundwater to the surface due to the strong surface evaporation, with salts crystallization extracted by water from the same rocks themselves, the salts transfer from the weathering sequences massive crystalline rocks, as well as with the salts redistribution and transportation from the sedimentary rocks, previously accumulated in salt mass (1). Relief making role of this process is very important. Formed by clay, loamy, less by sandy loam and sandy rocks in close proximity of the groundwater level saline lands form in the relief depressions

Almost all of the Caspian Depression is currently the accumulation of mineral salts, carrying to its territory by surface discharge from the Southern Ural, the Obshiy Syrt and Mugodzhar. Annually 385 thousand tons of salts carrying to low grounds border, which from about 90% brining in the period of spring floods (2). High saturation deficit and high evaporation cause the accumulation of large amounts of salts on surface soil, especially within local relief depressions occupied with takyrs (dry-type playas) and sors.

The presence of high-mineralized still dissolutions at large degree determines the general background of the high salinity of soil-forming materials. Low hypsometric location of the territory made it a region of intense salinization. The geochemical processes concerning with salt-dome structures leave its traces on the general background of the salinity in some areas.

The dynamics of the salinization is strengthening. Drilling mud spills and annually extracted stern edge water discharging on to field evaporation (lower areas, sors, saline depressions) is a result of strong salinization (on already existing sors) and occurring of new sor areas and artificial lakes over the oil pipelines, which sizes depend on the amount of the extracted edge water and the lows, in which it is poured. According to our observations, the annual growth of a small salt marsh near the Karaton Village was 10-15 cm at the average on the edge because of the oil spill, in the lower fields it was up to 0,4 m-0, 5 m, in other words the anthropogenic impact 3-5 times increases the growth of the salt marsh. Average speed of the natural salt marsh development is 3.3 cm per year with the close occurrence of the underground water and with the 5.7 m/s average wind speed (3) (average wind speed of the area is 5 m/s).

The oil field's edge water activating the sor formation process is the high- mineralized water (up to 200 g/l and more) (4), which may contain not only soluble, but partially soluble minerals as well (silicates, aluminates, ferrosilicates etc). Naturally, the flow of ready soluble salts on to the evaporation fields could not leave the trace for the physical-chemical composition of soils and subsoil. Prevalence of sodium chloride in the edge water, leads to occlude complex of soils saturated with the sodium which leads to strong alkalinity. Therefore the soils and subsoil are sometimes strongly salt-affected.

Thus, the "artificially" salinization process (through the formation water, drilling spills) is forming the relief, and changes the physical mechanical properties of the rock maker species as well, making them more metamorphic due to other process such as the eolian.

Processes having local development character are distributed limited, but at the same time carry a definite character to the overall distribution of modern processes.

Road erosion process activates along linear facilities, where the formation of anthropogenic soil take place. Along the Kosshagyl – Karaton track 1 m and in length to 10 m gills marked. The anthropogenic gills has also noted along the right side of the Komsomolsk – Kulsary railway line. Here they reach up to 2,5 m depths and 10-12 m length. The same picture observes in the 3-km south of the Kulsary-Toles line, in open pit mining locating at the 8 km east from the Kulsary Village, 5 km north-west from the Makat Village and in the Imankara open pit mining at surface of outwash plains.

Flooding and under flooding process is one of the consequences of modern transgression of the Caspian Sea. Sustainable increase of ground water elevation on the coast due to sea backwater notes at a distance of 1-3 km from the coastline in the sandy rocks with good permeability.

In eastern and southern territory at the region of argillaceous deposits the pore faveolate takyr formation process observes. They are confined to flat topographic law usually forms by karstification having the form of 1.5-2.0 m depth flat closed depression. The areal size of takyrs is varying between very wide limits. For example, within the southern part of the Mangyshlak observed up to 5-6 km^2 takyr sizes, and the larger of them usually have somewhat elongated shape. The takyr deposits are 10-15 cm and offer a mud filter cake having fractured surface separated to unit cells. This mud cake is often covered with ultra fine salt film, which makes the takyr surface whitish. On a basis of these indication effect, and rounded or slightly elongated configuration they identifiable on space images.

Occurrence of sheet flood is not the equal everywhere, because area is characterized by flat relief having insignificant fall toward the sea. At dividing range area where is many dead-levels the processes are going slow. During the autumn rains and spring snowmelt, they flow actively coinciding generally with dry bottomland narrows and gullies, as well as back-slope of inland basins and catholes, especially in the southern part of the West Kazakhstan. Dead valleys of gullies and narrows are few and short. Only at the head observes the bed and then it rapidly expanded and concentrated flow quickly transfers into the flat flow and vice versa.

Suffosion processes in this area are largely localized and occur only in the elevated areas along the cliffs. Usually it is strongly saline soil areas with deeper groundwater occurrence (5 m and more). Suffosion lows are slightly visible in the relief; they are differing with heavier stand from the rest surface.

CONCLUSIONS

Thus, a result of human impacts wind erosion and sor formation processes are increasing very much at the West Kazakhstan oil-fields. Other processes become localized, in sparsely populated areas and therefore less exposed to human activities.

Analysis of a regional ecosystem having low resistance to development pressure and low self-restoration capability giving us ground for finding ways for rational use of natural resources and environment protection. To solving this problem we need a comprehensive ecological approach, which consists of the following:

1) to establish a permanent observing and controlling systems over natural constituent: vegetative ground cover, groundwater and surface water, atmosphere;

2) to introduce modern monitoring systems and studying with quantitative and qualitative development assessment of the modern relief-forming processes (to study their development speed, area zones), especial-

ly the leading ones: sor forming, eolian processes, flooding on the basis of long-term stationary observations;

3) to attract the experts' attention for studying and mapping of relief-forming processes in the area of oil and gas exploitation;

4) to implement and accelerate a work development on math modelling of modifying processes, particularly of a regional development nature;

5) to study of modern processes using aerial photographs, space images, geophysical methods;

6) to expand the front of fundamental research on establishment and relationship of the modern relief-forming processes and anthropogenic factors in the oil and gas exploitation areas for scientific forecasting of surface changes under the human activities influence.

Of course, natural factors are not able to stop the growing processes of the anthropogenic influences, which lead to ecological disturbance and nature imbalance. In some cases this process requires an integrated development and environmental facilities' construction, in another case – large and immediate financial expenses. Considering that the region has great economic perspective operational measures for consequences prevention and elimination must be carried out.

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THE CASPIAN SEA: ENVIRONMENTAL PROBLEMS

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Keywords: The Caspian Sea, environmental hazards, ecological state, oil pollution, contamination of sea water.

INTRODUCTION

The Caspian Sea represents the most vast inland catchment in Eurasia, which covers the major industrial regions of Russia and Caucasus and suffers an increasing anthropogenic impact (Kosarev and Yablonskaya, 1994; Kostianoy and Kosarev, 2005; Zonn et al., 2010). In the Caspian Sea, chemical pollution is the most important. All of its principal constituents may be observed in the sea; the most important pollutants are oil and oil products, phenols, and, in the North Caspian, detergents (surface-active substances). The chemical pollution grows with the intensification of the human activity on the sea coasts and in the sea proper and represents one of the most hazardous kinds of anthropogenic impact on the Caspian ecosystem.

The main sources of pollution of the Caspian natural environment are transborder atmospheric and water transfer of pollutants from other regions, washing off with river flows, discharge of untreated industrial and agricultural wastewaters, municipal–domestic wastewaters from cities and settlements in the coastal zone due to the insufficient number of treatment facilities, oil and gas operations on land and offshore, oil transportation via sea, river and sea navigation, secondary pollution during bottom dredging operations, and sea level rise (Fig. 1). The increased concentrations of pollutants are characteristic of the near-mouth areas of the rivers. They are observed not only off the Volga River but also off the rivers of the western coast of the sea such as the Sulak, Terek, and Samur rivers.

Another particular feature is related to the fact that the degree of pollution of the eastern shelf of the Caspian Sea is lower than that of the western shelf because, in the latter case, the amount of pollutants is reduced due to a small number of sources – rivers and industrial enterprises.

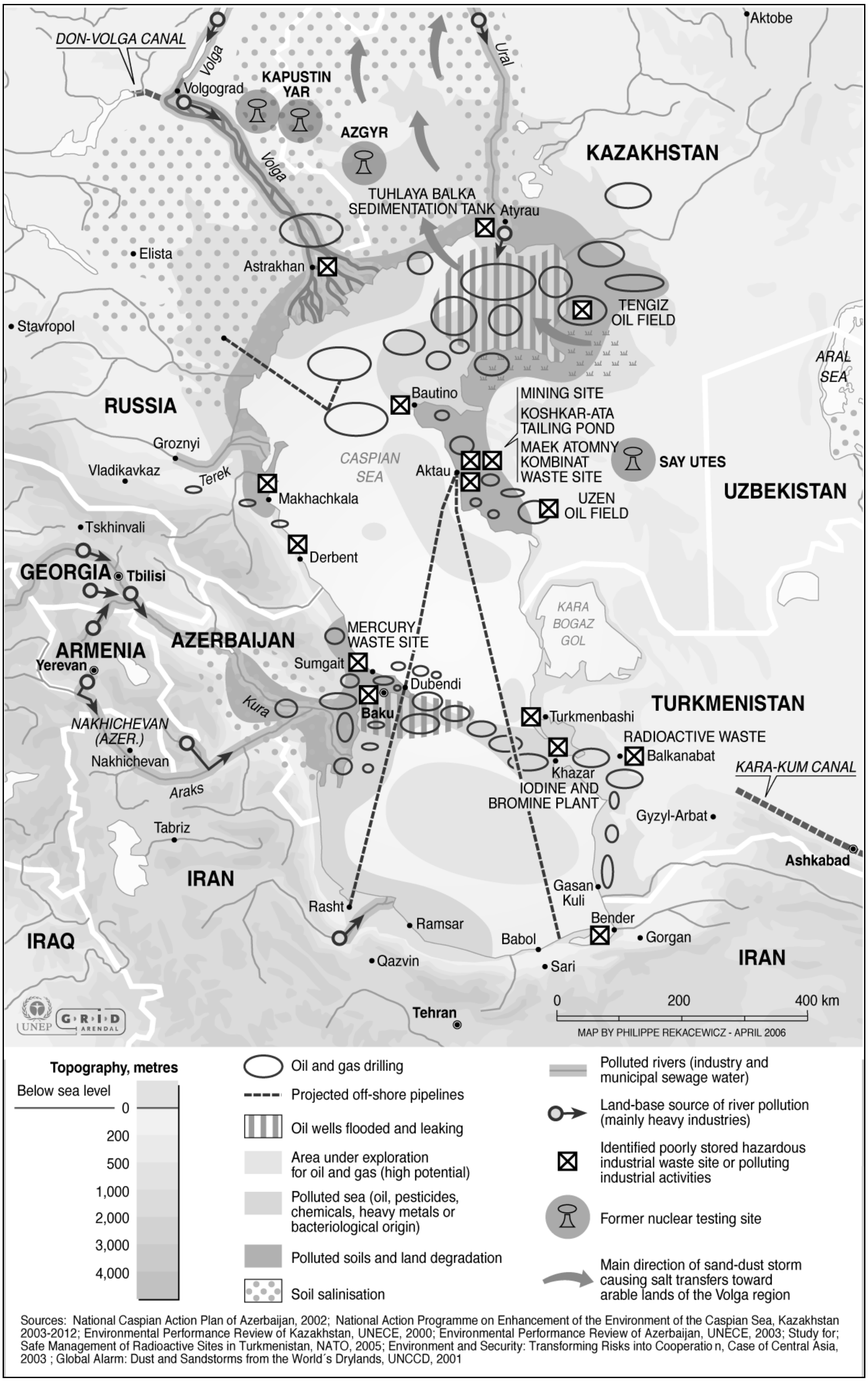

Fig. 1. Potential environmental hazards in the Caspian Sea Region. (2007). In *UNEP/GRID-Arendal Maps and Graphics Library*. Retrieved 21:02, May 22, 2009 from http://maps.grida.no/go/graphic/potential-environmental-hazards-in-the-caspian-sea-region

With the increase in the economic potential of the Caspian countries due to hydrocarbon extraction, construction of new sea ports, rehabilitation of existing ports, revival of the merchant and tanker fleet, enhancement of the navy component, and construction of oil and gas pipelines this environmental stress may grow. The risk of the negative effects of the hydrocarbon field development in the bottom and coastal regions of the Caspian Sea is especially great in the shallow-water Northern Caspian, which is exclusively important for development of the unique commercial biological resources of the entire Caspian Sea, and which is at the same time a nature-reserve zone.

Oil and chemical pollution of soils is observed over all the territories of the oil and gas fields. The main sources of this sort of pollution are breaks in oil pipelines, emergency flowing of exploratory wells, violations of the technologies of storage, accumulation, separation, and transportation via pipelines, and inadequacy of the constructions and equipment used in oil production and transport. The highest values of oil product pollution are noted in the areas near major cities, ports, and industrial regions such as Makhachkala, Neftyanye Kamni, Baku, and Turkmenbashi.

Intensive oil and gas development in the Caspian region resulted in extensive water, land and air pollution, wildlife and plant degradation, exhaustion of natural resources, ecosystem disturbance, desertification and considerable losses in biological and landscape diversity.

OIL POLLUTION

Estimates of the Caspian Sea Region's proved crude oil reserves vary widely by source. Energy Information Administration (www.eia.doe.gov) has estimated proven oil reserves as a range between 17 and 33 billion barrels, which is comparable to OPEC member Qatar on the low end, and the United States on the high end. In 2002, regional oil production reached roughly 1.6 million barrels per day, comparable to annual production from South America's second largest oil producer, Brazil. By 2010, the countries of the Caspian Sea Region are forecast to produce from 3 to 4.7 million barrels per day, which exceeds annual production from South America's largest oil producer, Venezuela.

Intensive development of coastal and offshore oilfields in the Caspian Sea started in late 19th century. Oil production has always been a major activity in the Caspian Sea region and now the area of Baku and “Neftyanye kamni” (now “Neft Dashlary”) is one of the most polluted areas of the Caspian Sea. The recent revival of the oil and gas industry only aggravates the environmental problems there. The increased transport of oil from the Caspian Sea can also have far reaching effects on the neighboring regions through which oil and gas are transported by ships and pipelines.

The Caspian Sea is the world’s first large water body to suffer from large-scale oil pollution. Estimates hold that since exploration of oil in the coastal zone of Baku, nearly 2,5 mln tons of crude oil has entered into Caspian waters in the course of routine production and transportation operations, which has had a dramatic environmental impact on the western shelf zone. Deterioration of facilities on the drilling platforms further aggravates the situation. Spillages of oil happen almost every day now. There is a high risk of ecological disaster, made worse by the fact that the Caspian Sea is an almost enclosed sea.

In cooperation with Russian Space Research Institute we have conducted satellite monitoring of oil pollution in the Caspian Sea, and a set of images obtained in different years and seasons over the “Neftyanye Kamni” area have been analyzed. In addition, images available in EoliSA database have been considered. In fact, nearly all images of the area bear imprints of oil spills around oil platforms. This means that huge amounts of oil are spilt into the sea almost every day (Lavrova et al. 2006). Figure 2 presents an Envisat Advanced Synthetic Aperture Radar (ASAR) Wide Swath image obtained on September 10, 2004, covering the Absheron Peninsula in Azerbaijan. Baku, appearing as a large bright area at the southern coast of peninsula, is the Azerbaijan's capital and one of the chief ports on the Caspian Sea. The oil platforms of Baku, built in the 1950s and 1960s, which appear as bright dots in the image, were the first offshore oil-drilling efforts in the world. Some oil slicks (black patches) are visible in the image on the Caspian Sea. The largest one of the size of the Baku city is related to Neftyanye Kamni oil rigs. The total area of oil patches reaches 200 km^2 here.

CONTAMINATION OF SEA WATER AND SEDIMENTS

Over the recent decades, the interannual variations in the contamination of the waters and sediments of the Caspian Sea were mainly caused by the influence of the sea level rise, the accidental oil losses, and the general fall in the industrial activity in the Caspian basin. In 1978–1995, a greater contamination was observed in the waters of the North Caspian subjected to the runoff of the Volga River. The mean annual values of the concentrations of oil products, phenols, and surface-active substances were 0.19, 0.006, and 0.08 mg/L, respectively. Smaller respective values were characteristic of the waters of the South Caspian, where the principal oil and gas fields are located (0.13, 0.005, and 0.045 mg/L) as well as of the waters of the Middle Caspian (0.08, 0.005, and 0.04 mg/L) (Korshenko and Gul, 2005).

