RUSSIAN GEOGRAPHICAL SOCIETY

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CONTENTS

This issue of the Geography Environment Sustainability journal contains selected papers presented at two international scientific conferences held in 2010.

The first conference "Ecological Consequences of Biospheric Processes in the Ecotone Zone of Southern Siberia and Central Asia" took place on September 6–8, 2010, in Ulaanbaatar, Mongolia. This conference was devoted to the 40-year anniversary of the Joint Russian-Mongolian Complex Biological Expedition of the Russian Academy of Sciences and the Mongolian Academy of Sciences. The conference discussed ecological and social problems associated with environmental pollution and desertification, causes and consequences of centennial dynamics of climatic conditions, ecological risks in anthropogenic systems, the current state of protected areas network, biodiversity, and problems of aquatic and wetland ecosystems of Lake Baikal.

The second conference "The Caspian region: Environmental Consequences of the Climate Change" took place on October 14–16, 2010, at M.V. Lomonosov Moscow State University, Moscow, Russia. The main goal of this conference was to discuss ecosystem feedbacks to climate change obtained by the international scientific community during its 20-year cooperative research efforts in the Caspian region. The conference addressed a wide range of multidisciplinary problems. Experts from various scientific fields – climatology, hydrology, oceanography, marine geology, geomorphology, cartography, palaeogeography, and geochemistry, participated in the conference and addressed fundamental and practical questions related to sustainable development of the Caspian region.

The Editors believe that providing information to the public on these two key Eurasian regions would strengthen international cooperation in environmental research.

A 100-YEAR ANNIVERSARY OF THE RUSSIAN GEOGRAPHICAL SOCIETY EXPEDITION TO KAMCHATKA (1908–1910)

For three centuries, the main task of geography in Russia was gathering information about the geographical features of the country. This was the driving force for the policy and activities of Peter the Great. It is not surprising that the first Russian geographers, Y.V. Bruce, I.K. Kirilov, and V.N. Tatishchev, were public figures, and the first Russian geographical expedition was organized by Peter himself.

The first national geographical entities appeared early in the XIX century: the Paris Geographical Society in 1821, Berlin in 1828, the Royal Geographical Society in London in 1830, and Mexico in 1833. In 1843, a circle of statisticians and explorers, under the leadership of an outstanding statistician and ethnographer P.I. Keppen, began to gather regularly in St. Petersburg to discuss issues relating to statistical and geographical surveying of the territory of Russia. Soon, the famous naturalist and explorer K.M. Baer (his name is reflected in the names of the Caspian lowland landscape features, i.e., Baer mounds) and Admiral F.P. Litke (a researcher

Fig. 1. Members – founders of the Russian Geographical Society. From left to right and from top to bottom: astronomer Vasily Yakovlevich Struve (1793–1864), Admiral Ivan Fedorovich Krusenstern (1770–1846), Admiral Ferdinand Petrovich Wrangel (1795–1870), Academician Karl Maksimovich Baer (1792–1876), geologist Gregory Petrovich Gel'mersen (1803–1885), Academician Petr Ivanovich Koppen (1793–1864), Admiral Petr Ivanovich Rikord (1797–1855).

Fig. 2. Members – founders of the Russian Geographical Society. From left to right and from top to bottom: writer and musicologist Vladimir Fedorovich Odoevsky (1803–1869), statesman Alex Iraklievich Levshin (1799–1879), Academician Konstantin Ivanovich Arseniev (1789–1865), writer and ethnographer Vladimir Ivanovich Dahl (1801–1872), explorer Platon Alexandrovich Chikhachev (1812–1892), surveyor Mikhail Pavlovich Vronchenko (1801–1852), General Field Marshal Fyodor Fedorovich Berg (1793–1874).

and Head of the 1826–1829 Novaya Zemlya and around-the-world expeditions) joined the circle. These meetings were the predecessors of the Russian Geographical Society (RSG). In the spring of 1845, Litke developed a draft charter of the RSG which proved to be so successful that it lasted more than a century – until 1948.

Among the founders of the RGS there were tireless explorers, courageous sailors, famous writers, and public figures (Figs. 1 and 2). A memorandum to his Majesty was drawn up. A portfolio of documents was assembled and the case was reported to the Emperor Nicholas I by the Minister on June second, 1845. This was accomplished with active participation of the famous V.I. Dahl, who served as the Officer for Special Assignments for the Interior Minister. The Emperor looked through all the submitted papers, dropped the word "statistics" from the title and forwarded the "case" to the Cabinet, where it was approved. Thereafter, on August 6, 1845, the Emperor announced the order "So be it".

The first meeting of the RGS founders was held on October 1, 1845, where 51 people were elected. Those were the first active members of the RGS. Within eighteen days, of the RGS members held their first general meeting in the conference hall of the Imperial Academy of Sciences and Arts, where the RGS Council was elected. Article 12 of the 1849 RGS Charter recorded that "if a member of the imperial family honors the Society by taking on the title of "Chairman" (in fact, this turned out to be the case), the Society shall elect the Vice-Chairman from its active members. Grand Duke Konstantin Nikolaevich, the second son of Nicholas I, whose tutor was F.P. Litke (Fig. 3), agreed to be Chairman of the Society. The prince was among the most educated people of the mid-century and took an active part in

Fig. 3. Grand Duke Constantine – the first Chairman of the Russian Geographical Society.

Петр Петрович Семенов Тян-Шанский
1827—1914

Fig. 4. Chairman of the Russian Geographical Society, Petr Petrovich Semenov-Tian-Shansky.

peasant reform. After his death, Grand Duke Nikolai Mikhailovich became Chairman of the Society until 1917".

The *de facto* leaders of the RGS were its Vice-Presidents: F.P. Litke (1845–1850 and 1857–1873) and P.P. Semenov (who subsequently added "Tian-Shansky" to his name) (1850–1857 and 1873–1914) (Fig. 4). The Society's branches expanded quickly throughout Russia. In 1851, the first two regional divisions – Caucasian (in Tiflis) and Siberian (in Irkutsk) were opened. Then, the Orenburg, Northwest (in Vilna), Southwest (in Kiev), West Siberia (in Omsk), Amur (in Khabarovsk), and Turkestan (in Tashkent) divisions were established. Eventually, a division of the RGS was created in Kamchatka.

The construction of the Society's own headquarters building at No. 10 Grivtsov (Demidov) Lane, in 1908 was the crowning event of the years when P.P. Semenov-Tian-Shansky served as Vice-Chairman of the Society. From then until the present time, the building has housed the management and secretariat of the Society, a wonderful library and archives (Fig. 5). When P.P. Semenov-Tian-Shansky died in 1914, the position was passed on to Y.M. Shokal'sky, who remained in the position after the overturn of the government in 1917 to 1931 (when he died). Then, N.I. Vavilov, who organized an incredibly fruitful expedition to the mountains of Central Asia and other continents to study the ancient cradles of agriculture, assumed the position until 1940.

The subsequent Presidents of the Geographical Society were Academicians ichthyologist and physical geographer L.S. Berg (1940–1952); creator of the theory of natural focal disease biology and biogeography E.N. Pavlovsky (1952–1964); glaciologist and physical geographer S.V. Kalesnik (1964–1978); and oceanographer and polar explorer A.F. Treshnikov (1978–1991). Later, the Society was headed by the professors of St. Petersburg University S.B. Lavrov and Y.P. Seliverstov; in 2002–2009 the Society was headed by Admiral A.M. Komaritsin. In December 2009 the Minister for Civil Defense,

Fig. 5. The building of the Russian Geographical Society at Demidov Lane.

Emergencies, and Disaster Management, Mr. Sergei Shoigu, became President of the Russian Geographical Society. Since 1945, the Chairman of the Society became known as the President. In rare cases, the Society had Honorary Presidents: Academicians Yu.M. Shokal'sky, V.L. Komarov, and V.A. Hoops.

From the beginning, the Russian Geographical Society was closely connected with the Academy of Sciences. F.P. Litke said, "The Academy was unable to do all for geography – more should be done – and this more is the task of the Russian Geographical Society". He further emphasized, "The Geographic Society, absolutely independent, is like the Academy extension with a special purpose". In 1938, these bonds were officially recognized. Now, there are nearly thirty scientific societies in the Russian Federation with RGS assuming first place based on the number of members.