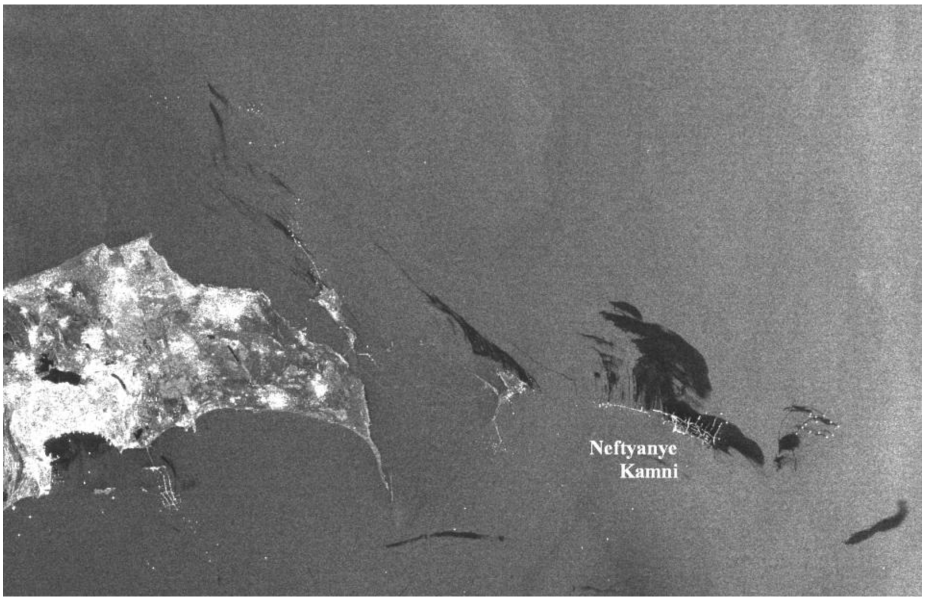

Fig. 2. Oil pollution around Absheron Peninsula on 10 September 2004 (ASAR Envisat, 75 m resolution, ©ESA). Image courtesy: O.Yu. Lavrova, Russian Space Research Institute

Nitrogen and phosphorous represents nutrients that can be seen as pollutants, as large concentations of those increase eutrophication. Nutrients are present in primarily commercial fertilisers and in sewage. A measure of eutrophication is biochemical oxygen demand (BOD), which measures the activity in the water column. High BOD means that there is low water quality (in terms of eutrophication) and high activity of bacteria in the water. Mercury and Cadmium are classified as toxic metals, and are persistant pollutants in the environment, that stays in the system and is accumulated through the food chains. The main release of these pollutants are on the west coast of the Caspian Sea, off the coast of Russia and Azerbaijan.

At the same time, the contents of contaminants in the sediments of the Caspian Sea varied within wider limits (oil products from 0 to 226 mg/L, phenols from 0 to 40 μg/L, and mercury from 0 to 4,7 μg/L) (Korshenko and Gul, 2005). The maximum values were detected in Baku Bay and off the cities of Sumgait (north of the Apsheron Peninsula) and Turkmenbashi; the minimum values were concentrated in the deep-water regions of the sea.

In shallow-water areas, bottom sediments represent sources for secondary contamination – at sea level rises under the influence of dynamic processes additional pollutants are supplied to the near-bottom layer of the sea. Over the entire area of the Caspian Sea, there is a tendency to a decrease in the concentrations of pollutants down the water column. For example, the contents of oil hydrocarbons, phenols, and surface-active substances are noted to decrease from their maximum values at the surface down to almost zero values in the 500–1000-m layer.

Although since 1995 the water level in the Caspian has remained relatively stable (Lebedev and Kostianoy, 2005; Kostianoy and Kosarev, 2005), a further rise of the sea level may still lead to emergency situations in oil production areas, flooding of drilling sites located in lowlands, breaking of protection embankments and levees around drilling sites, breach of on-field pipelines, and pollution of underground waters, which will subsequently contribute to the additional sea pollution.

CONCLUSIONS

Shipping activities, including oil transport and oil handled in harbors, and oil production at sea have major negative impact on the marine environment and coastal zone in the Caspian, Black, Azov, Mediterranean, and Baltic seas (Kostianoy, 2008). Oil and oily residue discharges from ships and oil platforms represent a significant threat to marine ecosystems. Oil spills cause the contamination of seawater, shores, and beaches, which may persist for several months and represent a threat to marine resources. One of the main tasks in the ecological monitoring of the Caspian and other European seas is an operational satellite and aerial detection of oil spillages, determination of their characteristics, establishment of the pollution sources and forecast of probable trajectories of the oil spill transport.

The threats of the deterioration of the environmental situation in the Caspian region and of the depletion of its natural resources directly depend on the condition of the economy and awareness of the society about the global character and importance of these issues. This threat is especially great because of the excessive development of the fuel-power industries, drawbacks of legal foundations of the nature conservation activities, restricted application of the nature-saving technologies, and low ecological culture, which increases the risk of technogenous catastrophes.

The unsettled delineation of the Caspian Sea and the uncertainty in its legal status are the main obstacles for successfully coping with many issues, including environmental protection and preservation of the biological resources (Zonn, 2005). Here, the key issue should be the provision of national and international environmental safety. This means elaboration of a system of coordinated state and interstate mechanisms, actions, and guarantees based on the compliance, by one and all states, with the common humanitarian principles and norms of the international legislations that are called to guarantee effective solutions or to prevent emergence of environmental problems of interstate and world community dimensions. Rapid settlement of the legal status of the Caspian is necessary for a transition to sustainable development capable of ensuring a balanced solution of the socioeconomic and nature-conservation issues in the interests of the Caspian countries and the whole world community.

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FEATURES OF CARRYING OUT OF ECOLOGICAL AUDIT OF ARID TERRITORIES

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Keywords: arid territories, environmental audit, negative influence, inventory of sources of influence, nature protection efficiency

GENERAL PROVISIONS

By definition [ISO 14050, 2002] ecological audit is the regular documentary issued process of check of objectively received and estimated auditor data for conformity definition (or discrepancies) to criteria of audit of certain kinds of ecological activity, events, conditions, systems of administration managerial control or the information on these objects.

Procedure of ecological audit (EA) is widely applied in foreign countries in all directions of economic activities, including EA the enterprises and separate technological processes, water economic and power supply systems, transport highways, municipal unions, territories etc.

Unfortunately, in our country ecological audit (EA) is not popular yet. However its carrying out allows to estimate efficiency of nature protection (ecological) activity of the enterprises, municipal unions, to receive the objective information on an ecological condition of territories, water areas or the whole regions, to make the forecast of development of a situation and to develop recommendations about its improvement [1, 2, 3]. According to experts EA is also the tool for regular check of ecological potential of object of audit and potential ecological risk [4].

Arid territories differ high degree of vulnerability and instability to any anthropogenous loadings. As a result of a becoming aggravated ecological situation in region of Caspian sea of a problem of the organisation, carrying out of environmental audit and acceptance on the basis of its results of administrative decisions in sphere of preservation of the environment become more and more actual.

REQUIREMENTS TO THE ORGANISATION OF ECOLOGICAL AUDIT OF TERRITORIES

Ecological audit of territories includes two large-size blocks (fig. 1):

1 – an estimation of existing anthropogenous loading by various kinds of economic and other activity;

2 – an estimation of natural factors and the components of an environment defining stability of geoecosystems to anthropogenous influence.

1. On the first block gathering and the analysis of the available information on an anthropogenous situation in region with carrying out of following procedures is spent:

– Definition of primary type of economic use of region;

– Inventory of sources of negative influence on environment components: atmospheric air, superficial and underground waters, soils, a vegetative cover and fauna;

– An estimation of influence of various kinds of economic use on components of an environment and their ecological condition;

– Inventory of the antropogenno-broken sites with instructions of the areas, degree and character of break.

The primary type of economic use of territories and water areas is defined by specialisation of region in leading branches.

Inventory of sources of negative influence on environment components is spent for the purpose of definition of scales and character of influence of economic development of territory on their condition.

Sources of negative influence concern:

– sources of mechanical influence on environment and geoecosystem components;

– pollution sources (mechanical, chemical, bacteriological) environment components;

– sources of harmful physical influence (radiating, light, noise, electromagnetic, vibrating).

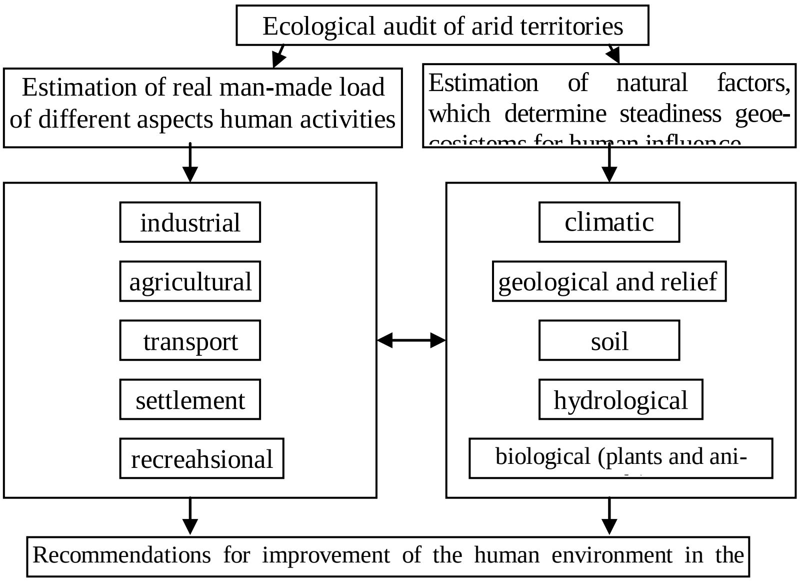

Fig. 1. Fundamental blocs and directions of the ecological audit of territory

Table 1

An estimation of a condition of an environment

Extent of human destruction of territory:	Estimation of condition environment
0 – 10 % don`t destruction	natural
11-25 % faintly destruction	good
26-60 % middling destruction	satisfactory
>61 % strongly destruction	bad

The estimation of influence of various kinds of economic use on environment components gives the chance to reveal ecologically dangerous objects, environment components on which there is an influence, and also its character, an orientation and intensity.

Inventory of the antropogenno-broken sites with instructions of the areas, degree and character of destruction allows to spend an estimation of an ecological condition of territory and admissible level of negative influence.

On the basis of the long-term data received on various regions, the scale of an estimation of a condition of an environment on degree anthropogenous нарушенности has been offered territory on four gradation (tab. 1).

Result of works in this direction is:

- an objective estimation of existing anthropogenous loading on components of an environment and a region geoecosystem as a whole;
- drawing up map-scheme an ecological condition of geoecosystems of region with definition of character, scale and degree anthropogenous нарушенности territories;
- definitions of level of admissible negative influence by economic activities kinds.

2. The estimation of natural factors and the components of an environment defining stability of components of an environment and geoecosystems to anthropogenous influence, develops of following characteristics:

- climatic indicators (a temperature mode, quantity and character of loss of an atmospheric precipitation, a wind mode etc.);
- a geologo-geomorphological structure of territory (a geological structure, relief type, density and depth of a partition of a relief, a steepness of slopes etc.);
- hydro-geological conditions (ground water level and quantity of water-bearing horizons, water-level, hydrochemical characteristics, stocks, etc.);
- a soil cover (type of soils and their specific variety, мозаичность a soil cover, development of a soil profile, mechanical structure, acidity, degree destruction, etc.);

- a hydrographic network (density of a river network, hydrological characteristics, hydrochemical and hydrobiological indicators, degree dampness of territories etc.);

- vegetation (vegetation type, a specific variety, character and degree of grassed territories, мозаичность vegetative associations, stability of vegetation to mechanical, chemical and other kinds of negative influence etc.);

- fauna (specific structure, number of separate kinds, the basic habitats and their condition, speed of reproduction, presence and a forage reserve condition, dynamics of number, etc.).

Climatic conditions of arid territories substantially form stability of natural complexes to anthropogenous influence. The combination of heats and a small amount of precipitation limits a specific variety and number of representatives of a plant and animal life, leads to formation weakness a soil profile, and consequently – its low stability to influence any kinds. Rare loss of deposits at presence calm conditions of circulation of atmosphere can lead to considerable pollution of atmospheric air in zones of influence of the enterprises and transport highways etc.

The geologo-geomorphological structure of territory is defined by landscape-structural features and mechanical structure of soil horizons. Intensity and scales of development depend on its characteristics erosive, wind-born, denudative and other processes, and, hence, and degree of stability of territories to various kinds of influence.

Hydro-geological conditions substantially define conditions of humidifying of territory (flooding, bogging etc.), salinization, a food of plants and a number of other characteristics of a condition of geoecosystems.

The soil cover plays a role of the natural filter interfering receipt of polluting substances in the bottom horizons. Distribution and a condition of vegetative associations depends on character and a condition of a soil cover.

The hydrographic network defines character and degree dampness territories, and, hence, conditions of formation of a soil-vegetative cover and habitats of representatives of a plant and animal life. Ability depends on hydrological and hydrodynamic characteristics of water objects to dilutation arriving pollution, and also self-cleaning and self-restoration processes.

The vegetative cover carries out soil – water- and шумозащитные functions, promotes clarification of atmospheric air. Stability of geoecosystems to any kinds of negative influences substantially depends on characteristics of vegetative associations.

Representatives of fauna can often serve as indicators of a condition of components of an environment since very quickly react to reduction of territories of habitats, fodder grounds, on pollution of atmospheric air, a soil cover, vegetation etc. Negative influences are shown under following factors:

- reduction of a specific variety of fauna,
- reduction of number of various populations,
- deterioration of a condition of separate individuals in population,
- reduction of number of posterity and change dimensions indicators,
- increase in a share of sick animals and life expectancy reduction.

Total results in this direction of environmental audit of territories are:

- an estimation of protective functions of components of an environment to negative influences;
- drawing up of the register of sites of the territory demanding carrying out of nature protection actions;
- working out of the list of nature protection actions with an estimation of scales and volumes of their carrying out;
- An estimation of nature protection efficiency of offered actions.

By results of environmental audit of arid territories the Conclusion containing is made:

- an objective estimation of an ecological condition of components of an environment and geoecosystems as a whole,
- the forecast of development of a situation,
- actions for decrease in negative influence on an ecological condition of region.

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ESTIMATION OF THE CASPIAN SEA BACKGROUND OIL POLLUTION BASED ON REMOTE SENSING DATA AND MODEL CALCULATION

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Keywords: Caspian Sea, oil pollution, model, advection, destruction, evaporations, sedimentation, satellite altimetry, satellite radiometry.

INTRODUCTION

The pollution level of the Caspian Sea defines condition of its ecosystem in various space-time scales and changes under action according to climatic, physiographic factors, hydrobiological processes and anthropogenous impact which amplifies every year.

According to statistics till 1985 offshore oil industry represent source 2% of total oil pollution (OP) World Ocean, natural sources – 9%, atmospheric precipitation – 13%, domestic and industrial wastewater (including of soluble petroleum products which are bring of perennial river runoff) – 46% and emergency situations and transportation – 30% (Izrael and Tsyban, 1989). At present time the share of transportation OP was reduced to 24% and the share of domestic and industrial wastewater OP has increased to 50 % (Patin, 1999) (Tab. 1). For the Caspian Sea as internal sea the share of these sources should be absolutely another. However according to data represented in Table 2 the OP share falling on emergency situations and transportation is strongly underestimated for this sea.

According to difference estimations the Caspian Sea oil resources volume variates from 16.0 to 20.5 billion tons. The leader of offshore oil industry volume and oil proved stocks is Kazakhstan. Azerbaijan and Turkmenistan have the second and third place. Iran yet does not conduct extraction of hydrocarbonic raw material on the Caspian Sea, though builds already oil platforms. Offshore oil industry data for 2004–2005 and the forecast of its extraction volumes by 2010 (without taking into account Iran) are presented in Table 3 (IEO, 2009).

Table 1

The basic OP sources of the marine environment (thousand tones per year and percents)
(Izrael and Tsyban, 1989; Patin, 1999; Mehdiyev and Gul, 2006; Mamedov, 2007; Mamedov et al., 2007)

Pollution Source	World Ocean				Caspian Sea	
	1985		2007			
	10^3 t/yr	%	10^3 t/yr	%	10^3 t/yr	%
Domestic and industrial wastewater (including of soluble petroleum products which are bring of perennial river runoff)	1,080.00	46.35	1,175.00	49.98	122.76	86.64
Emergency situations and transportation	700.00	30.04	564.00	23.99	0.10	0.07
Atmospheric precipitation	300.00	12.88	306.00	13.02	0.35	0.25
Natural source	200.00	8.58	259.00	11.02	17.25	12.17
Offshore oil industry	50.00	2.15	47.00	2.00	1.23	0.87
Total:	2,330.00		2,351.00		141.69	

At the average 131.4 oil tons is lost at offshore oil industry on each one million tons in the world (Patin, 1999). Therefore the OP at extracted share should make about 2,700 t/yr. This value is underestimated more than in 2 times (see Table 1–2). The affirmation is true for OP emergency situations and transportation (oil spills detected). According to statistical data (Patin, 1999) from 0.1 to 0.5% of oil transported it is thrown out to seas as a result of practice of flushing and ballast water dump. Now on the Caspian Sea tank-ers annually transport 12–14 million oil tons per year. Considering this factor, the volume of oil emergency situations and transportation as 100 t/yr (Table 1–2) most likely is underestimated at 1.5–2.5 time.

MONITORING SYSTEM OF OIL POLLUTION

At present day designing of OP monitoring systems for the Caspian Sea and all seas of Russia is actual problem. This system must include as analysis of *in-situ* and remote sensing data as oil spill (OS) transport modeling calculation. Usually for OS detection base on synthetic aperture radar (SAR) image because of weather and irradiance independence and high resolution (Rees, 2001).

SAR is an active remote sensing tool, in which a satellite antenna transmits microwave signals toward to the ocean surface and receives signal after its interaction with the sea surface. It's well known, that crude oil and oils form films of various thickness on the sea surface. Oil films floating on the sea surface locally dampen the short surface waves and change the sea surface roughness. For this reason oil spills look as dark patches on the SAR images (Alpers and Espedal, 2004) (Fig. 1).

Once oil is discharged at the sea surface, it is transported by the flow and affected by many processes such as evaporation, emulsification, dissolution, photolysis, biodegradation, etc., that depend on the properties of the oil (Garrett, 1972). Therefore OS transport model is important part of any OP monitoring systems (Korotenko et al., 2000; Korotenko et al., 2001). All these models are very multiple and used only for simulation of emergency situation.

Table 2

The basic OP sources of the Caspian seas (tones per year and percents)
(Mehdiyev and Gul, 2006; Mamedov, 2007)

Pollution Sources		Oil, (t/yr)	%
Soluble petroleum products which are bring of perennial river runoff		76,107	53.90
Azerbaijan	Kura	1,860	2.44
	other rivers	35	0.05
Iran	Sepidrud All rivers	200 52	0.26 0.07
Kazakhstan	Ural	1,260	1.65
	other rivers	170	0.22
Russia	Volga	70,430	92.23
	Sulak	560	0.73
	Terek	1,320	1.73
	Samur	270	0.35
Turkmenistan	all rivers	210	0.27
Domestic wastewater		19,453	13.73
Industrial wastewater		26,941	19.01
Emergency situations and transportation		100	0.07
Atmospheric precipitation		350	0.25
Natural source		17,250	12.17
Offshore oil industry		1,231	0.87
Total:		141,692	

Table 3

The offshore oil industry of the Caspian Sea (billion tons per year)

Country	2000	2005	2009	2020
Russia	–	–	–1	19.0
Kazakhstan	–	–	72.4	100.0
Turkmenistan	0.6	1.1	12.6	26.0
Iran	–	–	–	–
Azerbaijan	14.6	20.0	50.1	55.0
Total:	15.2	21.1	146.1	200.0

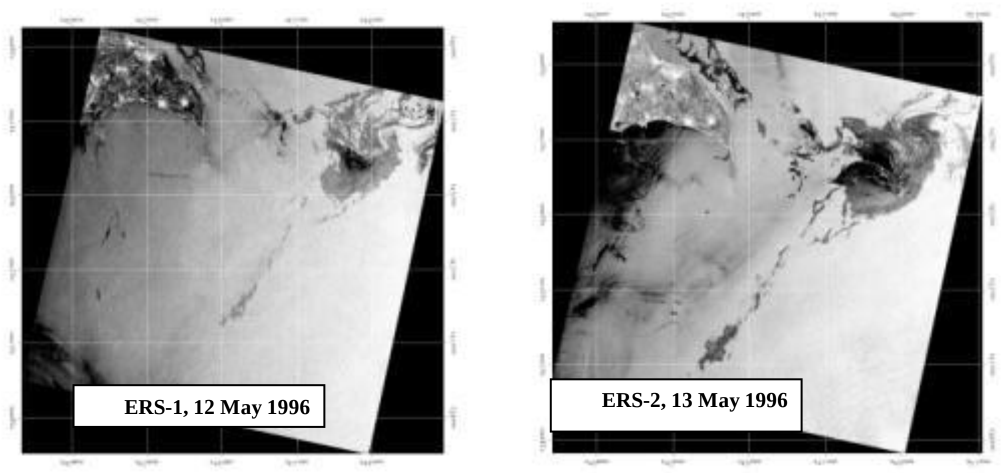

Fig. 1. Serial ERS SAR images acquired on 12–13 May1996 over the coastal zone of Neftyanyye Kamni/Caspian Sea (Gadimova, 2000)

Though for estimation ecological damage background OP data are necessary known. In the first place the background OP is generated as result of regular pollution based on domestic and industrial wastewater by Caspian Rivers (Table 2). According to these data the Volga input is the largest one with 92% of the total petroleum hydrocarbons input. A new OP transport model is necessary which work to real sea dynamic and pollution data.

BACKGROUND OIL POLLUTION MODEL

As a first approximation integrated pollutants (oil hydrocarbon, household organic, effluent of metallurgical works) are described as one pollutant that is binary medium (water and pollutant) is esteemed (Leonenko et al., 1991; Keondjian et al., 1992). In the basis of the model approach the solution of a two-dimensional equation of changes of pollutant concentration $C(x,y,t)$:

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} = D\,\Delta C - \frac{q}{\rho_0} + \frac{p}{\rho_0} \tag{1}$$

$$q = \lambda\, C\, \rho_0\, exp(-\lambda\, t) + C\, \rho_0\, \beta\, t \tag{2}$$

where D – coefficient turbulence diffusion, U,V – horizontal projections of speed on an $0x$ and $0y$ accordingly, $q(x,y,t)$ – speed of pollutant elimination from aqueous medium, $P(x,y,t)$ – speed of pollutant entry to aqueous medium, ρ_0 – sea water mean density, $\lambda(x,y,t)$ – parameter of biochemical and microbiologic pollutant destruction $\lambda = \lambda_1 + \lambda_2\, T(x,y,t)$, $T(x,y,t)$ – sea surface temperature, $\beta(x,y)$ – parameter of pollutant vaporization an additive in atmosphere and deleting it at the expense of a deposition.

The boundary conditions are set as follows: on firm borders $\partial C/\partial n = 0$ – condition un-passing.

The numerical solution of a problem is constructed on application of explicit difference scheme, and at integrating on each temporary step sequentially is esteemed an advection, diffusion and destruction of an impurity.

The model (1)-(2) is applicable to pollutants of two types. The maiden phylum conditionally called «organic», as most vivid example similar pollutant are oil the hydrocarbon. It is a pollutant, the destruction which one, as a first approximation, is described exponential on time by the law; vaporization in atmosphere and deposition – symmetric functions on time. The second phylum – «inorganic» is a pollutant. The destruction is considered which one unessential as contrasted to as deposition.

This model has well proved at simulation OP of the Baltic Sea, the Burgas Bay and Taganrog Bay of the Black Sea et al (for example see Leonenko et al., 1991; Keondjian et al., 1992). The input surface speed fields were calculated shallow water model of barotropic dynamic (Gill, 1982). For our calculation we suggest to use the remote sensing data of sea surface temperature and surface speed fields as input data for this model.

INPUT DATA

Accuracy of sea surface temperature (SST) measurement by IR and microwave satellite radiometry is 0.3–0.5°K and 0.6–0.7°K accordingly (Gemmill and Krasnopolsky, 1999; Keogh et al., 1999). This SST date have spatial resolution 1.1–4 km^2 for IK-sensor and 25 km^2 for microwave sensor. The swath width changes from 1400 to 4000 km depending on the sensor. In the investigation synoptic SST data of project Global Data Assimilation Experiment High Resolution Sea Surface Temperature Data (GHRSST) on regular grid (with spatial resolution 0.25° x 0.25°) was used (Donlona et al., 2007) (Fig. 3).

Synoptic dynamic topography (DT) was constructed on the basis of the superposition of the sea level anomaly (calculated on satellite altimetry data relative to the GSRAS09 MSS model) (Lebedev and Kostianoy, 2005, 2008) distribution over the climatic dynamic topography (or hydrodynamic level), which was calculated on the base of a three-dimensional baroclinic model (Popov, 2004) (Fig. 4).

Oil production, industry, and transportation have caused severe air, water, and soil pollution problems in the Caspian region. The Volga is a major (but not the only) conduit of pollutants to the Caspian Sea including OP. The estimated amount of the input is given in Table 1. According to these data the total amount of oil discharged by Caspian Rivers reaches about 76,107 t/yr and, among the rivers, the Volga input is the largest one with 95% of the total petroleum hydrocarbons input. Therefore the bring of perennial Volga river runoff as OP only sources.

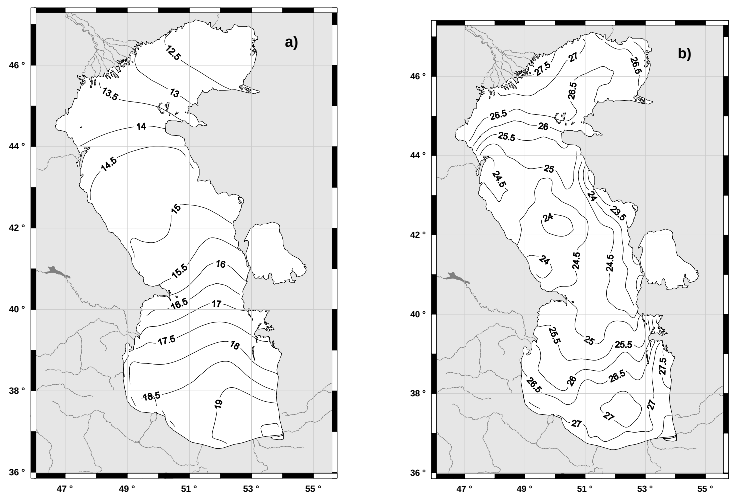

Fig. 3. Map of the SST (°C) Caspian Sea base on GHRSST data: (a) – climatic or mean field from time interval from January 1993 to December 2009; (b) – synoptic field on 6 June 2009

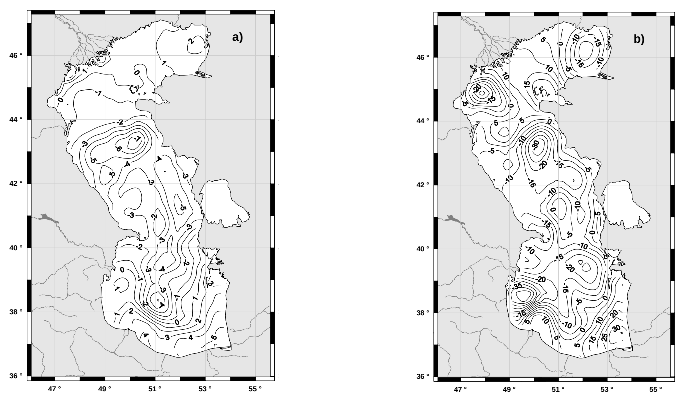

Fig. 4. Map of the Caspian Sea DT (cm): (a) – climatic or mean field base on three-dimensional baroclinic model (Popov, 2004), (b) – synoptic field on 6 June 2009

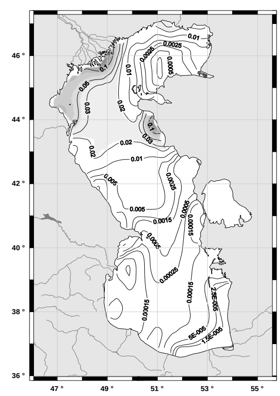

Fig. 5. Map of the Caspian Sea oil hydrocarbon concentration for June 2009

RESULTS

According to our calculation mean total concentration value is 14.42 10^{-3} mg/l for the Caspian Sea which is within limits maximum permissible concentration (0.05 mg/l of) for the river runoff as OP only sources. The analysis of spatial mean oil hydrocarbon distribution for June 2009 show that general OP concentrate in western part of the Northern Caspian Sea from western boundary of the Volga delta to island Chechen (Fig. 5). Mean temperature (Fig. 3a) and dynamic topography (Fig. 4a) regime of the Caspian Sea are cause of this oil hydrocarbon spatial distribution for June 2009.

ACKNOWLEDGEMENTS

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DEVELOPMENT KNOWLEDGE BASE OF CASPIAN REGION AS A PART OF "CASPINFO" PROJECT OF EUROPEAN SCIENTIFIC COOPERATION

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Keywords: the distributed databases, the knowledge base, WWW-service, a Web-browser, metadata, interactive technologies, project CaspInfo

INTRODUCTION

Natural heritage of unique Caspian region is shared by five coastal countries – Azerbaijan, Kazakhstan, Iran, Russia and Turkmenistan. Despite political and social distinctions, scientists and ordinary inhabitants of region share the general concern a condition of Caspian Sea and coastal territories. The decision of problems of an estimation, monitoring and, finally, the general problem of preservation unique ecosystem of Caspian region is connected with working out of means and technologies of gathering, structurization, storage and use of great volumes of the information – scientific, legislative, legal and administrative, spatially certain natural and anthropogenous. In article the way of the decision of a problem by control system creation by information resources of specially created WWW-service – knowledge bases of the Caspian region is offered.

RESEARCH PROBLEMS

Today the Caspian region faces considerable environmental problems, many of which are the problems of transboundary character defined both anthropogenous influence on ecosystem, and a number of the natural reasons. In the coastal countries long-term practical experience and huge volume of the scientific information, suitable for the decision of problems of ecological and social character are saved up. National priorities in areas of preservation of the environment, scientific researches, monitoring and gathering of scientific data as a whole are adequate. However absence of the uniform ecological legislation, inconsistent legal and administrative certificates of the different countries complicate joint regulation of activity in the field of wildlife management and environment protection. For the decision of this problem creation of the information model connecting a science, the legislation, the industry and structure business is necessary. One of the important elements at use of such model is presence, availability and reliability of the information on environment, including the sea, industrial activity, and the regulating certificates operating within the limits of the modern legislation of the different countries.

Realization of such model can be reached by working out and introduction of information service of European project CaspInfo (Caspian Sea Environmental And Industrial Data and Information Service) (http://www.caspinfo.net).) . Employees of Faculty of Geography of the M.V. Lomonosov Moscow state university within the limits of the international cooperation since 2009 conduct works under project CaspInfo which is included into 7 frame program of the European Union and is presented by 19 participants from the different countries. The basic idea of project CaspInfo is close to workings out of the largest European research projects SeaDataNet and SIMORG (http://www.seadatanet.org) which primary goals are compatibility and unification of the international and European standards of metadata, providing of access to the distributed bases of sea and ecological data. Data are given by the professional national centers of gathering of the information – components of the all-European network on maintenance of on-line access to databases.

Main objectives of project CaspInfo are:

- To initiate and maintain a Caspian Sea network of leading environmental and socio-economic research institutes, governmental departments, oil & gas industries, and international bodies, jointly working on the definition, development and operation of the CASPINFO service.

- Development and establishment of an Internet based CASPINFO Data & Information Service to facilitate the access to socio-economic and legal information, metadata and distributed datasets, managed by the regional partners, and to support marine environmental management.
- To explore and to develop a sustainable operation model for the CASPINFO service, thereby taking into account that the partners are coming from different backgrounds (public and private sectors) and possibly will deal with a mix of public and commercial data & information.

Thus, within the limits of project CaspInfo the new thematically directed search system which is based on data and knowledge of the Caspian region and online accessible users of different level will be created in a network the Internet.

Development of the interactive knowledge base of the Caspian region is a component of creation of information service CaspInfo. Its primary goal is maintenance of interactive access both to databases created within the limits of the project, and to already existing the European Meta databases, including procedures of an exchange and accumulation by modern trustworthy information. Among the European following catalogues are used:

- EDMO – European Directory Marine Organizations – the European Catalogue of the Sea Organizations. The catalogue contains the address information and the information about specialty scientific research institutes, the centers of science, supervising bodies, the state and private organizations which in this or that form participate in oceanographic and sea scientific researches. Now in the catalogue there is information on more than 1500 organizations (http://www.seadatanet.org/metadata/edmo).
- EDMERP – European Directory Marine and Environmental Research Projects – the European Catalogue of Sea and Ecological Research projects. The catalogue includes about 2000 research projects on a wide spectrum of scientific disciplines – physical, chemical and biological oceanography, sea meteorology, sea biology and a fish economy, an estimation of environment, research coastal and устьевых processes, etc. Research projects are characterized as sets of metadata with instructions of the most significant aspects of research (http://www.seadatanet.org/metadata/edmerp).
- EDMED – European Directory Marine and Environmental Datasets – the European Catalogue of Sea and Ecological Data. Now this catalogue describes more than 3500 data sets from 700 various organizations across all Europe. Data sets are described in the catalogue irrespective of their initial format. It both figures, and paper cards, photos and video data, geological tests and biological copies (http://www.seadatanet.org/metadata/edmed).

There is a considerable quantity and other projects, including international which possess great volume of the information of scientific, social and economic, legislative character. It is possible to carry the Caspian International Program to such projects (CEP) (http://www.caspianenvironment.org), EDIOS (European Directory of the Ocean-observing System), CSR (Cruise Summary Report) (http://www.seadatanet.org/metadata/csr) and a number of others. The fulfilled technology on the basis of Web-services allows to include and use the information practically any centers of gathering of scientific and other information at observance of corresponding rules of law. Therefore the local Meta databases compatible to existing bases EDMO created within the limits of project CaspInfo, EDMERP and EDMED, provide real possibility of construction of the full-function information knowledge base of near-Caspian region.

Significant advantage of the developed knowledge base is wide use of open network technologies. Providing of access through the Internet, and using standard programs Web-browsers (for example, Internet Explorer, Opera, Mozilla), not demanding installations of the additional software, users from the different countries will have possibility not only to carry out fast search of the necessary thematic information, but also to bring in base the information, forming, thus, an information field of near-Caspian region.

METHODS AND TECHNOLOGIES

Value of the geographical information especially claimed in systems of support of decision-making, increases with attraction of technologies and software of formation of knowledge bases. In the knowledge computer the same as also data, are displayed in the sign form – in the form of formulas, the text, files, information files, etc. Therefore it is possible to tell, that knowledge is in a special way organized data. The knowledge base, on a level with a database, – necessary component of systems support of decision-making (Lourie, 2010; Geoinformatics, 2010).

Creation of the interactive knowledge base of the Caspian region provides the decision of two problems:

- Working out of structure and the maintenance of the interactive knowledge base of the region reflecting the scientific, bibliographic, social and economic and cartographical information;
- Working out and creation of an interactive control system by information resources (knowledge base contents) specially created WWW-server of project CaspInfo, providing an exchange and information accumulation in catalogues of metadata.