The unique image of the Geographical Society is largely due to its expeditionary activities. The names of the RGS members, N.A. Severtsov, I.V. Mushketov, P.A. Kropotkin, I.D. Cherskiy, N.M. Przewalski, G.N. Potanin, M.V. Pevtsov, G.E. Grum-Grzhimailo, V.A. Obruchev, P.K. Kozlov, N.N. Mikluho-Maclay, A.I. Voeikov, Y.M. Shokal'skii and many others, have entered into the world treasury of names of explorers and researchers. The RGS field expeditions were financially supported by the state, including funds from the Academy of Sciences. There may, perhaps, be only one expedition – in 1908 to Kamchatka – that was organized using private funds, specifically, F.P. Ryabushinsky's.

In 1908, the famous philanthropist, a member of a distinguished family of entrepreneurs, Fyodor Pavlovich Riabushinsky, with the assistance of the Geographical Society organized the Kamchatka expedition, which was to explore and examine the flora and fauna of the Kamchatka peninsula, mainly in the area of volcanoes. The RGS Kamchatka Complex Expedition of 1908–1910 received the name "Ryabushinsky's Expedition" (Fig. 6). For a long time, the RGS had intended to explore Kamchatka. At the very beginning of the RGS's existence, in 1850–1854, F.P. Litke proposed such a project; in 1877, the Polish naturalist B.I. Dybovsky attempted it as well; and in 1903, V.L. Komarov suggested a similar expedition. These projects, however, were hampered by the lack of sufficient funds.

In 1906, having taken a course in geography, the very young F.P. Riabushinsky, became inspired to visit Kamchatka. He was struck by how little Kamchatka had been explored. Fedor Pavlovich was smitten by the idea of organizing the Kamchatka expedition and actively began to prepare for its implementation. Once he had almost decided to go on a recognizance trip there, but was stopped by his rapidly developing tuberculosis. Then, he turned to the Head of the RGS, P.P. Semenov, and with their mutual consent this expedition took place.

F.P. Ryabushinsky donated 200.000 rubles. However, his weak health did not allow him to participate personally in the expedition. In 1910, F.P. Ryabushinsky died from foudroyant phthisis. He instructed his heirs to see the matter through. As a result, a very well prepared and truly integrated scientific expedition was organized. This expedition was one of the most effective in terms of collected scientific material after a long-term period of inaction in Kamchatka research.

The Head of the expedition was a botanist Vladimir Leontievich Komarov (1869–1945), the future President of the USSR Academy of Sciences (Fig. 7). The expedition consisted of six separate divisions: geological, meteorological,

Fig. 6. Fedor Pavlovich Riabushinsky.

Fig. 7. Vladimir Leontievich Komarov.

Fig. 8. Members of the Geological division of the Kamchatka expedition.

botanical (led by V.L. Komarov), zoological, hydrological, and ethnographic.

The Geological division of the Ryabushinsky's expedition (see Figure 8) undertook a detailed integrated exploration of the southern part of Kamchatka, of the volcanic areas Shiveluch and Klyuchevskoy in the central part of the peninsula, and of the gulfs Karaginskij and Korf (Fig. 9) during three field

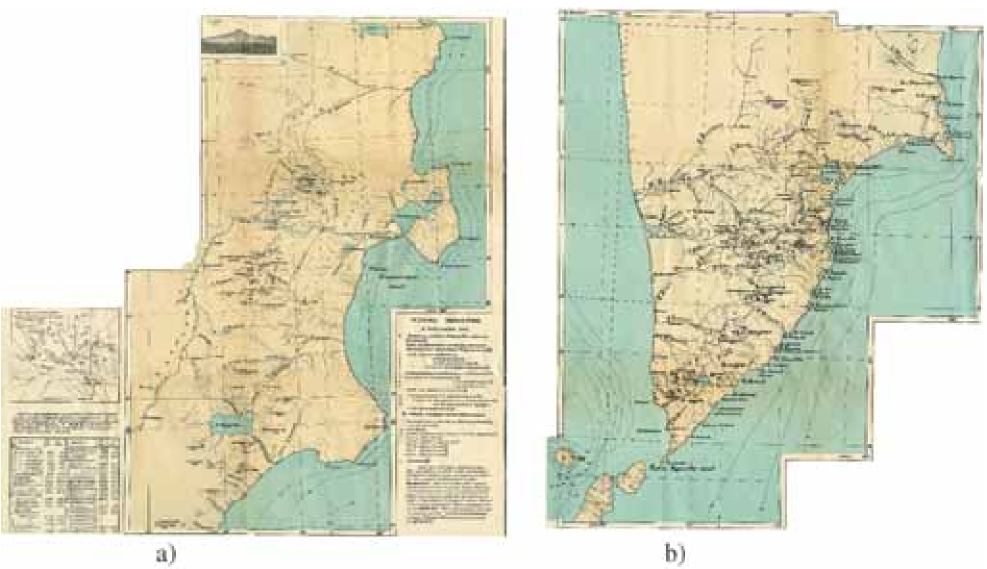

Fig. 9. Map of volcanoes of Kamchatka: the northern and southern sheets.

Fig. 10. Participants of the exhibition devoted to the Kamchatka expedition in December 1912.

seasons from 1908 to 1910. Additionally to the field studies, the Meteorological division organized five permanent weather stations in the city of Petropavlovsk and the villages Kluchi, Mil'kovo, Tigil and Bolsheretsk. The efforts of the Botanical division were summarized in the monumental three-volume work of V.A. Komarov "Flora of Kamchatka". The activities of the Zoological and Hydrological divisions were presented at the meetings of the Geographical Society and were published in its reports. The data gathered by the Ethnographic division were published later in books about Itelmens and Koryak people.

The material accumulated by the expedition was preserved in the collections of V.L. Komarov and P.Y. Schmidt, in the RGS archives, in St. Petersburg. An enormous number of photographic negatives and slides that reflect the geography, geology, anthropometry and life of the aborigines and zoology and botany of Kamchatka were also stored in the RGS's archives, in the collection "Slides and Negatives of the Geographical Society Expeditions in 1873–1957". Another interesting fact is that the RGS's archives have documents of a "lawsuit over the embezzlement by the Captain, 2nd Rank, Kuzmin-Karavaev, a former commander of the cruiser "Kolyma", of the money allocated for Iokhel'son". Out of 15.140 rubles intended for the needs of the Ethnographic division of the expedition, Kuzmin-Karavaev transferred to Iokhel'son only 7.500 rubles. The case was heard in the Naval Court of Vladivostok, which sentenced Karavaev to two and a half years in prison in a fortress.

The 1908–1910 multidisciplinary expedition of the RGS to Kamchatka was widely reported in the world press. The participants' letters about the events were published along with their reports, photographs, and summaries of the catalogs of the expedition's divisions. In 1910–1913, numerous articles about this expedition appeared in many Russian newspapers and magazines. The interest in the expedition was resumed when in December of 1912, the RGS arranged an exhibition devoted to the Kamchatka expedition (Fig. 10) in the Society's building. Within three weeks following the exhibition, P.P. Semenov-Tian-Shansky received a gift from the Winter Palace – a "brooch-pendant with the national coat of arms, decorated with sapphires and diamonds, and the accompanying certificate for the gift mercifully granted to the widow of hereditary and honorary citizen Tatiana Konstantinovna Riabushinsky".

In this context, it is appropriate to recall another detail. Shortly after the expedition, the RGS planned to publish six volumes of scientific works (for each expedition's division). Since the funding for the expedition came from a private party, it was necessary to settle differences with the heir of the patron, who was Riabushinsky's widow. T.K. Riabushinsky categorically stated on October 18, 1910, that she would publish the materials of the expeditions herself. That started the litigation process, which was reflected in the correspondence with P.Y. Schmidt. Judging by the fact that the expedition's results were published as scientific papers only in the Soviet era (in 1928–1930), and even then, not in their entirety, it may be concluded that the heiress was successful in having her way.

Over the past 100 years, the natural environment of Kamchatka has been studied extensively, but the attention was focused primarily on volcanic activity. In 1935, at the initiative of Academician F.Y. Levinson-Lessing, the Academy of Sciences established a volcanological station at the foot of the Kluchevskaya Sopka; this station is active to this day. Currently, scientists are studying the links between volcanism and seismicity, tectonics and modern ore formation, etc. These studies should lead to the creation of a geodynamic model of the transition zone from the Asian continent to the Pacific Ocean, where modern geological processes are most pronounced.