The interactive knowledge base is structurally organized in four separate databases (the catalogue of metadata): "Scientists", "Bibliography", "Social and economic data", the "Maps" which have been built in structure CaspInfo (fig. 1).

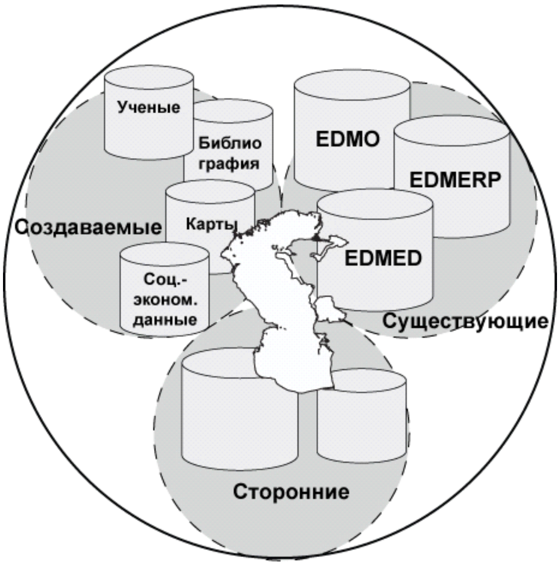

Fig. 1. The general structure of the knowledge base

By working out of databases the basic emphasis became on completeness of the information, access interactivity to databases, convenience at information entering, ease of search of the necessary information. The part of these problems has been realized by means of working out of the user interface, other part by means of working out of the original software – WEB-appendices.

The Meta database "Scientists" contains the information on researchers, the sphere of which scientific interests includes Caspian region. This base allows to find the contact information of the researcher, the name of its organization, scientific projects in which the researcher took part. As the section about the personal information has open access any researcher interested in an establishment of scientific contacts, has the right to include itself in a database.

The Meta database of "Publication" is the catalogue of scientific articles, monographers and other published sources (fig. 2). This base allows to find the scientific publications of various subjects connected with Caspian region, and gives possibility to the user to bring the information on the publication.

The Meta database "Social and economic data" represents the structured catalogue of social and economic data organized in the form of a set of separate files. The information containing in them can be of interest not only for scientists or experts in various areas of manufacture, but also and for the ordinary user living in near-Caspian region, or is used in the educational purposes as thematically in this database the most versatile information can be presented.

The Meta database "Maps" contains the information on the diversified maps of Caspian region. As the initial information in this catalogue of metadata can act both the published cards, and materials of remote sounding, and author's originals, schemes and other maps. Besides search and input of text metadata about maps, also, for better presentation, in system possibility of loading of sketches of maps is provided.

Technologically realization of databases was carried out as follows. As basic database it has been decided to use MYSQL. For each class of logic objects (Scientists, the Bibliography, Social and economic data, Maps) the database uses the basic table. Each record in this table corresponds to unique logic object and includes the unique digital identifier of object. Scalar attributes of logic object are stored in fields of the basic table, such as the text, date, and the numbered attributes represented in the form of the list of key codes.

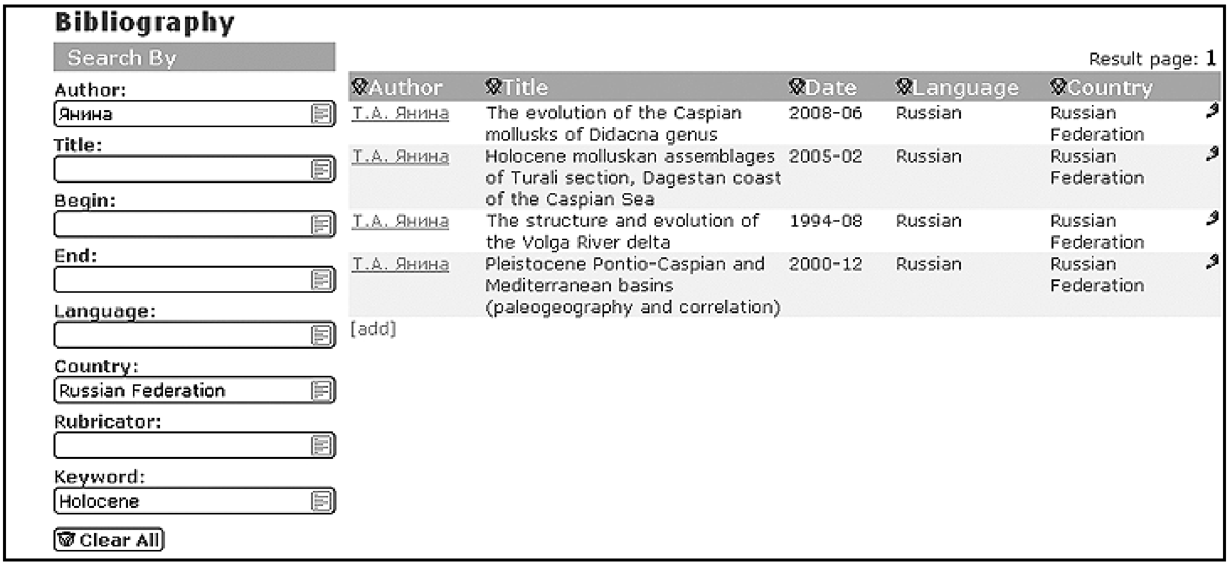

Fig. 2. Fragment WEB-interface of Meta database "Bibliography" (The right part – criteria of search, the left part – results)

For work with the numbered attributes of a database contain help tables of the description of such codes. So the office help table the "Country" based on international standard ISO 3166 numeric (http://www.iso.org/iso/country_codes), describes code designations of the states and dependent territories, and also the basic administrative formations in the states (Tab. 1).

Table 1

An example of the table the "Country" based on standard ISO 3166-1 numeric

3-Numerical code of the country	**3-** alphabetic code of the country	2 alphabetic code of the country	The country
036	AUS	AU	Australia
112	BLR	BY	Belarus
643	RUS	RU	Russian Federation
840	USA	US	United States

It is necessary to notice, that by developing of structures of Meta databases "Bibliography", "Social and economic data", "Maps" the specification of the standard of metadata Dublin Core (http://www.dublincore.org) – a simple and effective set for the description of the broadest range of network resources was considered. This standard has been developed by the international interdisciplinary group of professionals of library business, computer sciences, museum business and other adjacent sciences.

From the point of view of functionality the interactive database gives to users in a mode of real time following services: visualization of Meta database, search-filtration-sorting of the necessary information; visualization of the detailed information of the chosen object; entering of the information on objects with use of a control system by database contents. For meta database "Maps" specific service of display of the sketch of a cartographical source by means of realization of technology WMS – Web Map Service is provided, and for base "Social and economic data" possibility of preservation of the necessary information on a local disk of the user is provided.

Creation of an interactive control system by contents of the knowledge base of Caspian region is the basic and most labor-consuming problem of the executed workings out. It includes, first of all, system engineering of the user interface – the special program Web-application for maintenance of users with means of inquiry of the information concerning Caspian sea, its updating and editing in different Meta database placed on Web-portal CaspInfo (fig. 1 see), for simplification of access to the metadata and distributed data sets operated regional partners. These appendices are developed with use of the newest Web-technologies of architecture the "client-server", providing simple and rather cheap decision of a problem of collective access to databases in networks (Lorie, 2010; Geoinformatics, 2010). The application creation methodology is based on use of the standard Opened GIS- OpenGIS (OGC). Basis of the concept of open systems is simplification computing systems at the expense of the international and national standardization of hardware and program interfaces. For optimization of time of inquiry at creation of the graphic interface Web-application Map Server extended in an easy approach is used.

The developed Web-application consists of northern and client parts. For granting of services in placing of the information for the server party and for service of other Web-services one of servers IOC-IODC (International Oceanographic Data Center) – http://193.191.134.20/caspinfo/ is used

The client part of the application is realized as set HTML of pages with use of languages JavaScript and HTML, as (version 3) will allow ordinary users to work with server CaspInfo by means of network browsers Internet Explore or FireFox/Mozilla.

The search interface provides users with means of a choice of criteria of search for each field specified above databases. If the table or the connected tables have a spatial component, the user will have possibility to use a card for criterion formation "Spatial inquiry" (Spatial query). To set criteria a choice, the user should or click a mouse on a card and pull a rectangle, or enter values and ranges of widths and longitudes. Only the records which have got in full or in part in the set rectangle, will be included in result of search. Results of search can be presented in two forms: tabular and if it is possible, on a card.

Use Web-application Map Server allows to add GIS-functionality to search system. As base layers OpenLayers Library layers (http://www.openlayers.org), realized by means of technology WMS – Web Map Service are used. The Same service is realized for Meta database "Maps" for display of the sketch of a cartographical source.

CONCLUSIONS

The developed Meta database "Scientists", "Bibliography", "Social and economic data", "Maps", together with the created specialized software providing input, search and visualization of initial data serve as a prototype of the knowledge base of the Caspian region. Creation of such knowledge base is extremely important with scientific and with social points of view. Use of results to unite scientists of near-Caspian region, to find and give the necessary information, finally, to unite efforts of all people interested in preservation of unique natural region. The first results of work are presented on a site http://193.191.134.20/caspinfo/.

ACKNOWLEDGEMENTS

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Electronic resources

1. http://www.caspinfo.net
2. http://www.seadatanet.org
3. http://www.caspianenvironment.org
4. http://www.iso.org/iso/country_codes
5. http://www.dublincore.org

CASPIAN SEA GEOGRAPHIC INFORMATION SYSTEM "CGIS" AS A COMPREHENSIVE ENVIRONMENTAL MANAGEMENT MODEL

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Caspian Sea covers a surface area of about 384,000 square km and with a major economic role, is sandwiched between Iran, Turkmenistan, Kazakhstan, Russia and Azerbaijan. Even without considering the connecting channels (Don-Volga, Volga-Baltic and Garagum), its basin area is much larger and attain as much as 2865,000 square km area. Other countries like Turkey, Georgia and Armenia have to be also considered in eco-physiological and environmental equilibriums in the region. Obviously any change in environment or ecosystem of these eight countries has a direct consequence on the sea. Therefore in additional to Caspian Sea Environmental Convention (2003) the countries have to be further obligated and cooperative.

Geographic Information System (GIS) is a supportive decision making system, which is dominantly used in optimization of different activities and processes, as a powerful tool has high ability in environmental management. Creating a network or metadata GIS relating to Caspian Sea with special user names, passwords and also predetermined accessories would be a great help for the system generalization among the basin countries. The system name is suggested to be Caspian Sea Geographic Information System "CGIS". The institutions require extensive political and cultural concealments; nevertheless no one denies the necessity and swift project accomplishment. The current paper describes an action plan which concludes to ultimate approval process and its possible side effects.

SESSION VI.

FORECASTS OF THE CASPIAN SEA LEVEL AND ENVIRONMENTAL CHANGES

DANGEROUS WIND EFFECTED PHENOMENA IN THE KAZAKHSTAN'S PART OF THE CASPIAN SEA AND METHOD OF THEIR FORECASTING

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Keywords: Water level, short-term fluctuations, forecast, the Caspian Sea, Kazakhstan

INTRODUCTION

Short-term fluctuations of water level in the north-east part of the Caspian Sea depend on coastline contour, wind regime and background sea level. During especially dangerous periods of wind setup phenomena, the sea level can rise up to 3.0 m at the eastern most gently sloping seaside over a short period (a few hours), therefore the low territories are flooded up to 30 km. The coast line is not stable and it migrates permanently. Under average wind conditions the range of this migration is 3-5 km. Positive setups are very dangerous in shallow water areas with the low coast, where they cause flooding (Fig.1).

Fig. 1. Flooding in the Caspian Sea northeast coast as a result of the dangerous May, 2003 storm surge (The photo was made by P.V. Veselova)

The large water area and small water mass make the hydrological regime of this part of the sea vulnerable to external factors, including pollution. The practical side of these problems is very important due to the fact that coast flooding often has disastrous effects because of surges. Study of the surges transformation and wave setup dynamics are of both theoretical and applied interest.

STORM SURGES STATISTICS

Positive and negative setup statistics in the north-east Caspian Sea (according to observational sea data at the Peshnoy Station) shows 3-5 positive and 5-6 negative setups per month on average of different intensity. Much of the recurrence of negative setups is caused by south-east strong storm winds dominating in this area of the sea. The maximum frequency and height of surges in this area is noted to be in spring and autumn. The water level rises up to 1.0 m under 10-15 m/s wind speed and in the period from 10-12 hours to 1-2 days.

The range of sea level fluctuations during storm surge is shown in figure 2. The surge height runs 1.0-1.5 m and more under strong winds of 15-25 m/s velocity. Negative setups are also very dangerous for the coastline, when the drop in the water level in the Northern Caspian may be of 2.5 m. The amplitude of the storm surges fluctuations is 3 m.

It results in problems in water intakes, shallowing of harbors and navigation canals, reducing spawning and fattening areas of valuable fish, especially sturgeon, and also in changing landscape structure and desertification of coastal areas. Conditions for navigation become worse, and vessels are often not given full loads in the offshore part of the sea.

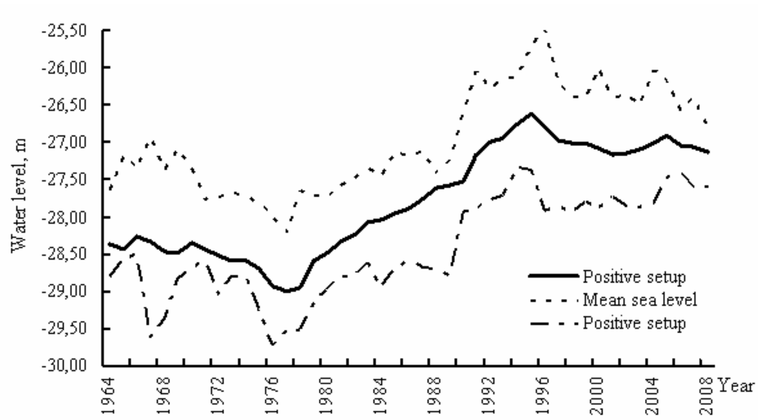

Fig. 2. The Caspian Sea water level fluctuations during the storm surge[3].

MATERIALS AND METHODS

In the last half of the 20th century the marine meteorological service extended considerably to satisfy demands of oil and gas production in the sea deposits, coastal construction, and operations on towage, decontamination and other kinds of sea activity, which are sensitive to the weather. While planning navigation, companies use wind and sea forecasts based on modern models of weather prediction and sea condition issued by the national meteorological service.

A method of hydrodynamic modeling, based on MIKE 21, a hydrodynamical module, designed at the Danish Hydraulic Institute, was selected because of the lack of observational data for researching dynamic processes in the region.

It models changes in water level and flows in response to the phenomena in reservoirs, river deltas and coastal zones. Water levels and flows are depicted on a rectangular coordinate scale covering a suitable domain, if bathymetric data, coefficients of bottom roughness; wind fields, hydrographic boundary conditions, etc. are available. The hydrodynamic module of the model solves a system of vertically integrated continuity equations and preserves momentum in the two horizontal dimensions.

This model has been used on daily basis to produce 5 day forecasts of storm induced surges in the Caspian Sea. The model is forced with meteorological forecast data of wind and air pressure.

The following effects are included in the equations: convective and cross momentum; wind shear stress at the surface; barometric pressure gradients; Coriolis force; momentum dispersion ('eddy'); sources and sinks (both mass and impulse); evaporation. To solve this system of equations, a finite difference scheme is used with the second order of accuracy. This takes into account the influence of perturbations in a layer of water on the dynamics of underlying layer, where they are changed quickly under the influence of atmospheric processes.

Bathymetry is one of the main parameters of the model. In this connection one had to develop numerical bathymetric models throughout the entire Caspian Sea (grid step 10x10 km) and its northern part (grid step 2x2 km). This was done in two stages. The first step was analyzing topographic and marine maps. The second step was to complete the maps with air photos and soundings made by different expeditions. To connect separate topographic maps, a horizontal level was read from the single sea level mark (minus 28 m). Because of flooding and dewatering in coastal zones, all areas up to the mark of minus 22.00 m were included in the model, an established maximum height for extreme storms. This also accounts for a possible rise during the next 20 years. The bathymetry models were a basis for model adaptation and for further hydrodynamic modeling of water level.

[3] **Note:** Sea levels are resulted in marks of the Baltic System. The uniform zero with a mark of minus 28 m is used as zero of heights at the Caspian Sea. The zero point of this system coincides with zero post in Kronstadt town (Kotlin Island in the Finland bay of the Baltic Sea).

Before selecting the calibration and run periods, analysis was carried out for about 400 wind setups observed at the Kazakhstan coast for 1940-2005. It showed that the greatest wind setup frequency was in April and November, the wind setups with an extreme wave height are observed in May – October. Two large unusual wind setups were chosen as model validation cases. They differed in form of their hydrographs (one-peak and multi-peak) and, therefore, in intensity of level rise and duration. These were the catastrophic surges of May 1-8, 1990 and September 4-15, 1996.

Surface weather charts for all simulation and verification periods at 6-hour intervals were used for estimating wind characteristics. The charts were integrated in series which showed tendencies in developing circulation processes in the atmosphere during individual synoptic events of 2-5 days.