The expedition to Kamchatka played a significant role in promoting science in the Russian Far East. Important scientific and public institutions were founded in this region as a result of this endeavor. The two institutions directly associated with the expedition are the Kamchatka branch of the RGS and the Institute of Volcanology and Seismology (Far Eastern Branch of the Russian Academy of Sciences). These institutions are important members of the Russian scientific community and are well known around the world. ■

Vladimir M. Kotlyakov,
Honorary President of the Russian Geographical Society

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EVOLUTION OF THE ELBRUS GLACIATION SINCE THE MID XIX CENTURY UNDER CHANGING CLIMATE. KEY FINDINGS OF THE GLACIO-CARTOGRAPHICAL MONITORING

ABSTRACT

Changes in the area and volume that have been occurring from the middle of the XIX century within the largest in Europe Elbrus glaciation were studied using lichenometry and digital cartography methods. There were cyclical, approximately 55 years long, frontal fluctuations of glaciers Bolshoi Azau (the largest Elbrus glacier) and Dzhankuat (which is representative of all Central Caucasus glaciation).

Quantitative data on changes in the area and volume of the Elbrus glaciation indicated that the greatest rates of its retreat coincided with the 1850–1887 period. Beginning in 1887, the area reduction was occurring practically evenly through time while the decrease in its volume has even slowed down. These facts suggest that global climate warming, which alternated with short-term cooling periods, began in the middle of the XIX century after the end of the Little Ice Age. The warming was most likely due to natural rather than anthropogenic causes.

KEY WORDS: Elbrus glaciation, global warming, digital mapping.

INTRODUCTION

Numerous studies conducted recently by climatologists suggest global climate warming, which started in the second half of the XX century as a result of greenhouse gases effect. A number of global climate warming models have emerged in Russia and the world [World..., 2003; Climate Change, 2001]. Mountain glaciers are sensitive to climate change. Increase in global temperatures should affect their regimes and parameters, specifically, the area and volume. This hypothesis can be tested through cartographic and aerial-satellite monitoring of the largest in Europe Elbrus glaciation which physical surface exceeds 140 km^2. The monitoring of this glacier has been conducted for over a century – from the end of the XIX century to the present time.

THE FRONT FLUCTUATIONS – THE GLACIER'S RESPONSE TO CLIMATE CHANGE

Russian Academician G. Abich [Abich, 1875] has established a foundation for long-term observations of some Elbrus glaciers. These observations are crucial in defining the glaciers' response to climate change. In 1849

Fig. 1. Location of the Bolshoi Azau glacier tongue on October 21, 1849. Picture by G. Abich [Abich, 1875].

and 1873, G. Abich made two trips to the Bolshoi Azau glacier. During his first trip, G. Abich found that the glacier had intruded on a mature pine forest. This fact was later accepted as a fundamental evidence of the glaciation expanse in the Central end Caucuses in the middle of the XIX century [Tushinski, 1958]. It was assumed that the glacier's was at a well defined moraine line at the bottom of the river Azau valley at 2295–2300 m elevation in the vicinity of the present-day M.V. Lomonosov Moscow State University (MSU) Elbrus station. There were no cartographic surveys in Elbrus prior to 1887 and many researchers of that time [Dinnik, 1890; Mushketov, 1882; Salatskyi, 1866] provided contradicting assessments of the spatial position of the glacier. Such assessments are hard to interpret and reconcile without G. Abich's data.

G. Abich's work, for some reason, still remains unknown to most researchers and, therefore, deserves a detailed presentation especially of its parts related to the Bolshoi Azau glacier. G. Abich conducted thorough studies of the Bolshoi Azau glacier tongue fluctuations in 1849–1873 using instrumental observations. He defined the glacier's elevation (on October 21 1849) at 2322 m from barometric leveling and a known benchmark near the city of Pyatigorsk. He did not expect to return to the area in the future and limited his studies to the use of angular measurements with a portable sextant to draw general boundaries of the glacier (Fig. 1). This drawing was made from a point located at a well-marked rocky ledge of Mt. Terskolak's slope above the forest level across from a modern hotel Cheget.

During his second visit to the glacier in September 17, 1873, G. Abich found the retreating glacier (Fig. 2). He made the same barometric leveling using the same instrument and benchmark. Different environmental conditions (atmospheric pressure and temperature) in 1873 compared to 1849 resulted in a different end moraine elevation measurement (2317 m). G.Abich accepted this measurement as the final result. The glacier linear retreat from 1849 to 1873 was measured at 180 m. The third measurement taken by G. Abich was the difference in the elevations of the foot of the moraine line at the glacier end in 1849 and the elevation of the point of the upper apex abutted against a more ancient end-lateral moraine covered with mature pine forest. This difference appeared to be 37,5 m. The moraine slope of such relative height exists only in the area of the lower station of the cable-way "Elbrus".

The difference in the elevation of the moraine crest and the low water line of the river Azau in the vicinity of the MSU Elbrus station is 27 m. Therefore, the glacier could not be located there in 1849.

Fig. 2. Location of the Bolshoi Azau glacier tongue on October 17, 1873 Picture by G. Abich [Abich, 1875].

We found the point from which G.Abich made his drawings of the glacier in 1849 and 1873 showing the end moraine line in front of the glacier. A phototheodolite survey conducted from this point in August 1981 showed well preserved traces of recent glaciation. However, from this point, the end moraine line can't be seen in the vicinity of the MSU station (it is obstructed by the river Garabashi mudflow cone); but the end moraine line in the vicinity of the cable-way "Elbrus" is well visible. Furthermore, it was the far most moraine end line where a buried pine was found in 1968; the analysis showed that this tree's annual rings growth is similar to that of pines appeared in the Azau valley in the first half of the XVII century. Modern elevation of the foot of this line at the bottom of the valley is 2315 m, which corresponds well with G. Abich's measurement of 2317 m. These data are sufficient for a precise determination of the spatial location of the end of the ice-flow of the Bolshoi Azau glacier in 1849 (Fig. 3).

Later research activities of the end XIX – beginning XX centuries documented by maps describe the exact location of the glacier tongue. These maps are a 1:42000 scale topographic map compiled from the 1887–1890 Corps of Topographical Engineers surveys and a 1:20 000 scale map compiled from the data of the 1911 phototheodolite survey by G. Burmester [Burmester, 1913].

Elevation benchmark systems of these maps should be reconciled with the modern map compiled from the phototheodolite survey conducted during the International Geophysical Year (IGY). I.A. Labutina (1968) determined the elevations of the 1991 map to be 20 m lower than that of the modern map. Therefore, the elevation of the end of the ice-flow of the Boshoi Azau glacier in 1911 was actually 2345 m (or 2325 m on the G. Burmester's map). This also corresponds well with the actual glacier's location. The 1911 map shows the glaciers tongues at approximately 70–80 m higher than the waterfall of the river Malya Azau in the canyon. The modern map shows the elevation of 2345 m, which is 75 m higher than the elevation of the same waterfall.

Fig. 3. End moraine in the mid. XIX century at the bottom of the Azau river valley. Phototheodolite image taken on July 15, 1981.

Fig. 4. The tongue of the Bolshoi Azau glacier. Image by A.V. Pastuhov on August 5, 1890.

The 1887 and modern (of the Elbrus southern slope) maps benchmark systems correspond well with each other. Therefore, the 1887 Bolshoi Azau ice-flow end elevation can be obtained by overlaying the 1887 and 1957 maps, which excludes distortion caused by dead ice near the glacier tongue. This elevation is 2330 m. On the photo taken on August 5, 1890 by A.V. Pastuhov (1893), the location of the glacier's front at the end of the lava line, which some time ago had blocked the Azau canyon, can be seen clearly (Fig. 4).

It is also helpful to review observations of other investigators According to 1881 N.I. Dinnik (first after G. Abich to visit the glacier in 1881, but who unfortunately did not conduct any instrumental measurements), the lower part of the ice-flow ended with a steep slope crossed by cracks; the right part of the ice-flow was adjacent to the open rocks which were at about 2327 m elevation from the low river level. In 1911, G. Burmester described the glacier as growing or as about to be ready to transition to the growing phase. The evidence of that were: a steep glacier's front, absence of the end moraine, intense cracking of the entire glacier below the icefall, and the presence

Fig. 5. The tongue of the Bolshoi Azau glacier. Phototheodolite image by A.V. Blryuhanov. August 1958.

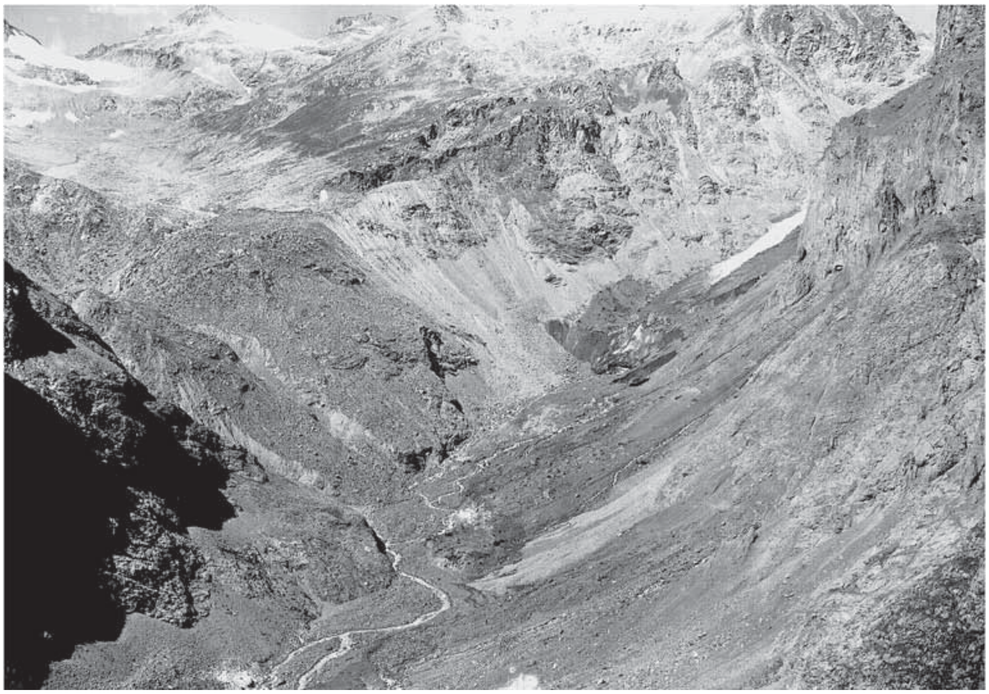

Fig. 6. The tongue of the Bolshoi Azau glacier. Phototheodolite image by Ye.A. Zolotarev. August 31, 2002.

of a surface swell wave sliding between 2600 and 2700 m elevation. According to V.P. Rengarten's communication with S.P. Soloviyev in 1913, the glacier advanced 15 m ahead compared to 1911 [Soloviev, 1933]. In 1925, V.Ya Altberg (who worked at the glacier in 1925–1928) reported that the glacier was 20 m higher than the waterfall in the canyon and was again retreating [Altberg, 1928].

We used works by Ye.P. Oreshnikova [1936] (who surveyed the glacier in 1932–1933), P.V. Kovalev [1961] (who provided data on the glacier retreat at the end of 1940s), materials of the Elbrus phototheodolite survey in 1957–1959 (Fig. 5), the survey of the glacier tongue in 1969, and our surveys of 1973, 1980, 1987, 1997, and 2002 (Fig. 6) to compile a chart of the Bolshoi Azau glacier tongue fluctuations from 1849 to 2002 (Fig. 7). The surveys were reconciled using a 1 : 5000 topographic map, which we created for a site at the Azau river using data of the 1987 phototheodilite survey when the valley was completely free of dead ice.

A distinct feature of the glacier retreat is a simultaneous formation in the valley of a large volume of dead ice that hampered the identification of its front location. Thus, for example, on the 1957–1959 map, the glacier front was 700 m above its actual end position in the valley and 40 m above its bed. This made it difficult to systematize elevations of the glacier tongue by earlier researchers [The glaciation..., 1968].

The aforementioned information may also help to explain the peak rates of the glaciers retreat in 1959–1969. During this time, the area was simply getting free of dead ice. Overall during 150 years, the glacier has retreated 2860 m, i.e., the average retreat rate was about 19 m/year. This retreat was cyclic and interrupted by short delays and small advances during its early phases and in the 1970s, with 55-years intervals between the cycles.

During special research efforts, we found a similar cycle with an insignificant time shift at a representative of the Central Caucuses

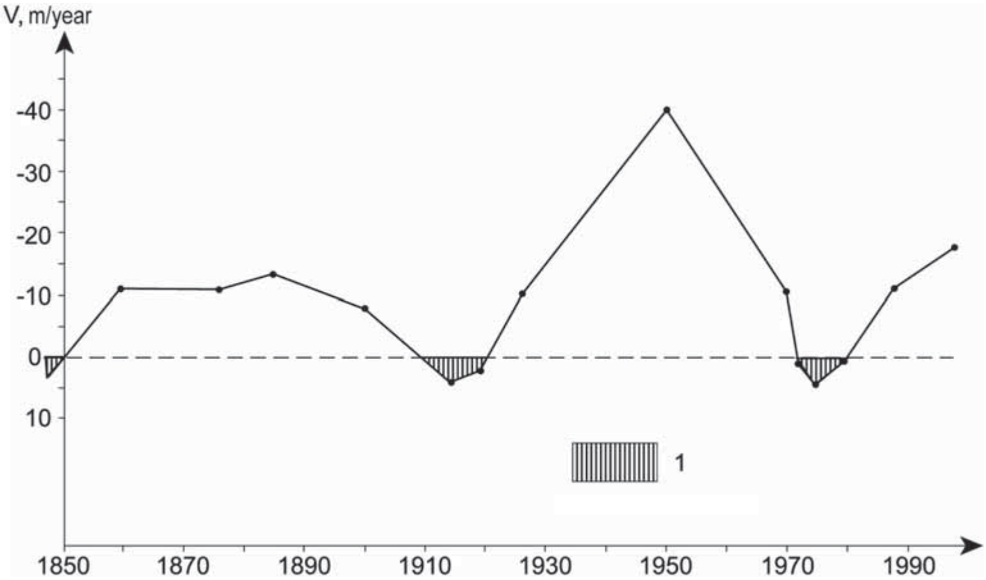

Fig. 7. Fluctuations of the Bolshoi Azau glacier from 1849 to 2002. 1 – the glacier advancement.

glaciers the Dzhankaut glacier. This fact suggests that air temperatures were the main climatic parameter that influenced the glaciers response [Zolotarev and Popovnin, 2003]. Changes in air temperatures cause changes of the ice-flow end ablation while the ice inflow stays relatively constant during a long period of time in the accumulation area of the glacier. The difference between the ice inflow and loss at the end of the ice-flow determines if the glacier retreats or advances.

ANALYSES OF CARTOGRAPHIC MATERIALS ON ELBRUS GLACIATION

Analysis of the 1887–1890, 1 : 42000 scale, topographic survey map. The first instrumental (plane-table) survey of the entire Elbrus glaciation was conducted by a team of the Corps of Topographical Engineers in 1887–1890. The survey was compiled into a 1:42 000 scale map. First, it had to be determined if it is possible to superimpose the modern map with the old map to obtain quantitative parameters of spatial changes of the Elbrus glaciers during 1887–1957. Analysis of the maps confirmed that it was in principle possible to make cartographic measurements on the 1887 Elbrus map. A correct superimposition of similar surfaces shown on multitemporal maps is challenging even for the modern cartographic material; there are no standard solutions for this problem. In our case, we decided to convert the map from a 1 : 42000 into a 1 : 25000 scale using the coordinate and elevation benchmark system of the more modern map. This transition was done by zones using at least three identical control points on the modern and old maps. When converting the old Russian elevation system (Russian fathom) into the metric one and drawing elevation contours, a 5 m systematic error correction was applied to all glaciers except to those located on the southern exposure slopes. This newly compiled map was refined later on; especially when the glacier boundaries were reconciled when new data became available.

Then, this and the 1957 maps were digitized and used in computer models to determine changes in the area and volume of the glaciation. It should be noted, that the 1887 map can only produce reliable estimates for the glaciers' tongues, i.e. up to approximately 4000 m elevation. The research conducted indicated that above this mark, changes in elevation may be within an error of measurements [Zolotarev, 1997]. However, special research efforts aimed at comparison of multitemporal digital models of Elbrus compiled using aerial photography of 1979 and 1997 indicated that over 90 % of volume changes are associated specifically with the area below 4000 m. Therefore, the 1887 map is also suitable for the studies of the Elbrus glaciation evolution. It should also be noted that the area of glaciation in 1887, which we measured on the newly-compiled map using digital methods (147,5 $км^2$), is approximately 1 % different from the area measured by K.I. Podozersky [1911] on the original map using measuring grid. This is consistent with the negligible error of estimates.