Measured and modeled sea levels compared well, indicating that the model was performing satisfactorily. Overall, the model-measured differences did not exceed 15 percent for amplitudes of 1.3-2.5 meters.

RESULTS

One can use the model as a component of the technological process for the operational forecasting system of storm surges with 120 hours lead time. . The system allows meteorological information to be received through channels of communication from the European Centre for Medium-Range Weather Forecasts (ECMWF), and hydrological information from Kazakhstan stations on the Caspian Sea, to process it and make forecasts in a short time frame, providing advance warning of the probable consequences from storm surges.

Water level forecasts are made at six points at the Northern Caspian coast and four points at the Middle Caspian. They are selected to take into account morphometric conditions and synoptic processes specifically developing in the region and the availability of daily hydrometeorological data. The reference sea level is determined from the observational data coming from observing network through the communication channels. If the calculated sea level reaches close to the critical mark for dangerous positive or negative setup, a sea level forecast and storm warning of the positive and negative setup are issued. The form of the forecast includes the following: a text summary, a map of hourly water level variation, and information on possible consequences (flood, dam damage, navigation problems).

To improve the calculation of water level by applying the surge model, the annual and seasonal fluctuations of water level are taken into account. In that respect the model includes average primary elements of water balance (river inflow and "visible" evaporation) and ice condition information. The largest rivers of the Caspian Basin are the Volga, Ural, Kura, Terek, Samur and Sulak rivers. Their runoff influences Caspian Sea water level fluctuations and therefore were included in the calculations as one of the basic elements of model testing.

About 88 % of the runoff to the Caspian Sea comes from the northern part of its basin, within the limits of which there are the Volga and Ural rivers. Most runoff into the sea is from the Volga, up to 85 %; 15 % be from the other basin rivers. To input river inflow into the model, the average water inflow over the previous ten years was calculated and model coordinates for five so-called sources were determined. Since the Terek and Samur rivers are close to each other their inflows were combined into one source. Of course to get more precise inflow estimation, actual inflow data and its daily and 5-day lead-time forecasts are necessary. However it is impossible to get such data for the Caspian Sea at the time of forecast production.

Therefore, long-term inflows of the main rivers into the Caspian Sea were investigated and determined, provided that their time resolution was no less than a month. It is quite obvious that inputting only river inflow characteristics into the model leads to water level distortion. Therefore inputting into the model calculated values of "visible" evaporation (precipitation with the deduction of evaporation) from the Caspian Sea surface became the next forecast upgrading task. Since the surge model was not intended for modeling elements of the water balance, time series of evaporation were calculated by a water balance model, developed by Wardlaw (2000). A current sea level equal to minus 27 m was used as a background level; this can be modified in the future.

The Caspian Sea is characterized by seasonal ice cover. It is remarkable for the large-scale heterogeneity of ice development due to varied climatic conditions in different parts of the basin. Due to the nature of the developing ice processes for the Kazakhstan sector of the Caspian Sea, it is subdivided into several areas: (1) the water area to the north-east of the Kulaly Island, annually covered by steady shore-fast ice; (2) the water area in the centre of the Northern Caspian Sea, most years covered by floating or unstable motionless ice; (3) coastal areas, bays and gulfs of the east coast of the Middle Caspian Sea, including a shallow Kazakh Bay where local ice is formed or floating ice arrives from the Northern Caspian Sea. Annually the Caspian Sea only freezes in the shallow northern part. The deep areas of the Middle Caspian Sea are always free from ice.

Ice conditions are formed for each year depending on the features of the atmospheric processes above the sea, and the thermal conditions of anomalies during the autumn and winter. The ice period for the Caspian Sea has three natural synoptic seasons: autumn – from October to December; winter – from January to March; and spring – from late March to May. Reference and observation analysis has shown that the Northeast Caspian Sea is an area with 100 % probability of ice formation during a cold period. It is quite obvious that condition of ice cover has to be taken into account when modeling the water level surface. The MIKE 21 model allows this to be included if there are ice cover maps for different periods of ice formation and ice decay. When making these maps one had to analyze all observation data and to determine the specific dates of changing ice cover. For this purpose all available satellite images made in real time, as well as observational data from Kazakhstan stations were used.

Based on analyzing satellite images and observational data, the model maps of ice fields for the Northern Caspian on a scale 10x10 km, and more precise maps at 2×2 km for specific periods, were made by the MIKE 21 facilities. The map input into the model can be corrected on-line during the winter, taking into account the actual information on ice conditions. Consideration of the ice conditions and the primary elements of the water balance when calculating water levels allows improved calculations and good agreement between measured and calculated water levels.

Estimation of precision and efficiency of short and middle range forecasts of the Caspian Sea water level has shown that the accuracy of the automated method of a 3-day forecast is on average 87 %, for the 5-day forecast – 80 %; therefore it is expedient to use the method. Analyzing the model output maps of a level surface obtained each 6 hours permits us to produce information on the fluctuations of extreme water level, and to identify potential flooding zones for the North-East part of the Caspian Sea. Thus, in conditions of limited information, the use of the mathematical modeling methods permit us, without major capital investments, to carry out numeral experiments and to use model results for solving practical tasks connected with the actual marine basin.

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CASPIAN SEA LEVEL PREDICTION BY MEANS OF ARTIFICIAL NEURAL NETWORK AND EMPIRICAL MODE DECOMPOSITION

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Keywords: Caspian Sea level, Empirical Mode Decomposition, Nonlinear prediction

INTRODUCTION

The Caspian Sea is the largest intercontinental reservoir without water flow, which demonstrates the unique global evolution on an extent of a huge interval of time. In geological scale the history of the sea is represented by the repeated change of transgressive and regressive phases. That is noticed by illegible traces of paleodata, by scanty historical information and also by the monitoring on short instrumental period. In holocene, for example, the fluctuations of sea level were caused by climate changes. It is not excepted, that the sea level was brought about not only by water balance but also by tectonic changes of the bed of sea for another time intervals. Up-to-date raising of the Caspian sea level is already in its 18 years. To the beginning of 1996 year the level had reached point of -26,6 meters and area of the sea had increased on 40 000 square kilometers. This situation complicated by the wind has produced lot of problems.

Economics of regions near Caspian Sea proved to be dependent on nearest episode of the dynamic sea scenario. On the first sight problem of modeling the dynamic of such reservoir without flow is not so difficult. But simple schemes of probabilistic prediction based on balance arithmetic of the flow and evaporation was not successful: the correlation connections of balance components are very simplified and the evaporation is not described by correct method.

EMBEDOLOGY AND NONLINEAR PREDICTION

The alternative approach for modeling and prediction of dynamic regimes of sea level can be based on the chaotic dynamics (Makarenko, et al., 2004). According to the general assumptions about properties of unknown dynamic model of sea level we can reconstruct the diffeomorphic copy of its attractor in n-dimension space. This technique called embedology is wide known (Sauer et al., 1991). We used it to create the nonlinear scheme of sea level prediction. Embedology methods assume the observed variable is typical and contains all the character scales of dynamics. However Caspian sea level data have being measured only since 1830 year and they don't contain an information about global variations of the sea level. Thus, one can hope only on short-term prediction (no more than two or three years). In fact, prediction horizon is determined by maximum positive value of Lyapunov exponent (Schaw R., 1981) according to $T \; » \; \frac{\log_2 N}{k l^{+}_{\max}}$, where N is time series length, k=[1,3]. Applying embedding dimension with m=3, lag is $\tau = 2$, and nearest neighbors is 20 we obtained Lyapunov exponents: l^{+}_{1} =0.302797, l^{-}_{2} = -0.14458, l^{-}_{3} = -0.838176 for instrumental time series. Kaplan-Yorke dimension is 2.18876, that is close to embedding dimension. In our case lengh is N = 1955 and prediction horizon is T≈12-36 months.

The reconstruction of the copy of the attractor into Euclidian space R^m gives possibility to obtain the follow predictor (Makarenko, 2003):

$$y\left(\left(k+l\right)\Delta t\right) = F\left(\mathbf{y}\left(k\right), \mathbf{y}\left(k-\tau\right), \mathbf{y}\left(k-2\tau\right), ..., \mathbf{y}\left(k-m\tau\right)\right).$$

Unknown function F-predictor is nonlinear and continuous function of m vectors of the reconstruction. Their best approximation is found by means of Artificial Neural Network (ANN) (Poggio, Girosi, 1989). ANN training is carried out using train set constructed on available values of CSL data. Whether a lag is $\tau \neq 1$, one can obtain τ predicted points forward at once for the interval, which amounts to Takens' vector delay. The lower estimation of embedding dimension m > 8 was obtained with the help of False Nearest

Neighbors method. We used m=27 и $t = 37$ to construct vectors y. The prediction horizon is limited by the time series length and rate of divergence of close reconstructed trajectories. Particularly, the prediction horizon of instrumental monthly CSL data is estimated to be 12-36 months, as mentioned above.

EMPIRICAL MODE DECOMPOSITION (EMD) FOR CSL

The main difficulty for construction global nonlinear prediction is small proportion of determinism in month instrumental time series. To avoid this difficulty we apply well known Empirical Mode (EMD) decomposition (Huang et al., 1998) and approximate time series by sum of smooth empirical modes. According to this method it is possible to use coarse-grained approximation of signal, excluding high-frequency details, without breaking global structure of the signal (Figure.1).

Signal = low oscillation+ high oscillation

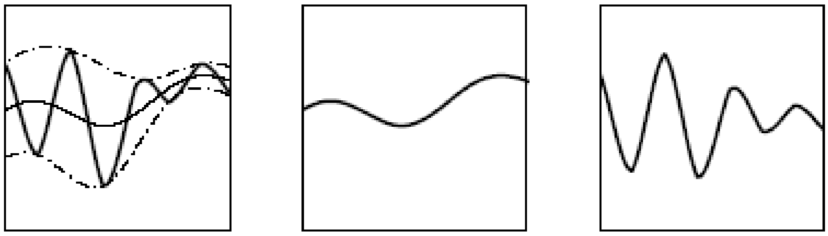

Fig. 1. Decomposition of the signal by means of empirical modes

Nowadays method of decomposition of a signal by means of empirical modes (Huang et al, 1998; Flandrin et al, 2003), that represents the signal as a set of functions corresponding to various oscillations in observed signal. These ones are Intrinsic Mode Function (IMF), that are calculated directly from the data and at the same time are empirical. A basic operation in EMD is the estimation of upper and lower “envelopes” as interpolated curves between extremums. The nature of the chosen interpolation plays an important role, and our experiments tend to confirm (in agreement with what is recommended in (Huang et al., 1998) that cubic splines are to be preferred. Other types of interpolation (linear or polynomial) tend to increase the required number of sifting iterations and to “over-decompose” signals by spreading out their components over adjacent modes.

Given a signal $x(t)$, the effective algorithm of EMD can be summarized as follows (Flandrin , et al, 2003) :

1. identify all extremes $e_{\min}, e_{\max}$ of signal $x(t)$
2. interpolate between minima maxima, ending up with some envelope $e_{\min}(t),\ e_{\max}(t)$
3. compute the mean $m(t) = (e_{\min} + e_{\max})/2$
4. extract the detail $d(t) = x(t) - m(t)$
5. iterate on the residual $m(t)$.

In practice, the above procedure has to be refined by a *sifting* process which amounts to first iterating steps 1 to 4 upon the detail signal $d(t)$, until this latter can be considered as zero-mean according to some stopping criterion. Once this is achieved, the detail is referred to as an *Intrinsic Mode Function* (IMF), the corresponding residual is computed and step 5 applies. By construction, the number of extremes is decreased when going from one residual to the next, and the whole decomposition is guaranteed to be completed with a finite number of modes. For calculation of empirical components software batch http://perso.ens-lyon.fr/patrick.flandrin/emd.html was applied.

NUMERICAL RESULTS

During the experiment there were used monthly data from January 1837 to December of 2002. From 8 constructed empirical modes there were taken sum of following modes 2, 4, 5, 6, 7, 8 for which correlation coefficient with original data was 99,8%. Prediction interval is 37 months: XII.1999 – XII 2003. For selected lag interval is predicted at full length of 37 months.

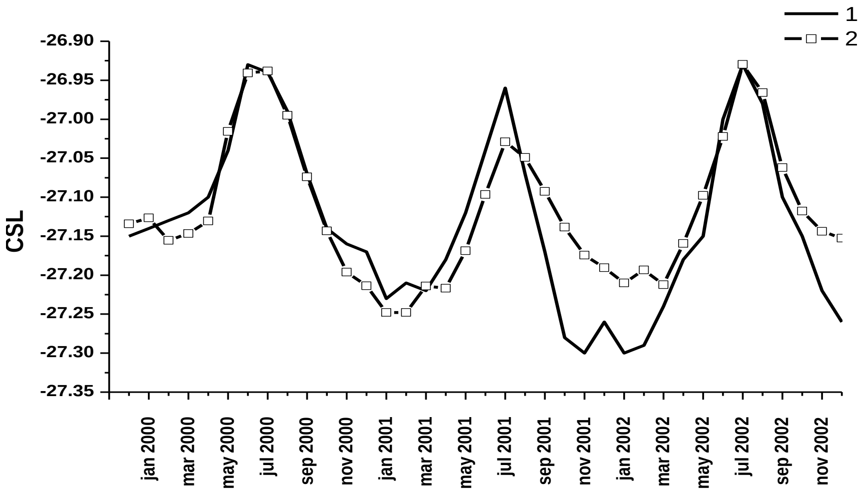

Fig. 2. CSL real month data (1) and prediction (2)

All predictions of the Caspian Sea level time series were carried out by means of Artificial Neural Network, namely *Statistica Neural Network v4.0E*. Figure 2 demonstrates real CSL month data (1) and prediction (2). Figure 3 shows CSL real monthly data, prediction made with the help of EMD and mean values of three predictions. Deviation of predicted values from real data not greater than 1%.

CONCLUSION

Our experiments have shown principal possibility to create prediction of Caspian Sea level on the intervals 1-3 years using appropriate smooth approximation Caspian Sea level time series. It is necessary to point out that this conclusion is correct for epigones, as selection of the most probable variant from asset of predictions stays unsolved problem.

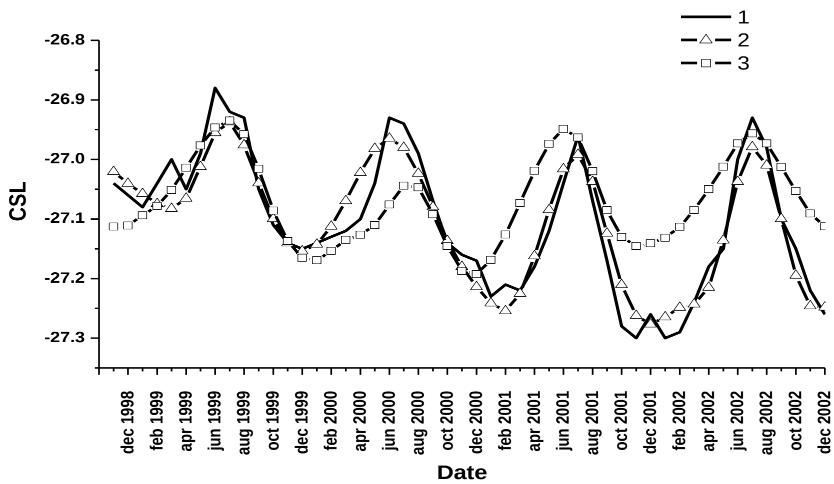

Fig. 3. Comparison real CSL monthly data (1), prediction based on EMD decomposition (2) and mean value of three predictions (3)

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REGULARITIES OF CLIMATIC CHANGES IN THE CASPIAN REGION AND THEIR FORECAST IN REGARD OF THE PROBLEM OF GLOBAL WARMING

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Keywords: Caspian Sea, climatic changes, Holocene, climatic optimum, global warming, forecast

INTRODUCTION

Now all are in the expectation of catastrophic consequences of global warming of a climate of the Earth. Thus it is considered to be the main originator of this warming the anthropogenic factor. But the climate has not fallen asleep. “A long-term condition of atmosphere”, and the system, which in itself is in process of development and changes. Without having revealed law of changes, it is impossible to define a share of the anthropogenic factor in this process and to make more or less exact forecast of climate change for the nearest and more the long-term future. The forecast for the next decades is nowadays most actual this and next century. For this purpose it is necessary to reveal laws of climate change in Holocene (the last 15-10 thousand years), historical time (the last some thousand years) and the period of tool supervision (the last 100 with superfluous years).

HOLOCENE

The problem of a climatic optimum Holocene is one of debatable problems. Under the scheme of a partition Holocene by Blitt-Sernandera 100 years ago this optimum, i.e. the warmest and damp period Holocene, is necessary for the Atlantic period (8-4.5 thousand years ago). This representation concerning Northern Eurasia and North America dominates till now. Vegetation testifies as if in favor of this. Judging by its structure, Boreal (10-8 thousand years ago) is colder than Atlantic. For the Atlantic period in a wood zone it is necessary a maximum of thick-leaved breeds, and out of a maximum wood in general.

The analysis of a considerable quantity of palinologic spectra carried out by us in Holocene deposit having dating of absolute age, has shown the following:

First, “the cold” on structure character of vegetation boreal in connecting with that at the beginning at warming the vegetation from flora was formed by the previous glacial epoch as the present flora was not in time yet migrate here from the south. Itself: before steppe vegetation [Isaeva-Petrova, 1985], hazel communities [Zelikson, 1977] and other types, nowadays weren’t.