Modern cartographic materials on the Elbrus glaciation. During the IGY (1957–1959), scientists from the Laboratory for Aerospace Methods (at that time, the Laboratory of Aerial-Photo Methods) of the Department of Cartography and Geoinformatics of the MSU Faculty of Geography conducted a phototheodolite survey to assess the evolution of the Elbrus glaciation. They compiled a 1:10 000 scale map, which became a base map for the future cartographic-aerial-space monitoring of the Elbrus glaciation [The glaciation..., 1968].

In 1980–1983, a preliminary recognizance work for the second survey was undertaken [Knizhnikov et al., 1984]. In 1986–1987, the phototheodolite survey was repeated for the entire Elbrus glaciation. In addition in 1979–1987, its aerial photographic survey was conducted.

During the 1986–1987 phototheodolite survey, a lichenometric study of stadial moraines was accomplished. Its materials were used to determine the Elbrus glaciation area and volume in the mid XIX century. It appeared that these parameters were close to the maximal parameters of the "Little Ice Age" (XIII-mid XIX) [Solomina, 1999].

All these data together with the digital orthophtographic map compiled from the 1997 aerial photographic survey provided a unique opportunity to study tendencies in the glaciation changes, which have happened during a 100-years time-period.

RESEARCH METHODS

Lichenometrical method of determining the maximum limits of the glaciation in the last millennium and middle of the XIX century. The founder of the lichenometrical method R. Beschel [Beschel, 1961] believed that through their lives, lichen thallus grows at different speeds. In the beginning of growth, the speed is high becoming constant in the middle of the growing cycle till lichen reaches its maximal diameter for given environmental conditions, after which the growth rate decreases. Practically, this means that different annual growth values for different lichen diameters have to be used for proper age-dating. Challenges of determining such dependency for each specific region is the main reason that makes wide scale application of this method difficult. Special importance should be given to methodological research built on Beschel's ideas to establish a mathematical model that describes a maximal lichen thallus diameter as a function of age of its growth substrate. This is achieved by using lichens from different age-control sites; the age is determined using other methods, e.g., historical, cartographical, or radiochronological [Golodkovskaya, 1981]. These efforts demonstrated the influence of environmental conditions on lichen growth. Thus, data on growth obtained for the northern slope of the Central Caucuses appeared to be unacceptable for age dating of the southern slope moraines [Golodkovskaya, 1982].

In our opinion, this undoubtedly valuable work is lacking a critical evaluation of the source data accuracy resulting in an unjustifiably accurate claimed precision of age dating. It should also be considered that historical and cartographical sources provide only a time of formation of a relief form, i.e., a substrate where lichens may appear in the future and at different times. Dating errors related to older control sites may comprise several decades. In this case, one has to be especially careful to exclude inconsistencies between the age of boulder trains and the diameters of lichens that grow on them. Such inconsistencies may be a result of a limited life span of lichens growing under temperate climate (according to Beschel, 1500–2000 years). Considering all these facts, it is reasonable to conclude that there may be a decade-long dating error for the last century dating. For a thousand-year period, one can only date to a century with more or less satisfactory level of confidence despite any reliable mathematic models applied to data processing. Therefore, it is also reasonable to conclude that at the end, differences in the annual lichen growth for the sites with different environmental conditions may result in dating differences that are within the limits of these errors. Then, a simplified solution is possible, i.e., specifically, a statistical processing of the annual lichen growth data from control sites with different environmental conditions may be applied. In this case, deviations from the mean values of the annual growth of a given size can be determined. These deviations characterize a probable error in age determination. Specifically this very method was applied to study the Elbrus and Baksan river basin glaciers changes during the last century.

Along with the moraine, mudflow deposits, which compared to ice have a certain advantage of being even-aged, were widely used in our research as control sites. Overall, there were 20 mudflow basins in the valleys of Preelbrus'e within which over a hundred of 1400–2000 m elevation sites were processed.

Twenty five control sites on mudflow sediments with known descend from 1909 to 1979 were used together with 14 sites (in six glacial valleys) on the stadial moraines within the 1930s to 1850 age interval. Besides, three sites with the ancient mudflow and fluvioglacial sediments with known radiocarbon dating data [Kaplin et al. 1971; Kotlyakov et al. 1973] and our dating data "IGAN-747" were used.

The following dependencies were established through processing of these data: a) no lichens were found on the deposits younger than 10 years; b) the minimal visible size of lichens was 1 mm; c) a sharp decline in the annual lichen growth occurred during the first decades of their lives (to 50 years); and d) beginning from the diameter of about 100 mm and bigger, the annual growth has practically stabilized and was 0,15–0,11 mm/year.

Based on these data a generalized graph of the annual lichen growth was compiled for different environmental conditions [Seinova and Zolotarev, 2001]. The annual growth generalized curve was drawn using the annual growth average values for different diameters. The upper and lower enveloping curves allowed assessing real accuracy of the annual growth values. For convenience, this graph is presented in a tabular format (Table 1). The annual growth values are presented with a possible standard deviation. Also, the annual growth data are supplemented with the data on the sediments age and absolute values of the mean-root-square error (year). It was assumed that lichens inhabited the sediments not earlier than 10 years after their formation.

The values of the mean-root-square error of the sediments age and the error of the radiocarbon dating for a respective point on the graph (diameter of about 100 mm) coincide, which confirms the credibility of the results obtained.

The actual data used to obtain the annual growth values correspond to the absolute elevations in the 1800–2000 m interval. There is no clear dependency between changes in the growth rates and absolute elevations. However, in reality there is a tendency to a fast increase in the growth below 2000 m elevation noted by V.I. Turmanina [1971]. A lack of actual data does not allow one to quantitatively express this tendency. In order to date the sediments located above 2300 m (the middle of the interval of our actual data on absolute elevations) it seems feasible to use the lower enveloping curve on the growth graph (see Table 1) adding absolute values of the standard deviation to the age values.

Using data from published sources on maximal diameters of *Rhizocarpon*

Table 1. Annual growth of different sized lichen Rhizocarpon geographicum and dating of the respective deposits for the northern slope of the Central Caucasus (absolute elevations 1800–2900 m)

Lichen diameter, mm	Annual growth, mm	Age of deposits, yrs	
1	–	10	XX c.
2	–	12	
5	1,00 ± 0,10	15 ± 1	
10	0,78 ± 0,11	20 ± 2	
15	0,65 ± 0,12	30 ± 5	
20	0,55 ± 0,11	45 ± 7	
25	0,47 ± 0,10	60 ± 10	
30	0,43 ± 0,09	80 ± 12	
35	0,39 ± 0,08	100 ± 15	XIX c.
40	0,37 ± 0,07	120 ± 18	
45	0,34 ± 0,07	140 ± 23	
50	0,33 ± 0,06	160 ± 26	
55	0,31 ± 0,06	180 ± 29	
60	0,29 ± 0,05	210 ± 31	XVIII c.
65	0,27 ± 0,05	240 ± 35	
70	0,25 ± 0,04	290 ± 40	
75	0,23 ± 0,04	330 ± 45	XVII c.
80	0,22 ± 0,03	360 ± 50	
85	0,20 ± 0,03	420 ± 55	XVI c.
90	0,18 ± 0,03	500 ± 60	
95	0,16 ± 0,02	570 ± 70	XV c.
100	0,15 ± 0,01	666 ± 80	XIV c.
105	0,15	700 ± 90	XIII c.
110	0,14	760 ± 100	
112	0,14	820 ± 110	XII c.
120	0,13	900 ± 120	XI c.
130	0,13	1000 ± 130	X–IX c.
140	0,12	1200 ± 140	VIII c.
150	0,12	1360 ± 150	VII c.
160	0,11	1450	VI c.
170	0,11	1550	V c.
180	0,11	1650	IV c.
190	0,10	1900	III-II c.
200	0,10	2000	I c.

Table 2. The age of the stadial moraines of the river Baksan valley glaciers identified with the lichenometry method.

Maximal diameter of lichens (mm) on the stadial moraines in the glaciers valleys							Time of formation of the morainic ridges
Bolshoi Azau	Malyi Azau	Terskol	Irik	Yusengi	Dzhankaut	Bashkara	
		115		125			XIII c.
		85		85	90	80	First half of XV c.
	66		64				End of XVII c.
50		51	50	50			End of XVIII c.
38		40	40	40	41		Mid XIX c.
34	34	30	33	32	33	30	1880th
20	21	24		20	21	21	1910th
15	15	17			14		1930th

Fig. 8. Changes in the Elbrus glaciation from the end of the XVII century. 1 – area of ice that melted during 1700–1887; 2 – lava; 3 – glacial divides. Glacier boundaries: 4 –1987, 5 –1957, 6 –1887, 7 –stadial moraine line of the mid. XIX century.

geographicum lichen growing on the stadial moraine of several glaciers [Turmanina, 1971] supplemented with our own observations, the following representation of changes in the southern Elbrus and Baksan river glaciation was obtained (Table 2).

As shown in Table 2, the middle and end of the XIX century stadial moraines were represented most fully. They were well preserved –the fact noted previously in published literature. The moraines with lichen diameters of 115–120 mm were preserved in fragments as remnants. In the river Yusenga, this moraine towers over the frontal apron near the right valley side in 2 km to the tongue of the Becho glacial (2400 m elevation) and in the river Terskol valley –amidst the avalanche and scree deposits of the left side of the valley in 1 km to the modern tongue of the glacial (2540 m elevation).

The end moraine lines with lichen diameters of 85–90 mm were found near five out of seven studied glaciers. The end moraine lines were well visible in the relief, have the greatest relative elevation, and were apparently formed during the longest period of the stationary state of the studied glaciers. For the glaciers Djankaut and Bashkara, these moraines had been dated earlier to the mid XVII century based on the data on the annual lichen growth of 0,3 mm/year [Turmanina, 1971]. In general, the data from Table 2 suggest that a consecutive decline of the glaciation during the last two millenniums was interrupted by periodically advancing glaciers. Judging by the morphology of the end moraines and the lichen size on their surface, the glacialtion in the second millennium AD in this region of the Central Caucasus has reached its maximum in the mid of the XVII century and after some retreat, has come back to almost the same magnitude in the middle of the XIX century.

The results of the lichenometric survey of the stadial moraines allowed determining the Elbrus glaciation boundaries at the end of the XVII and middle XIX centuries (Fig. 8). Their identification was based on a large scale (1:10 000), 10 m contour topographic map of the Elbrus glaciation compiled from the 1957 survey where practically all ridges of the stadial moraines are shown with special cartographic symbols. The map was used to identify the area and volume of the glaciers during their maximum development. This was accomplished by interpolation of the contour lines from the ridges elevation for the areas occupied by the glaciers at the end of the XVII and middle of the XIX centuries.

Thus, for each glacier from its tongue to the upper level of the stadial moraine, the maps were compiled and digitized together with respective sites shown on the 1957 topographic map. Multitemporal digital models were developed from these data for each glacier. The difference in the estimates between these two models allowed determining changes in the average elevation and ice volumes of all Elbrus glaciers tongues from their ends to 4000 m elevation (Table 3).

Digital photogrammetric processing of ground and aerial photography. Until the end of the XX century, stereo-autograph processed phototheodolite surveys were commonly used to capture spatial positions of mountain glaciers. The results of the data processing served as a basis for large scale maps used in cartographic analyses and compilation of thematic maps. The aforementioned 1:10 000 scale Elbrus glacial system map serves as an example of such maps.

The modern state in cartographic research is characterized by digital photogrammetric processing of ground, aerial, and space imagery. This stage is associated with "digital imagery", that is obtained in Alpine glaciology through scanning and digital aerial or phototheodolite surveys.

Processing of digital photographic pairs is performed with the help of digital photogrammetric computer software packages (developed also for personal computers). Let us review in detail a

Table 3. Change in the area and volume of the Elbrus glaciation beginning from the mid. XIX c.

Name of glacier	Area of glaciers in horizontal projection, km³					Volume of glaciers, km³				
	1850	1887	1957	1979	1997	1850	1887	1957	1979	1997
Elbrus peaks (area above 5200 m elevation)	4,818	4,818	4,818	4,818	4,811	0,480	0,480	0,470	0,480	0,481
1. Ulluchiran	13,914	12,944	12,124	12,277	12,301	1,589	1,269	1,227	1,318	1,230
2. Karachaul	6,638	5,918	5,748	5,538	5,485	0,610	0,605	0,552	0,595	0,548
3. Ullu-Kol + Ullumalien-derku	6,146	5,826	5,186	4,960	4,882	0,481	0,475	0,412	0,439	0,488
4. Mikelchiran	6,014	5,564	4,834	4,670	4,604	0,613	0,607	0,479	0,503	0,460
5. Ice field Dzhikiugan-kez	34,832	31,762	29,042	27,295	25,581	4,929	4,339	3,207	3,032	2,558
6. Irichkat	3,006	2,816	1,806	1,735	1,680	0,260	0,256	0,196	0,196	0,168
7. Irik	12,605	12,425	10,995	10,763	10,671	1,425	1,405	1,174	1,233	1,067
8. Terskol	8,428	7,818	6,988	6,901	6,975	0,832	0,826	0,700	0,769	0,697
9. Garabashi	6,321	5,781	4,911	4,744	4,689	0,621	0,561	0,479	0,517	0,469
10. Malyi Azau	10,256	9,826	8,806	8,508	8,363	1,074	0,974	0,866	0,913	0,836
11. Bolshoi Azau	23,102	22,662	21,032	20,677	20,460	3,270	2,900	2,330	2,222	2,046
12. Ullukam	3,950	1,882	1,620	1,561	1,440	0,160	0,151	0,141	0,146	0,144
13. Kyukyur-tlyu	8,119	7,269	7,039	7,226	6,913	0,752	0,747	0,696	0,700	0,691
15. Bityukt-yube	2,560	2,330	2,170	1,997	2,212	0,254	0,251	0,221	0,231	0,221
Clif glaciers №№ 1–9	8,450	7,475	5,395	4,058	3,783	0,530	0,450	0,390	0,407	0,378
Total for Elbrus glaciation	159,159	147,516	132,514	127,728	124,85	17,880	16,296	13,540	13,741	12,482

cartographic digital method applied to the glaciers using a digital Elbrus map compiled from the 1997 aerial photographic data. The map was created using a digital photogrammetric software package that we developed for a personal computer, which includes the following main components: program stereocomparator for measuring coordinate points on digital images; programs for photogrammetric bundle adjustment; programs for automatic measurement of parallaxes and digital relief model point sets; stereo editor for editing stereo models and contour digitizing during visual interpretation of the stereo model from a personal computer monitor using LCD shutter glasses; and a program for building a digital elevation model (DEM) and creation of orthographic imagery. Photogrammetric processing included measuring control points, phototriangulation, measuring points for DEM, and compiling an orthophotomap. Digital imagery was obtained beforehand through scanning of original aerial photographs on a photogrammetric scanner.

The elements for relative orientation of images and computation of spatial coordinates of measured points were defined based on block photo-triangulation using a large number of control points over the entire aerial photographic area, which allowed reaching 1,5 m horizontal and vertical coordinate measurement accuracy sufficient for compilation of a 1 : 10 000 scale map.

The base elements of the content of the compiled orthographic map were the 1 m resolution orthographic images of the area; relief represented by 10 m contours, and an interpreted glacier boundary.

The relief mapping was done using the DEM data as an intermediate step. The DEM point sets were defined with the stereo-pairs on relatively oriented images. The necessity of selection of a large number of points for building a detailed elevation model dictated the usage of automated stereo-measurement methods that were applied to obtain 96 % of all DEM points. The rest of the points were selected through visual examination of the measurement results using stereo editor after automated processing of each stereo-pair. There were about 1 mln points in total for the entire territory processed. The obtained DEM was used to build contours and to perform imagery orthotransformation.

The glaciation boundaries were defined from visual interpretation and stereoscopic examination of the images enlarged with stereo-editor to approximately 1:5 000 scale, which permitted their detailed delineation. The interpretation methods developed in the Laboratory for Aerospace Methods of the Department of Cartography and Geoinformatics during the compilation of the Elbrus glaciation map [The glaciation..., 1968] were also applied. Additionally, the ends of the glaciers tongues ice that is entirely covered by the moraine mantle and not previously shown on the 1957–1959 map (as it was considered to be stagnant) were included in the boundaries (Fig. 9).

Adjustment of multitemporal data of repeated surveys. Monitoring of glaciers elevations is important for assessing their volume changes.

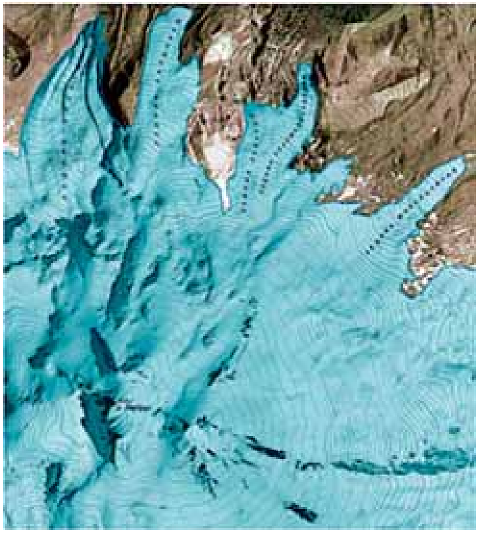

Fig. 9. Fragment of the 1 : 10 000 scale digital ortho map of Elbrus (1997) (reduced size).