Secondly, maximum thick-leaved breeds, actually, in different regions have for the various periods. Their Atlantic maximum is only frequent and not the most numerous case.

Thirdly, the maximum of the wood specifies are demonstrate on displacement of wood border, that on the north “It is defined not only both not so much mid-annual temperatures and quantity of an atmospheric precipitation, how many duration of the vegetative period, summer temperatures and depth of seasonal thawing frozen soil” [Danilov, Polyakova, 1989].

Fourthly, in a subtropical zone in the Atlantic period are fixed not warm, and, on the contrary cool enough conditions [Aleshinskaya et al., 1985; Selivanov, 1994; Trubikhin, 1989].

Fifthly, by this time there is a considerable quantity of data according to which the thermal Holocene maximum is necessary on period of Boreal (10-8 thousand years ago) when are fixed also maximum in Holocene of concentration CO_2 in atmosphere and values of radiation.

Thus, the climate of the Atlantic period was not the optimal, is more exact the warmest, in Holocene. The available data was spoken about otherwise. Most warm in Holocene was the period of Boreal – 10-8 thousand years ago. And this means, that since then there is a process of a cold snap which should lead to the beginning of glacial age. But this perspective for us is far. Previous Riss-Wűrm (Mikulino Interglacial) lasted about 50 thousand years – 125-75 thousand years ago [Zelikson, 1977]. And ours “interglacial” lasts no more than 15-17 thousand years.

THE HISTORICAL PERIOD

We have researches of S.S. Veliyev and J. Dj. Gadiyev about the historical period. They have counted up quantity cold (with frosts and a snow in the winter and colds in other season) and damp (with storm rains, thunder-storms, flooding and flow) years in each century of last of 1.5 thousand years. Their percentage parity has been established and 6 periods are allocated [Veliyev, Gadiyev, 1999].

VII-IX centuries. Prevalence of cold and damp years, and the greatest share cold years is necessary for VIII century. For this period concern one of maximal of levels Caspian Sea and approach of glaciers in the Alps and Tan-Shang.

X-XII centuries. The Maximum share of dry years and their maximum is necessary for XI century. To XI-XII centuries concern one of minimal of levels of Caspian Sea. This period is called "a small climatic optimum".

XIII century. The considerable quantities are cold and damp years. By this time concern maximum for the considered period Caspian Sea level and approach of glaciers in the Central Caucasus and in the Alps.

XIV and XV centuries. The considerable quantity of cold and damp years suffices at small quantity of the dry.

XVI – mid XIX centuries. The considerable quantity of cold and damp years at small shares of dry years. This period is named a small glacial epoch. For Caspian Sea it is characterized by its last as much as possible high level of the end XVIII – the beginnings of XIX centuries.

THE PERIOD OF INSTRUMENTAL SUPERVISION

Despite the big efforts of scientists at drawing up of methods of the forecast of a climate, this question while remains opened. Over the last 50 years the decision of this problem has demanded many efforts. In many countries have been developed models of the general circulation of atmosphere for the climate forecast. In result it has appeared that these models are not applicable for drawing up of such forecasts for following reasons: 1) at integration of the equations after one year processes repeat; 2) decisions system of the equations of hydro thermodynamics are limited; 3) Its integration for longer term (more than 50 years) leads to nonlinear instability.

Therefore we consider that at drawing up of methods of forecasting of a climate to need to consider influence of stationary forces i.e. to reveal solar cycles. Still need to develop methods for the account of years of the Galaxy as the Solar system at rotation about the Galaxy centre for 300 million years can lead to climate changes.

Early researches on periodicity revealing in climate changes was carried out by E.A.Brikner. He collected an extensive material of instrumental supervision during 1700 on 1880 years and made their statistical processing. Under the data of change of temperatures received by it occurs almost simultaneously on all Globes, and the amplitude of their fluctuations averages nearby 0.8º. E.A.Brikner has drawn a conclusion about presence 35 flight cycles in a mode of temperatures, atmospheric pressure and deposits.

To these researches the big push was given by opening of conformity in change of solar activity. They have shown that solar activity is subject to the cyclic fluctuations having average duration about 11 years. In from-efficient cases duration of cycles fluctuates from 7.3 till 14.6 years. Eygeyson [1954] has found out 5-6 and 80-90 summer cycles of solar activity.

We have spent data processing of meteorological supervision for periodicity revealing in climate changes. But the primary meteorological data because of the big variability is a little comprehensible to research. Therefore to reveal the latent periodicity in the environment of meteorological numbers apply different methods. We have applied a method revealing cycles by means of the sliding averages, which has no analogues.

Advantage of the given method consists in its simplicity. It is known that any number of supervision it is possible to present in a kind harmonious functions. However, the periods of observable numbers frequently on length not always coincide with harmonics. The decisions of questions of the numbers connected with periodicity are considered in work of Shuster.

The object of our research was the data of meteorological stations of three cities of Azerbaijan: Baku, Cuba and Ganja. The analysis of integrated curve fluctuations of temperatures on cities our republic also has shown, what during the period for 1881-1940 of temperature fall of temperatures approximately on 0,10C is noted, and for 1940 – 1970 the temperature became on 0.20C above norm. After 1971 till 1990 it is noted falls approximately on 0,10C, then till 2007 it again became above norm approximately on 0,10C.

Thus, by means of the spent analysis have been revealed 8, 24, 40 – year's rhythms. After their revealing we having approximated functions also have constructed schedules. On fig. 6 we are shown for Baku the forecast of temperature till 2100 is presented. Apparently from dividing of the calculated temperatures, they will well be coordinated with the actual. The same it is possible to tell and for stations of Cuba and Ganja.

Revealed 8, 24 and 40-year-old rhythms allow to give the temperature forecast of atmosphere on the next decades. The received periodical press well justify for them. From fig. 5 it is visible that, since 1881-1905 in Cuba actual and settlement schedules on a phase was opposite. It is possible to explain it absence at that time meteorologist supervision. And in 1881-1920 for other cities has occurred a fall of temperatures, both on actual, and on settlement values. Till 1960 actual and settlement schedules on a phase coincide, temperatures were rising. After 1960 of a deviation of temperature goes down to 0.10C, further in raising they it is reached a maximum (0.50C) in 2030г. After there will come the tendency to a falling with weak amplitude. The amplitude difference thus makes only 0.50C. From 1960 till 1980 marked a falling, and with 1980 to 2007 increasing with weak amplitude of temperatures.

In a whole, all three schedules can be used as the forecast of temperature of atmosphere. According to it, with 2007 to 2025 sharp difference is expected lowering by temperature to -0.0C from lower norm, with 2025 to 2040г. – the same increase on + 0.30C, with 2040 to 2090 again falling on -0.20C from more low norm, and after 2090 the weak increasing on +0.20C from above norm.

CONCLUSION

Summarizing all stated, it is possible to firmly tell that about one-sided climate change is more exact than temperatures, in the future has not to speak. If to start with large cycles in thousand and ten thousand years we have taken place for a long time already peak of warming and we are at a cold snap stage, moving to a new glacial age.

In the relation to smaller cycles – of 500 years – there is a return process – that global warming about which now often speak. And the reason of this process is natural factors. Activity of the humanity, for certain, somehow strengthens the given warming, but, in our opinion, not essentially, at least, for the contemporary time.

That cold snap which expects us the next 20 years, judging by rhythms of the period of instrumental supervision testifies to it. We feel it already now, and now we should prepare not for warming, and to, though also small, but a cold snap.

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HISTORICAL CHANGES OF THE CASPIAN SEA LEVEL AND ITS FUTURE POSITION

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Keywords: Caspian Sea, sea level changes, climatic changes, global warming, forecast

The considerable factors influence on a level regimen of the Caspian Sea. Among them: planetary development of the Earth and its position in a space, geological changes of the geo-surface and tectonics, receipt of the radiation to the Earth and solar activity, fluctuations of the climate and anthropogenous influence on the natural process.

The established changes of the sea level in the geological past for the long time-intervals (millions and hundreds thousand years) were defined mainly by development of geological processes and influence of tectonics and, as consequence of it, earth movements and deformation of the Caspian depression.

The geological history of the Caspian Sea evolution was characterized by certain cycles with the periods from tens millions and hundreds thousands to several thousands, tens and several years in recent time. It is established that changes of the planetary geodynamic and geophysical processes on the Earth are defined mainly by the gravitational influence of helio-space factors. This process conditions the development of the Earth cycles, synchronism of natural processes, their planetary inversion and asymmetry, the unity of the mechanism of excitation and variations of activity for all natural processes and their power.

The researches show that volcanic activity of the Earth will be accumulate, causing warming development in which result there is an intensification of global changes of processes of water exchange.

Calculations on global climatic models of changes of an atmospheric precipitation in the Volga river basin have shown that to 2100 year they will increase more than 15 % and will cause the increasing of the Volga river drain to almost 60 %. The analysis of historical changes of the Caspian Sea level and water-balance calculation have shown, that the level of the Caspian Sea can raise more than 10 m with climate warming on 3°.

ADDITION

ECOSYSTEM PROCESSES, BIOPRODUCTIVITY AND BIODIVERSITY OF THE CASPIAN SEA

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Keywords: Caspian Sea, bioproductivity, biodiversity

The formation of biological productivity of the Caspian Sea, the water body relatively small in area and, above all, isolated from the World Ocean, interannual and long-term changes in its productivity are based on climate generating processes (atmospheric motion, heat and moisture circulation) that cover the sea area and its catchment basin.

This is the main difference of the Caspian Sea from open seas where against the background of climatic zoning such factors as quasi-stationary dynamics of waters and circulation processes affecting the formation of biological productivity are of particular importance.

In addition to external factors the so-called internal factors are also involved in the formation of biological productivity. They present a set of physical-geographical (morphometry, meridional or latitudinal location of the water body, climatic zoning, orography of shores, water depth etc.), physical-chemical (general circulation and dynamics of water, saline composition and chemical features of the water body etc.), biological (structure of biocenosis, trophic and species composition, their long-term changes etc.) characteristics of the water body and man impact. In recent years there has been revealed a probable negative impact of subsurface decontamination in the Middle Caspian depression – emission of water-gas fluids in the areas of seismically active fractures (Katunin, Golubov, 2001a; Golubov, Katunin, 2001b).

G.K. Izhevski (1961) established that the formation of biological productivity in northern European seas (the Greenland, Norwegian and Barents Seas) and seas of the continental zone (the Azov, Black and Caspian Seas) was determined by the influence of the Atlantic Ocean on atmospheric motion over Europe highly developed during the cold season. At that, he indicated the antiphase development of atmospheric motion over the water area of northern European seas and the continent of Europe. This mechanism is the most evident when analyzing long climatic processes.

While external factors largely affect the formation of general biological productivity of the water body, internal factors are of primary importance for the spatial distribution of zones of increased productivity.

This may fully refer to the ecosystem of the Caspian Sea.

Among "internal factors" affecting every water body there should be considered the following:

- geographical location of the sea, its radiation regime and heat balance affecting water temperature in different areas;
- climatic characteristics (atmospheric motion, wind regime, atmosphere pressure, relative moisture and air temperature, precipitation);
- orographic characteristics of the land adjoining the sea;
- sea bed topography (islands, underwater eminence);
- spatial distribution of continental runoff entering the water body;
- ice conditions;
- major macrocirculation processes in the water body and general water dynamics.

All the above mentioned characteristics are very important for the development of hydrological and hydrochemical regime of the water body, the Caspian Sea in particular, as it has a long meridian extent (1200 km) that includes several climatic zones.

Subsequent investigations confirmed G.K. Izhevski's conclusions concerning interrelations between atmospheric processes in the Atlantic section of Europe and climatic conditions in the basin of the Caspian Sea as well as antiphase development of circulation in oceanic and continental zones.

Yu.Yu. Marti and co-authors (1974) considered two trophic systems with different flows of energy in the Caspian Sea. One of the ecosystems, the northern Caspian, develops under the influence of biogenic substances coming together with the Volga and Ural flows. The second, the middle and southern Caspian, uses biogenic substances accumulating in hollows of the middle and southern parts of the sea to maintain autotrophic production processes. These biogenic substances are drawn into the upper euphotic layer due to bathymetric movements of water in the zones of dynamic inclusions or convective mixing.

Based on the above it may be concluded that biological productivity of the northern Caspian ecosystem is formed under the influence of global processes of atmospheric motion in the Atlantic section. The state of stocks of the main commercially important fish species of the generative-freshwater complex depends on breeding conditions in the delta of the Volga River and feeding conditions in the Northern Caspian. They are the most favorable in the years with water content that is enough to supply 20-50% of the Volga River flow. The northern Caspian ecosystem also differs from the middle-southern one in having river and marine subsystems.

Biological productivity of the middle-southern Caspian ecosystem develops under the influence of certain parameters of natural-climatic processes, such as winter severity, upwelling development along the eastern coast of the Middle and partly Southern Caspian, evaporation intensity in the shelf zone in the east of the Southern Caspian to maintain water aeration in the near-bottom layer.

Consideration of natural-climatic factors affecting the formation of biological productivity in two ecological systems of the Caspian Sea makes it possible to conclude that favorable conditions for the development of production processes in the northern part of the sea arise during those climatic epochs when meridional circulation affected by increased cyclogenesis intensifies the process of moisture and heat entry into the Volga River basin thus contributing to the rise in sea level.

On the contrary, potentially favorable climatic conditions develop in the middle-southern Caspian ecosystem in the years when zonal circulation intensifies and cyclones move in more northern trajectories while anticyclonic circulation predominates over European territory of Russia (Rodionov, 1989). Its increased development results in a deficiency of precipitation in the basin of the Volga River, decreased level of heat entering the region, more severe winters, increased convective mixing and sea level drop.

The general conclusion concerning mechanisms of the formation of biological productivity in different parts of the sea is fundamental in analyzing the long-term dynamics of production processes in the sea and changes in stocks of hydrobionts in long-term forecasting.

The development of flora and fauna in the Caspian Sea is closely connected with geological history of the water body. Connection between the Caspian Sea and the Sea of Azov, Black and Mediterranean Seas through the Kumo-Manychskaya Depression, Straits of Bosporus and Dardanelles did not exist any longer which led to multiple changes in the saline regime of the sea. Its population included several groups of different origin: autochthonous species, Mediterranean invaders that penetrated into the post-glacial epoch through the steady connection with the Mediterranean Sea, present freshwater and brackish water organisms and arctic species. Though the Caspian Sea was not affected by freezing during the glacial period for some time it was connected with the Arctic Ocean through lake and river systems of the Great Russian Plain. Until now a relict complex of species has remained in the Caspian Sea: hydroid polyps, Polychaeta, Cladocera, Mysidae, Cumacea, Amphypoda, Copepoda, bivalve mollusks.

The sea is inhabited by more than 500 species and forms of algae, some 120 species of brackish water, marine and up to 300 species of freshwater plankton, about 400 species of zoobenthos. But not more than 100 species of plankton and benthos occur every year showing the highest frequency of occurrence.

Researchers began to study plankton of the Caspian Sea both of vegetable and animal origin only in the early 19^{th} century. Regular studies of benthos in the northern part of the sea were started in 1935 while those in deep water areas of the Middle and Southern Caspian in 1956.

During all periods of investigation phytoplankton was dominated (in the number of species) by diatoms (Bacillariophyta). Qualitative characteristics of phytoplankton are subject to significant seasonal and annual variations when one species is replaced by another. The species diversity of algae decreases from the north to the south. The qualitative composition increases and rapid development is recorded in all groups of phytoplankton during the period of sea level rise and high water temperature in summer.

In the early 1930s quantitative characteristics of development of diatoms and pyrophytes were identical. Small-celled phytoplankton was dominant. One of the pyrophyte species *Exuviaella cordata* prevailed in biomass (more than 40%). The amount of small-celled phytoplankton decreased when the Caspian Sea was invaded by the diatom *Rhizosolenia calvar-avis*. Until the early 2000s the species *Rhizosolenia calvar-avis* affected the total abundance and biomass of phytoplankton.

Under present conditions of sea transgression the quantitative characteristics of *Rhizosolenia calvar-avis* development decreased by an order of magnitude in comparison with the 1960s and by several orders of magnitude in comparison with 1977 when the sea level was the lowest. The phytoplankton in the northern part of the sea consists of small-celled blue-green algae and diatoms while it is formed by pyrophytes in the middle and southern parts. Biological pollution of the sea by alien species increased considerably. In addition to *Rhizosolenia calvar-avis* six species of diatoms (*Nitzschia seriata, Certaulina bergonii, Chaetoceros pendulus, Ch. peruvianis, Tropidoneis lipidoptera, Ditulum brightwelii*), one species of blue-green algae (*Oscillatoria subtilissima*) and two species of pyrophytes (*Pyrocystis lunula, Peridinium conicum*) develop actively now. These invaders spread throughout the sea, compete with native species and affect quantitative characteristics of phytoplankton.

Zooplankton in the northern part of the sea is qualitatively and quantitatively richer than that in deep water areas. Biodiversity is based on autochthonous species, i.e. most species are of Caspian origin. Summer zooplankton comprises a lot of species that are mainly freshwater and brackish water by origin. The highest productivity of zooplankton in the Northern Caspian was recorded during the flood period in the Volga River. Minimal quantities were recorded when the sea level was extremely low.