Cartographic methods are traditionally used to measure elevations on multitemporal cartographic material. However, mapping of glaciers with phototheodolite data or aerial photography is time consuming. This fact together with the need to improve accuracy of measurements of changes by using raw data from repeated surveys without creation of intermediate maps required applying multitemporal data adjustment using broad-based photogrammetric instruments. Under this method, the stereo-pairs from repeated survey were oriented using maps compiled from earlier surveys. Measurements were made by pointing a coordinatograph finder device over a map contour or a node of a regular grid while simultaneously pointing a stereograph tick mark over a stereo model surface. Pointing at contours eliminates a map-based relief interpolation. Measurements based on the nodes of a regular grid, on contrary, require such interpolation, but they are preferable for the reconstruction of a continuous surface of elevation changes. Both versions of this method allow determining elevation changes more precisely than cartographic methods. Such work was conducted to identify changes in the Elbrus glaciers during 1957–1987 [Zolotarev, 1997].

This labor intensive method and its limitations associated with technical capabilities of repeated images and maps adjustments are the main factors that determined transitioning to analytical methods of imagery processing. There have been several attempts to determine changes through the comparison of the DEMs developed from multitemporal stereo pairs. It has been experimentally established that selecting points on a regular or some other arbitrary network and using structural lines or some other ways of space detalization obtained from independently measured stereo pairs, did not substantially increase the accuracy of measurements. It appears that the surface of changes obtained analytically differs substantially from the actual surface. The solution was found in conducting coordinated measurements of the stereo-pairs – at the same points with previously established planimetric coordinates [Zolotarev and Kharkovets, 1996]. In this case, the values of elevation change in a point are obtained directly without intermediate interpolations with a substantially higher accuracy provided by application of analytical methods. If necessary, the location of points may be tied to regular grid nodes within a planimetric coordinate system. The implementation of this method became possible with stereocomparators that transfer values of measured image coordinates directly to a computing system and conduct coordinates interconversion between images and real space directly during pointing of a stereoscopic tick mark on to a glacier surface under specified parameters of external orientation. Thus, the tick mark coordinates are adjusted and its position at the glacier surface in a point with necessary planimetric coordinates is reached.

ASSESSMENT OF THE ELBRUS GLACIATION VOLUME DURING DIFFERENT PERIODS OF ITS EVOLUTION

The assessment of the total volume of the Elbrus glaciation is particularly interesting because the assessment of changes in volumes during a 100-year period could provide evidence of the glaciation relative stability or, in contrast, of its substantial retreat. V.I. Kravtsova [Kravtsova, 1967] estimated the Elbrus glaciation volume at 6 km^3 using a map of the Elbrus ice thickness that was compiled during the IGY from the results of phototheodolite surveys of the ice cliffs elevations and depth of clefts, and analysis of the glaciers' valleys profiles. It was assumed that the thickness of the ice for the larger part of the firn icecap was 20–50 m and reached 100 m along the axes of the large glaciers. The average thickness of the ice for the entire Elbrus was estimated at 50 m. At the present time, it is possible to compare these assessments with the actual data for some glaciation sites.

Based on drilling and radiosounding data at the southern slope of the Elbrus (the glaciers Garabashi, Malyi Azau, and Bolshoi Azau) obtained in 1987–1989 by the North Caucasian expedition of the Institute of Geography of USSR Academy of Sciences, the average thickness of the firn icecape was 90 m, sometimes reaching 200 m [Rototaeva et al., 2003]. The ice thickness on the northern slope should be even greater. The assessment of the volume of melted ice indicated that for the Dzhikiugankez plateau, the results of assessments of the ice thickness in 1957 were underestimated by a factor of two, approximately. It means that the average ice thickness for the entire Elbrus glaciation is possibly around 100 m, and the volume of the glaciation in 1997 can be then estimated at approximately 12,5 m^3; and at 13,6 и 16,2 km^3 for 1957 and 1887, respectively. Therefore, during the last 110 years, the glaciation volume decreased by about 22 % (or 0,2 % per year). From comparison of the estimates of the glaciation volume and ice annual average losses it is reasonable to conclude that during the nearest centuries, the Elbrus glaciers are unlikely to disappear.

COMPILATION OF THE POST IGY ELBRUS GLACIATION EVOLUTION DIGITAL MAPS AND THEIR ACCURACY ASSESSMENT

The assessment of the post IGY Elbrus glaciation evolution is based on three fixed dates: 1957, 1979, and 1997, that form two approximately even time-intervals: 22 and 18 years. We digitized a 1:10 000 scale topographic map compiled by the Laboratory

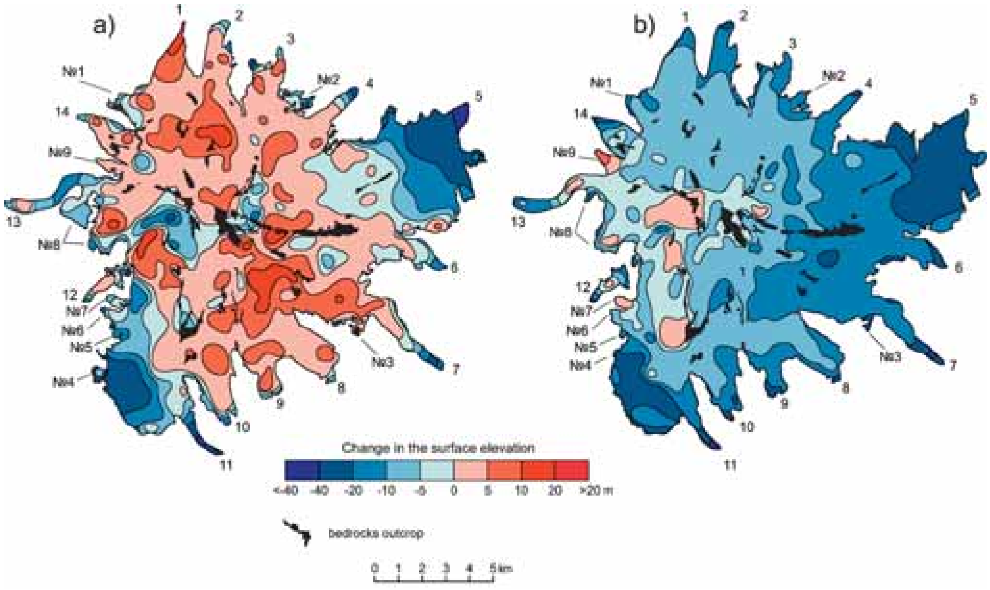

Fig. 10. Changes in the elevation of the surface of Elbrus glaciers during the intervals: a) 1957–1979 within the 1957 boundaries, b) 1979–1997 within the 1979 boundaries. Glaciers: 1 –Ulluchiran, 2 – Karachaul, 3 – Ullukol and Ullumalienderku, 4 – Mikelchiran, 5 – Dzhikiugankez, 6 – Irikchat, 7 – Irik, 8 –Terskol, 9 – Garabashi, 10 – Malyi Azau, 11 – Bolshoi Azau, 12 – Ullukam, 13 – Kyukyurtlyu, 14 – Bityuktyube.

for Aerospace Methods of the Department of Cartography and Geoinformatics of the Faculty of Geography of the MSU during the IGY. In addition, we digitally processed aerial photographic data for 1979 and 1997. As a result, for each of the dates we created digital models for the entire glaciation. The superimposition of these maps allowed measuring changes in the boundaries and elevation of the glaciation surface for each of the time-intervals. All three models were compiled using the same coordinate system and surveying control points, which substantially facilitated the models comparison. The maximal possible standard horizontal and vertical errors during the superimposition of theses multitemporal models was 2,5 m calculated from 20 contour points recognized on the maps and photographs. Because elevation measurements were conducted within the entire area of the glaciation in at least 1 mln points, the algebraic sum of errors tends to zero, as follows from the properties of random measurements errors [Reference Book..., 1966]. Therefore, a relative measurement error of changes in the glaciation surface elevations can be ignored. These theoretical discussions, in our case, were supported by the fact that the values of changes in thickness (ΔH) and volumes of the glaciers during the 1957–1997 period were obtained using two independent methods, i.e., by comparison of the digital models of 1957 and 1997 and by algebraic summation of ΔH_1 and ΔH_2 values for the corresponding periods in 1957–1979 and 1979–1997. In the ideal case, $\Delta H = \Delta H_1 + \Delta H_2$, however, due to errors associated with superimposition of multitemporal models, in reality, we had to deal with a discordance (δH) for each of the glaciers and the entire glaciation. This allowed us to define a relative measurement error for the entire glacial surface elevation at 2,6 %. A similar error of measurements for the glaciation volume was 1,8 %. Thus, the sufficiently large volume of measurements increased the end result accuracy of measurements by an order of magnitude compared to the initial estimates. It should be noted, that the 1957 topographic map, in this case, was digitized from 10 m contours. This allowed obtaining a detailed picture of changes in the surface elevation and avoiding errors in digital models based on interpolation of scattered points.