In spite of a season and hydrological conditions zooplankton in the Middle and Southern Caspian with rather a stable saline regime was dominated by Copepoda and Mysidae. Abundant commercial stocks of kilka have always been attributed to the high biomass of Copepoda, a Caspian endemic, two species of Eurytemora and an arctic species of Limnocalanus.

All changes in the Northern Caspian productivity are connected with some complicated climatic factors among which the volume of freshwater flow and sea level are the most important. These changes in the Middle and Southern Caspian productivity are connected with the rate of biogenic runoff into the euphotic zone as a result of vertical circulation of water.

Spontaneous invasion of the Caspian Sea by the ctenophore *Mnemiopsis leidyi* reduced the influence of climatic factors and made biological pollution of primary importance. Ctenophore almost destroyed the unique fauna of zooplankton. At present another spontaneous invader of the 1980s, the copepod *Acartia tonsa,* dominates the Caspian Sea. Its nutritive value yields considerably to that of organisms of autochthonous and arctic complexes.

Zoobenthos has always been the basis of development of fish productivity in the Caspian Sea. High qualitative diversity of organisms of soft benthos (higher crustaceans, annelid worms) and mollusks contributed to the development of food resources for all benthophages: carps, gobies and sturgeons.

Biological productivity of the Caspian Sea is greatly affected by the rivers flowing into it, the Volga River in particular. The distribution and quantitative development of benthic invertebrates are mainly determined by water salinity that depends on the volume of river runoff, duration of flood period and the speed of floodwater rise.

The mass development of bethos in the Middle and Southern Caspian is recorded at depths 20-50 m where the runoff of the Volga River, rivers of the Caucasian and Iranian coasts also have positive influence on benthic fauna productivity. The stock of benthic invertebrates outside a 50-m contour, their biodiversity decrease significantly. At that salt-loving forms of the Mediterranean complex become more important.

The rapid drop in sea level in the 1970s, reduction of its area, increased salinity of waters in the Northern Caspian and growing isolation of its eastern part resulted in a decline in benthic food invertebrates of weakly brackish and brackish water complex. Though the sea level rises now there has not been recorded complete restoration of food resources so far. One of the causes is the ctenophore *Mnemiopsis leidyi* that feeds actively on plankton larvae of food bivalve mollusks. At present the number of spontaneous invaders considerably exceeds the useful biomass of native and acclimatized species that were naturalized due to deliberate introduction. The species diversity of plankton has also increased. The number of species of phytoplankton in the Northern Caspian at a present sea level of 27.16 m is 215, that of zooplankton is 98 and that of zoobenthos is 75 against 193, 95 and 75 respectively during the period of sea regression (-28.8 m).

Aquatic biological resources of the Caspian Sea basin are an essential part of Russian fisheries. Ichthyofauna of the Caspian Sea is fairly diverse. The sea is inhabited by the world's largest population of sturgeons. A lot of natural-climatic and anthropogenic factors affecting the ecosystem of the sea and contributing to the development of its biological productivity influence many commercially important species.

The specific feature of the Caspian ichthyofauna is a great number of endemics as this water body has been an inland one for a long period of time. Its ichthyofauna is dominated by species and subspecies that belong to marine (44%) and river (34%) fish which live only in the sea or in fresh waters. In contrast to them migratory fish (15%) feed in the sea until they become mature and then migrate into the river to spawn. Semimigratory fish (7%) inhabit desalinated areas of the sea and migrate for spawning to the sections of the river located not far from the river mouth usually within delta limits.

In recent years recruitment of sturgeon populations through hatchery production decreased considerably. Natural spawning success also declined because of an insufficient number of wild spawners entering remaining spawning grounds.

Kilka (anchovy kilka, big-eyed and common kilka) dominate marine fish by ichthyomass.

After the loss of a significant part of the population the commercial stock of anchovy kilka began to increase. In recent years the size of common kilka stock was noted to increase due to widening of its range. Judging from research catches in gangs of nets the stock of marine shads is based on Dolginka shad. The stock of migratory black-backed shad in recent years began to recover. Its catches in 2007 reached 72.7 tons. The proportion of fish of older age increased owing to repeated spawners. This is indicative of sparing fishing regime and a high survival level of spawners after spawning.

The inconnu belongs to the family Coregonidae. It is endemic to the Caspian Sea, a commercially valuable fish species inhabiting the northern, middle and southern parts of the sea. Prior to the construction of hydroelectric stations at the Volga River inconnu spawning grounds were located in the Oka, Sura, Kama Rivers. After Volga River damming the spawning migration of inconnu became shorter. The abundance of its population decreased. Beginning from 1959 the commercial fishery of inconnu was banned. Its population is presently maintained by stocking artificially reared juveniles. Higher rates of its rearing, updated biotechnique, higher survival rate of juveniles in natural water bodies are likely to increase the abundance of this valuable fish species.

Semimgratory and river fish species spawn in water bodies of the delta flooded during the high water period. The spawning of each fish species has its own specific features: different areas and time of spawning, requirements for substrate, water temperature and flow velocity. This allows them to use spawning areas most successfully. Biomass development in the Northern Caspian takes five months. When water temperature drops the whole fish stock aggregates in the shallow coastal area of the Volga River pre-estuarine zone where they spend the winter.

In future the restoration and stable state of semimigratory and river fish stocks will be largely determined by the volume of spring flood flow, its parameters, the rate of artificial reproduction as well as by stable environmental and feeding conditions in the Caspian Sea.

PRESENT CHARACTERIZATION AND BASIC TENDENCIES OF LONG-TERM CHANGES IN THE TOXICOLOGICAL STATE OF THE VOLGA DELTA ECOSYSTEM

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Among present priority problems related to the threat to environment there is an accumulation of dangerously large amounts of toxic chemical compounds in abiotic and biotic components. Hydrocarbons and heavy metals require special attention as they are very toxic and decomposition resistant. They are characterized by bioaccumulation and may be an object of transboundary transport by air and water. They precipitate at a large distance from the source of blowout accumulating in environment. Anthropogenic pressure on the ecosystem of the Volga River delta is directly connected with industrial and economic development of adjoining territories and natural conditions. As a result of river damming and changes in qualitative parameters of the river flow, the hydrological structure of water changes and eutrophication processes in surface water intensified by water pollution increase [1]. In addition, some areas of the delta have different characteristics of environmental components caused by physical and geographical peculiarities, hydrological, morphological and geological factors.

The main task of the study was to perform a toxicological monitoring of the level of main toxic pollutants in the components of aquatic environment in the Volga Rive delta.

Long-term changes in the level of pollutants reveal a broad spectrum of natural and anthropogenic processes which take place not only in the Volga River and its catchment basin, but also far away from its boundaries.

Analysis of long-term (1999-2009) changes in the content of extracted petroleum hydrocarbons (EPH) in waters of the Volga River delta, taking into account values from the delta apex to its marine end, provides relatively homogeneous data. The range of hydrocarbon concentrations in watercourses of the delta reached 8.1 MPC (maximum permissible concentration) with average 3.2 MPC ($\sigma = 68.9$). The highest values were recorded in 2001 and 2005 when the water level in the river was rather high. But after the period of excess of the average long-term value beginning in 2007 a tendency towards a decline was noted.

Due to the study of spatial variability the maximal level of the average annual content of pollutants was revealed in the coastal area of western waterways (up to 9.6 MPC). Most concentrations (up to 84.6%) recorded in the central and eastern zones of the delta varied within a narrow range of 1.3 to 3.2 MPC.

Because of its hydrophobe properties hydrocarbons can be easily sobbed by suspensions and enter into bottom sediments during sedimentation. These bottom sediments may reduce the content of hydrocarbons in water and under certain conditions may be a source of repeated water pollution.

During a long period there has been observed a stable tendency towards a decrease in the average level of hydrocarbons in bottom sediments and water of the Volga delta waterways. Two periods may be noted when considering long-term data: 1999-2005, when the values were close to an average long-term one, and 2006-2009, when the values were lower. The interdependence of these values for bottom sediments and water was quite negligible: $r = 0.23$ at $p<0.05$.

Average annual values of EPH in bottom sediments of all waterways under examination were very close to each other. Hydrocarbon concentration was on average 16.5 μg/g of dry sediment at $\sigma = 11.8$. The distribution of organic compounds, hydrocarbons in particular, in bottom sediments, as is well known, depends on the degree of their dispersion. The proportion of a fine fraction in the composition of sediments in the lower Volga River increased together with EPH concentrations. The zone of the most intensive accumulation of hydrocarbons is Sizy Bugor Village (95.5 μg/g) located in the middle zone of the eastern delta where bottom sediments consist of sludgy sand.

Hydrocarbon concentrations in sediments in the central and eastern parts of the delta increased toward a marine end of the delta where sediments consisted mainly of sludgy sand with vegetable inclusions.

In addition, as during previous periods of investigation (2004-2007), high levels of pollutants were recorded in sediments of the western part of the delta. Increased levels of pollutants were discovered in the area of Privoljye Village, in the upper zone of the delta where sediments consisted mostly of small-grained and course-grained sand with a touch of sludge (1%) which was indicative of a low level of organic matter accumulation.

For lack of approved standards of EPH content in sediments, to interpret the results a conventional background value for the given water body is usually used. It is within the most frequently occurring frequency interval of concentration changes. The interval of 5.0-25.0 μg/g was modal for the Volga River delta and affected the geochemical background of hydrocarbons.

Data on the interannual variability of the content of monoatomic volatile phenols that along with hydrocarbons belong to widely distributed pollutants in the main branches of the Volga River delta indicate rather a stable content of pollutants in water - 2.4 MPC with a range of concentrations 2.0 MPC ($\sigma = 0.56$). Considerable increase in their content in waters of the delta was recorded in 2007 and 2009. During other periods of investigations average annual concentrations remained quite stable and somewhat exceeded fisheries MPC.

The increased content of phenols in delta waterways under study was recorded in the coastal zone of western branches where processes of sedimentation were quite intensive. High concentrations of compounds under examination in the central and eastern areas were recorded in the upper zone of the delta near Tabola Village and at the source of the Buzan River. Other parts of the water area under investigation had low levels of content, which is probably due to natural processes of phenol production in aquatic environment.

When conducting monitoring in the Volga River delta, the most toxic elements characteristic of Volga River waters were selected from a large group of heavy metals (more than 40): Hg, Cd, Pb, Cu, Ni, Zn, Mn and Fe.

Concentrations of metals under investigation varied widely: Zn – 120.0 μg/l (σ = 21.22); Fe – 93.0 μg/l (σ = 14.31); Cu – 13.9 μg/l (σ = 1.88); Mn – 11.0 μg/l (σ = 1.38); Pb – 2.3 μg/l (σ = 0.52); Ni – 2.8 μg/l (σ = 0.58); Cd – 1.44 μg/l (σ = 0.13). As is obvious from the data presented, dissolved forms of Zn, Fe and Cu were the most variable probably because of specific character and degree of anthropogenic pressure on the water body as well as metal ability to form complexes, precipitate and accumulate.

Average annual concentrations of elements under examination increased during various seasons depending largely on the way natural and anthropogenic processes developed in catchment territory. As a result of analysis of long-term data on the content of dissolved heavy metals in major waterways of the Volga River delta, it was revealed that the highest level of zinc that exceeded an average annual value (2.4 MPC) by a factor of 1.2 and 1.4 was recorded in 2006 and 2007 respectively. Manganese content in different years was similar to that of zinc the increased level of which was observed during 2006-2007. The maximal average annual concentration of copper (5.0 MPC) was recorded in 2001 when water level in the river was high. In other years of observations values varied within 3.1-4.1 MPC showing relative stability. The content of cadmium in delta waters increased from minimum during 2001-2002 to maximum in 2006 when water level in the river was low. During the subsequent period of investigations there appeared a tendency towards a decline in cadmium proportion in the elemental composition of waters. The highest level of lead was recorded in 2004 (0.6 MPC) and the lowest was noted in 2001-2002 (0.25 MPC). Beginning in 2005 its concentrations changed negligibly from 2.3 to 2.9 μg/l. At present the content of dissolved heavy metals in waters of the major channels of the Volga River delta is characterized by an increase in Fe, Zn and Ni ions along with a decline in concentrations of other elements in relation to average long-term values. Reduction to background values recorded in maximal concentrations of most heavy metals was indicative of sporadic and short-term negative effects and sufficient assimilating capacity of the basin.

The increased level of water pollution with heavy metals was recorded in the eastern part of the delta where maximal concentrations of most elements, such as Hg, Cd, Zn, Mn and Fe, were discovered. Waters of the central part of the delta showed the highest concentrations of Pb (0.45 MPC) and Ni (0.23 MPC) in comparison with other waterways under exploration.

The spatial distribution of heavy metals was characterized by higher concentrations recorded for several years in the upper section of the delta near Tabola and Privoljye villages. Self-purification processes in these parts of the river were very likely to promote the minimal removal of heavy metals from water. The stable high level of water pollution with Zn ions that exceeded the standard by a factor of 3.3-9.1 was recorded in the upper zone located above Astrakhan (Privoljye Village). Increased levels of Cu (3.4-16.5 MPC), Pb (3.3 μg/l) and Hg (0.074 μg/l) were revealed mainly in waters of the lower zone of the western delta apparently as a result of secondary pollution of water because of roiling bottom sediments in shallow areas and insufficient intensity of sorption processes.

Migration cycles of elements in the ecosystem end in bottom sediments where they accumulate indicating the quality and ecological state of aquatic animals. The content of heavy metals in bottom sediments is largely affected by physical-chemical and biological processes, such as adsorption, desorption, complex formation, accumulation rate and chemical composition of detritus, capacity of cation exchange in the solid phase, availability of lightly exchanged cations in the solid phase, chemical composition of pore waters and higher aquatic plants, plankton and benthos. Organic substances are very important for transformation of elements of bottom sediments as they facilitate their concentration in river sediments.

In the interannual dynamics of accumulation of heavy metals in bottom sediments of the Volga River delta there may be singled out the year 2007 when the content of most elements reached their maximums.

Only mobile forms of Mn and Fe were exceptions as their maximal concentrations were recorded in 2008.

A high level of pollution of bottom sediments with heavy metals was observed mainly in the central and eastern parts of the delta. Their average annual concentrations differed negligibly.

The fact that increased contents of most elements were recorded in the coastal zone may be explained by a decline in dynamic properties of waterways because of sea backwater effect and, as a result, sedimentation of heavy metals. Maximal levels of copper, lead and manganese were recorded in the upper zone of the delta, those of nickel and iron were discovered in the lower one.

When analyzing the results of the assay of heavy metals in water and bottom sediments, a close correlation between Zn and Cd as well as between Mn and Cd was revealed (table 1).

Table 1

Correlation coefficients of heavy metals

No	Natural environment	Zn-Cd	Mn-Cd
1	Water	0.83 at $p<0.05$	0.89 at $p<0.05$
2	Bottom sediments	0.78 at $p<0.05$	0.81 at $p<0.05$

Copper content in bottom sediments correlates positively with most elements and EPH under study due to its light dynamic activity and inclination to the formation of complex compounds with organic components. There was no relationship between concentration levels of heavy metals in sediments and water because of extreme variety of their sources and, as a result, variability of their spreading.

Thus, the reduction of industrial and agricultural production has recently led to some mitigation of man-caused pressure on the ecosystem of the Volga River delta. But the proportion of man-caused and biogenic pollutants in the Volga River flow remains rather large. With river waters the Caspian Sea annually receives from 26 600 (2003) to 55 400 tons (2005) of hydrocarbons, from 250 (2003) to 490 tons (2008) of phenols, from 4000 (2001) to 8700 tons (2003) of zinc, from 700 (2006) to 1100 tons (2003) of copper, from 300 (2001, 2002) to 800 tons (2004) of lead.

Analysis of correlational relations between interannual variability of water flow and removal of toxic pollutants under examination revealed the general tendency of positive dependence for most heavy metals, phenol compounds and hydrocarbons probably due to the general unidirectional effect of natural and anthropogenic factors. Relations change from close to very weak in a row of toxic pollutants: Ni > phenol compounds > Cd > Pb > EPH > Cu > Mn > Zn > ($r = 0.75$-0.33 at $p<0.05$). The interrelation between the runoff of phenol compounds, cadmium, nickel and lead and water content in the river is indicative of their natural genesis. Very weak positive relation between manganese ($r = 0.33$ at $p<0.05$) and zinc ($r = 0.30$ at $p<0.05$) removal and Volga River flow, close relation between the flow of heavy metals and their concentrations ($r = 0.83$ for Mn and $r = 0.86$ for Zn at $p<0.05$) were evidence of a considerable proportion of anthropogenic component in the cumulative runoff of these elements [2].

It should be noted that the main portion of the Volga River flow (about 70%) comes through the inter-channel space of the shallow zone of the delta and delta front where self-purification processes are active due to a biological filter formed by higher aquatic plants, microorganisms, phytoplankton and active transformation and sedimentation of solid runoff [3].

Based on the above-stated data and calculated indices of substance pollution ecological and toxicological conditions were estimated as satisfactory. The distribution of pollutants in the delta waterways under investigation presented scattered pollution that developed owing to geo-chemical natural input of toxic pollutants and general human activity in the catchment basin.

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EFFECT OF THE CASPIAN SEA-LEVEL CHANGE ON COASTAL EVOLUTION

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Keywords: The Caspian Sea, sea level changes, climatic conditions, coastal zone, types of shoreline

INTRODUCTION

The Caspian Sea is a unique body of water. Lying deep inland, thousands of kilometres away from the ocean, the Caspian possesses many marine characteristics. At the same time it is the world's largest lake, accounting for more than 40 per cent of the overall volume of the global lacustrine waters. The length of the Caspian Sea shoreline totals about 7,000 kilometers. Water-level fluctuations in the Caspian Sea largely affect the dynamic processes in the coastal zone and evolutionary patterns of all different types of shoreline.

THE CASPIAN SEA LEVEL CHANGES

The Caspian Sea water level was rather low by the end of the 4th century-it stood at 7 m below MSL [Klige, 1983; Klige, Myagkov, 1992]. In the 5th and 6th centuries the sea level was close to -30-35 m. There is reason to believe that the Caspian stood at its lowest in the 6th century (within the frame of historical reference) Transgressions appear to be a characteristic pattern in the 7th and 8th, as well as in the 10th century. Low levels were typical of the end of the 10th century, and in the 11th and early 12th centuries. As of the latter half of the 12th century, there began a steady rise in the Caspian level; this rise continued for nearly 7 centuries and amounted to a gain of more than eight meters. On the whole, the variations in the Caspian Sea water level during historical time is estimated at 15 meters, from 20 to 35 m below MSL.

Rise of the Caspian Sea water level in the 12th century was conditioned by general cooling in the Eurasian continent touched off by the onset of what we call the Little Ice Age. There must have been an increase in the amount of precipitation in the Volga river basin and, in consequence of lower temperatures, a decrease in the degree of evaporation. Historical documents and annals note cold winters with abundant snowfall in the Russian plain and rainy summers with frequent floods. Computation data on the Caspian water balance dynamics over the past 2,000 years (specifically, the interdependence between the water balance and the heat balance) show that as a result of climatic variations, the evaporation of sea water in 20 years could differ from the present level from -28 to +5 per cent on the average; the margin for precipitation was +82 per cent, and that for river inflow, from -39 to +20 per cent [Klige, 1983]. Since the launching of instrumental surveys in 1837, the amplitude of Caspian Sea water-level fluctuations totaled 4 metersa, from -25.3 m in the 1880s to -29 m in 1977. In the same period of time the annual values of sea level rises exceeded the 30 cm mark on three occasions (38 cm in 1867, 32 cm in 1979, and 39 cm in 1991), while the negative values did it twice (32 cm in 1851 and 31 cm in 1937). The mean positive gain of the annual level from 1978 to 1991 totaled 14.3 cm, while the mean negative gain between 1930 and 1941 was 16 cm.

The main factor affecting the level-related regime of the Caspian in the past few decades has been climatic changes. This is evident from an explicit dependence between the level of the Caspian and the components of its water balance [Golitsyn, Panin, 1985; Klige, 1983]. The basic factors implicated in man's economic activity that affect the fluvial discharge most of all are these: irrigation of arid tracts of land, construction and use of reservoirs, land-and-forest improvement projects, as well as water consumption for industrial and household needs [Shiklomanov, 1988]. In 1990 the gain of river water in the Caspian decreased by 41 cu km as a result of economic activities. According to estimates, had it not been for anthropogenic activities, the present level of the Caspian would have been from 1.2 to 1.3 m higher than it actually is, and its reduction would have ceased as early as the end of the 1950s.

The last rise of the Caspian is likewise due to corresponding changes in the components of its water balance. The average annual river inflow in this period is estimated at 305 cu km. Thus, the annual gain through the Volga was by 17 cu km above the mean figure. Particularly much water was drained in the years 1979 and 1990, when the Volga brought in 297 cu km and 310 cu km, respectively. The visible evaporation level stood at 5-7 mm lower than the norm. By some estimates the contribution of evaporation proper to the sea rise level may exceed 30 per cent.

The rise in the Caspian sea level, setting in since 1978, is caused by a significant change of climatic conditions [Isayev, 1987]. From 1972 on, there has been a change in the circulation pattern, characterised by an increasing frequency of the latitudinal form of propagation and a diminished occurrence of the meridional one. Particularly abrupt climatic changes have been taking place since 1976. This is obvious above all in the altered pattern of cyclonic activity which has intensified by 12 per cent on the average compared with the preceding decade (by 31 per cent in August and by 38 per cent in September). There has been an increase in the number of Atlantic (by 48 per cent) and West European (by 31 per cent) cyclones, accompanied by a simultaneous growth of their water content by 35 and 18 per cent, respectively. Under the conditions of the global rise of air temperatures, this has led to an increase in cloudiness and in the amount of precipitation (and, as a result, in river inflow), and also accounted for diminished evaporation. The latter trend was likewise stimulated by a drop in the Caspian water temperature [TES, 1992].

A combined analysis of synoptic data on the Caspian basin and those on the sea level has revealed a sufficiently explicit correlation between these two processes. In the years of sea rises the number of rainy seasons was far above that of dry seasons (especially during the cold seasons) and, conversely, the periods of "scantier rainfall" were in good agreement with the periods of the dropping sea level. On the other hand, comprehensive analysis of tectonic activity shows that it has little, if any, effect on changes in the sea level.

EFFECT OF SEA-LEVEL CHANGE ON COASTAL EVOLUTION

Water-level fluctuations in the Caspian Sea largely affect the dynamic processes in the coastal zone. The rise in the Caspian Sea level and man's activities on the coast have resulted in a situation when aggradational processes, predominant during regressions, were succeeded by those of marine erosion. Depending on different types of shoreline, changes of the coastal zone proceeded in a variety of ways [Leontyev, 1988; Ignatov et al., 1992; Leontiev, Veliev, 1990; Ignatov et al., 1993].

The Caspian coast is characterised by several types of depositional coasts (lagoonal, with adjoining depositional terraces, with various accumulation forms), erosional and deltaic coasts, as well as mud flats, or low-lying coastal areas that formed by sediments brought in by wind-driven waves. Deltaic coasts occupy considerable expanses on the coast of the Caspian basin: these are the deltas of the Volga and Ural in the north, of the Terek and Sulak in the northwest, and of the Kura in the southwest. Even not quite so long ago the above rivers used to carry in a significant amount of clastic products (e.g., the Kura contributed as much as 43 mln tons) and thus were actively involved in the formation of protruding deltas. This process intensified during drops in the sea level. The deltas protruded with the formation of mouth and insular bars and spits, as well as through mud flats, which were turning into islets and drained terraces [Leontyev et al., 1977]. Until 1957 the Kura delta prograded at a rate of 50-60 m a year, the northern edge of the Sulak delta at a rate of 100-200 m a year, and some parts of the Volga delta had been adding as much as several kilometres a year. In the North Caspian, in the deltaic regions of the Volga and Ural, the sea has retreated by dozens and even hundreds of kilometers since 1929. Roads and various industrial and residential structures have been built on what used to be the sea floor.

The erosion of the Caspian deltas had begun probably well before the current transgression succeeded regression. The late 1950s and the 1960s saw the launching of large-scale hydraulic engineering projects. Around 1957 there began an intensive erosion of the eastern sector of the Kura delta due to a dramatic downturn in the amount of sediment transported by this river (by nearly two-thirds) caused by the construction of the Mingechaur water reservoir in its valley. In the 1960s and 1970s canals were dug in the estuaries of the Terek and Sulak, a factor contributing to the erosion of the delta edges. There has been an abrupt increase in the erosion of all the deltas owing to a rise in the Caspian level. The low-lying deltaic coasts of the North Caspian have become inundated to a considerable extent. This process concurs with the erosion of the depositional landforms that arose earlier. At present, many off-delta islets are subject to intensive erosion. Thus, the western shore of Maly Zhemchuzhny Is. has been retreating by 2 to 4 meters each year, while Morskoi Ochirkin Is., more than 0.5 km long still in the 1970s, was as good as completely eroded by the end of 1982.

Large tracts of the Caspian coastal zone are flat coasts formed as a consequence of the regression of the basin in the 1930s through the 1970s when the sea level was dropping. The mud flats occupied the northern part of the Caspian, they surrounded the Kirov Gulf in southern Azerbaijan, and were quite common in the district of the Krasnovodsk Gulf and southwards. During regression the aggradation of the coasts in the northwestern sector of the sea proceeded at a rate of 60-100 m a year, in the Kizlyar Gulf the accretion of land reached 150-200 m a year, and northwards--as much as 700-800 m a year. In the Kirov Gulf the wind-induced mud flats were up to 1.5 kilometres wide, while offshore winds turned the gulf into a marshland. The Kura spit, separating the gulf in the north, dried up and converted to marsh swamps.

Drop in the sea level caused less advancement of land on the eastern seaboard. For instance, south of the Cheleken Peninsula the average rate of shore advancement in the period from 1929 to 1957 was 34-36 m a year [Leontyev et al., 1977].

The change of the regressive regime to the transgressive one has affected the situation on the "drained" shores with mud flats in dramatic fashion. Owing to gentle gradients (nearly 0.0001) of the submarine coastal slope, passive floodings of the coast are quite common there. Thereby the coastal zone profile is not changed, and no significant redistribution of deposits occurs. A rise in the sea level results not only in land submergence but also causes a rise in the groundwater table; the consequence thereof is salinisation of the ground water and the swamping of adjacent lowlands. The latest rise in the Caspian Sea terlevel in the past few years has touched off like processes on mud flats. Water has filled the Kirov Gulf again, and its form is back to one prior to the regression of 1929. In the vicinity of the Kilyazinskaya Spit (northern Azerbaijan), a flat coastal terrace formed during the sea level drop of 1940 is partly flooded and partly swamped. Large tracts of lowland have been flooded on the northern coast of the Caspian on either side of the Volga delta--including pastures, roads and structures.

The sea level rise causes significant changes on depositional coasts as well. As noted above, the process of sediment accumulation, concomitant to the regressive regime, took in nearly all of the coastline. However, the pattern of this process was somewhat different and several free accumulation forms grew from sediments drifted along the shoreline from erosional segments. With the drop in the sea level, cliffs were inactivated, the longshore drift ceased and spits, especially in their proximal parts, were eroded (the Kura and Astrakhan spits off the western shore, the accumulation form of Cape Rakushechny, the Kenderli and Krasnovodsk spits on the eastern shore). With the drop in the sea level, accumulation occurred, by and large, as a result of changes in the lower and middle parts of the submarine shore slope and through clastic products transported from sea bottom to land. The intensive landward transport of sediments inhibited the longshore drift.

With the rise in the sea level, the inactive cliffs have been revived, and erosion has intensified. The transgressive regime also causes a remodeling of the submarine shore slope. However, respective changes affect mostly the upper part of the submarine slope near the water edge and are accompanied by the erosion of the frontal parts of coastal accumulation forms or by the formation of a beach-ridge near the water edge, which develops into a bar backed by a lagoon upon relative land submergence. The lagoon is formed within a land depression due to overwash and rainfall discharge from land.

Lagoonal coasts arise in many parts of the coast of Daghestan and northern Azerbaijan on the western seaboard. Thus, under regressive conditions, a young aggradational terrace has been formed on a strip between the towns of Kaspiisk and Derbent, with the gradient of the submarine shore slope being 0.005. This terrace protrudes seaward and is flanked by wide, gently sloping sand beaches. The present rise in the sea level has been instrumental in the formation of a distinct beach-ridge along the water edge, 1.5-1.7 m high and 30-60 m wide, backed by a lagoon, 0.5-0.8 m deep and 25 m wide. With the further water rise this beach-ridge, while retaining its parameters by and large, has been advancing on the lagoon, creating the impression of a shoreline retreat. Tacheometrical surveys, carried out in 1981-87, show that the newly formed terrace shrunk by 200 m in width over the preceding decade. One can expect further retreat of the shoreline under continued transgression. The newly-formed beach ridges are built of benthic material that is coarser grained than one found on regressive terraces. The lagoon thus formed keeps expanding despite the landward advancement of the beach-ridge separating it from the sea. The flooding of dry land and the rise in the ground water table are conducive to lagoon expansion and deepening. Similar characteristics apply to the northern sector of the Azerbaijanian coast many parts of which are water-logged or under shallow lagoons.

Parts of the Daghestan and northern Azerbaijan coasts, characterised by higher gradients of the submarine slope (up to 0.01), have shore-attached bars built of coquina; about 1.5 m high, such bars have an asymmetrical profile and show distinct signs of migration towards young terraces back of them. Backbar lagoons are not formed in this case, for land slopes are here rather steep and hypsometrically lie above sea level. Finally, slopes of the coastal zone above 0.01 contribute to a very active erosion of the Holocene and recent accumulative features, a trend resulting in the significant landward retreat of the shoreline. The development of this type of coast agrees, by and large, with the pattern of coastal zone reformation known as Bruun's rule [Bruun, 1962]. An area north of Makhachkala (at Karaman) furnishes a good example. A rise of the sea level there has led to the intensive wave erosion of the beach; this erosion cut a scarp 1-1.5 m high. The shoreline here retreats at rates about 10-12 m a year. On some coasts of Daghestan and Azerbaijan the rates of the erosion of the Holocene marine terrace are as high as 15-20 m a year and as a result, many residential and industrial structures are threatened in towns like Makhachkala, Kaspiisk, Derbent and Lenkoran. The latter town sustains particularly heavy damage: only one storm, breaking out there in October 1990, caused the shoreline to retreat by 5 to 6 m in some parts.

The present transgression has likewise affected the development of the abrasion shores. Such shores are in common occurrence along the eastern seaboard (Mangyshlak Peninsula, an area north of the Kara-Bogaz-Gol Gulf, Cheleken Peninsula, etc.) and in some parts along the western seaboard (Daghestan, Lenkoran, Apsheron Peninsula, etc). On the Daghestan coast the length of abrasion parts has increased from 10 to 40 per cent relative to the entire coastline; this increase has been, respectively, from 20 to 55 per cent on the Azerbaijan coast, from 8 to 13 per cent in Kazakhstan and from 7 to 22 in Turkmenia. The latest drop in the sea level has left abrasion cliffs in many coastal areas beyond the reach of waves. Benches or adjoining depositional terraces composed of series of small beach ridges have been formed in front of these cliffs. True, land advancement through the drainage of offshore shallows has been minimal due to the steep slope of the shore. On the northern shore of the Mangyshlak Peninsula built of Miocene and Paleogene sandy clays, erosion has affected only some of the promontories jutting out far into the sea. Rectilinear stretches and coves there are flanked by wide (up to 100 m) depositional terraces.

On the western coast, in southern Kobystan, erosionbal geadlands built of clays and loams of the Baku and Upper Khvalyn period are fringed by a clay bench that is almost bare of sediments. These capes were being actively eroded before 1929, with 7-10 m high cliffs being formed. Sea regression arrested this abrasion, for storm waves broke against the bench surfaces. Some parts of the Daghestan coast were protected against wave erosion by ridge relief features in the offshore zone. The submarine ridges composed of Sarmatian limestones had, until recently, blocked the shores.

Benches and ridges are flooded under the present rise of the Caspian Sea level, with storm waves reaching the cliff bases, especially during surges. In areas where the cliffs used to be protected by aggradational terraces there is now an active process underway whereby clastic products are reworked; partly they are dragged into the outer zone of the submarine slope and partly drawn into the longshore drift. Overall, sea waves are exerting a more active impact on the coast above the water edge; as a consequence, the land edge is being cut back at faster rates. In some parts of the Daghestan and Lenkoran coasts abrasion proceeds at a rate of 20-25 m a year and, as we have noted above, many residential and industrial structures are jeopardised in some towns like Makhachkala and Kaspiisk.

Therefore, the recent rise of the Caspian level has significantly affected the dynamics and general evolutionary patterns of all coastal types identified. The evolution of coasts subject to relative submergence exhibits certain variations depending on the gradient of the submarine shore slope. Different variants of the accumulative coastal development under sea level rise have been examined in several works dealing with the situation in the Caspian [Kaplin, 1989, 1990; Ignatov et al., 1993; Kaplin and Selivanov, 1995]. The Caspian Sea coastal dynamics shows some mismatch between regressive and transgressive marine regimes, on the one hand, and the cycles of coast evolution, on the other. The regressive regime generally corresponded to the prevalence of depositional processes. However, erosion of the accumulation forms of the Caspian began back in the 1960s, i.e. at a time when the sea level was still dropping. Certainly, one of the causes of this activation of abrasion might be due to man's economic activities: construction of man-made lakes and of irrigation networks, something that has reduced the river inflow and led to the deficiency of sediments in the coastal zone.

On the other hand, there is an objective, natural cause why the erosional cycle has succeeded the accumulation one. The point is that both a drop in the sea level and its rise under transgression are associated with reformation of the submarine shore slope and with its erosional cutback. Yet under regression the zone of shore slope erosion shifts seaward, not landward, involving parts of the outer slope where bottom material is of finer grain size. In time the deposits of fractions that can be transported landward and build accumulation forms are depleted. This is a natural process, of course. But what is striking about it is that the cycle of respective coastal processes is relatively brief. Thus, the process of shore accretion under continuous regression lasted for about 30 years, from 1929 to early 1960s. Therefore, one have to look into the current processes implicated in the erosional development of the Caspian Sea under transgressive conditions so as to predict their duration.

Although the rates of the Caspian coastal processes are much higher than of those on the coasts of the ocean, these processes are essentially similar. Therefore, research into the Caspian Sea coastal dynamics goes beyond the regional significance. It may be of much use for simulating the formative laws applying to the coastal dynamics, the more so that the global sea level is rising and will keep rising in the future as a result of the global warming of the climate.

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