Table 4. Average annual changes in the area, elevation of the surface, and volume of the Elbrus glaciation below 4000 m elevation, for different periods

Parameter	1850–1887	1887–1957	1957–1997
Decrease in area, km^2/yr	0,310	0,210	0,190
Decrease in elevation of the surface, m/yr	0,530	0,350	0,320
Decrease in volume, km^3/yr	0,058	0,035	0,027

The compiled maps (Fig. 10) clearly show the glaciation response even for short climate change periods. In 1957–1979, despite a general decrease in the area, at almost all glaciers except for the Dzhikiugankez Plateau in its north-eastern part and Hotyu-Tau in the south-western part of the glaciation, increase in the surface prevailed reaching 40m at the northern slope of the Ulluchiran glacier. This resulted in a low positive mass balance of the entire glaciation during this period assessed at +0,94 m of water equivalent. The process was clearly a result of the total decrease in air temperatures of the Northern Hemisphere during the 1960s [Kotlyakov, 1994] when the Elbrus glaciers were advancing [Panov, 1993]. During the second period of observations (1979–1997), a universal decrease in the surface elevation took place, except for an insignificant area near the Elbrus summit. The greatest decrease was noted at the glaciers of the glaciation slope –Chungurchatchiran and Birdzhalychiran, combined under the common name the "Ice Field of the Dzhikiugankez". Here, the average value of the surface decrease for the entire glaciation area was 16,8 m reaching 40 m at the tongues.

CONCLUSIONS

In general during 40 years after the IGY (1957–1997), the Elbrus glaciation volume has decreased by 1,2 km3 which is equivalent to 1 km3 of water; 45 % of this amount falls on the two aforementioned glaciers of the

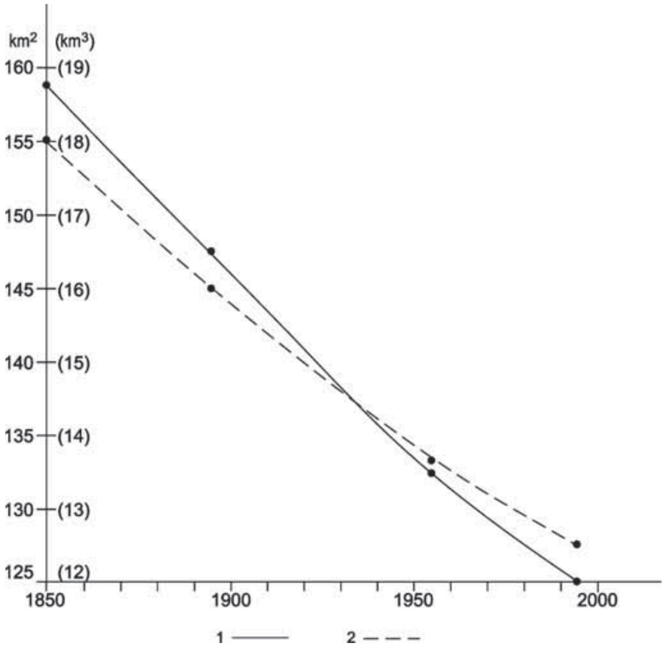

Fig. 11. Change in the area and volume of the Elbrus glaciation for 1850–1997. 1 – change in the area, km^2, 2 – change in the volume, km^3.

northeastern slope. The major portion of this volume (i.e., 98 %) is contained in the lower part of the glaciation, specifically from the ends of the tongues to the elevation of 4000 m. This fact allows tracing the rate of glaciation retreat that began in the mid XIX century because the decrease in the volume and area of the glaciation was due to melting of the glaciation tongues (Table 4).

These reasonably reliable quantitative data indicate that the greatest rate of the glaciation decrease was associated with the earlier period (1850–1887). Beginning in 1887, there has been practically even decrease in the area while volume reduction has slowed down (Fig. 11).

These data suggest that global climate change, which alternated with short periods of cooling, began in XIX century after the end of the Little Ice Age and was more likely due to natural than anthropogenic causes.

ACKNOWLEDGEMENT

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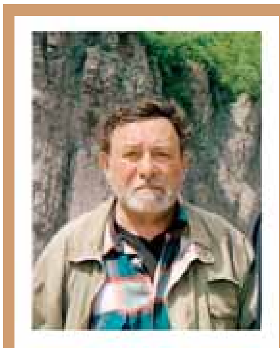

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SEA LEVEL AND PALAEOCLIMATIC CHANGES IN THE SOUTH AND MIDDLE CASPIAN SEA REGION SINCE THE LATEGLACIAL FROM PALYNOLOGICAL ANALYSES OF MARINE SEDIMENT CORES

ABSTRACT

A review of pollen, spores, non-pollen palynomorphs and dinocyst analyses made in the last two decades is proposed here. Building on spare palynological analyses before 1990, a series of new projects have allowed taking cores in the deeper parts of the Caspian Sea, hence providing access to low-stand sediment. However, still nowadays no complete record exists for the Holocene. The first steps towards quantification of the palynological spectra have been taken. Some of the most urgent problems to solve are the uncertainties related to radiocarbon dating, which are especially acute in the Caspian Sea.

KEY WORDS. Caspian Sea, pollen, dinocysts, Lateglacial, Holocene, climate, sea level

INTRODUCTION

The Caspian Sea has known many small and large-scale changes of its water level: c. 160 m in the last glacial-interglacial cycle and > 3 m in the last century [Kroonenberg et al. 2000]. In the latter period, these changes have had a dramatic impact on socio-economical activities around the sea [Kazancı et al., 2004; Leroy et al., 2010]. To reconstruct past sea level changes in the Caspian Sea (CS) and past climates 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. 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 (Fig. 1). Their multidisciplinary analyses covering both low and high stands holds the key to understanding firstly when sea level changes occurred, which is a step before understanding why they occur and secondly how climate changed, how fast and what were its drivers.

DRIVERS OF CASPIAN SEA LEVELS

In summer 2010, extreme temperatures well above 30 °C have affected Moscow for nearly two months. As a direct result of this and combined drought, extensive wildfires occurred in the Volga region. Global Climate Models have suggested that drought over the Volga basin would occur when ENSO is in La Niña phase [Arpe et al. 2000], and this is what occurred in 2010.

Figure 1a: Location of the Caspian Sea in relation to neighbouring seas;
1b: Location map of the cores and the main inflow in the Caspian Sea

Figure 2: Flooded mosque on N-E Iranian coast, view from the Ashoorade Island (Miankale Spit) to the Elburz Mountains (photo by S. Leroy in 2005)

Precipitation during summer plays a dominant role on sea level and this explains well the two major events that happened in the 1930s (drop) and after 1977 (rise) [Arpe and Leroy, 2007] (Fig. 2).

Nowadays the Volga River brings 80–85 % of the river water to the CS. However a few centuries ago, the Uzboi River (now defunct) brought water from the Amu-Darya [Létolle, 2000] a river whose source is in the Pamir and Tien-Shan and therefore its water is derived from the melting of monsoon-fed glaciers. Therefore the Caspian Sea water levels may be influenced both by climate of northern Europe and by climate over the western Himalayas.

PROXIES

Besides pollen (for example the former work of Abramova [1980] and Vronsky [1980] and the current work cited here) 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 have many endemic forms in 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, and nutrient content [Mertens et al., 2009]. Therefore this method is a proxy for sea-level changes. Plates 1 and 2 show some forms characteristic of the Caspian Sea and the Karabogaz Gol.

SURFACE SAMPLES

Surface samples are essential to interpret past changes, as they are a stepping stone to quantification by linking microfossil assemblages to environmental and climatic conditions (analogues). A collection of surface samples form useful training sets

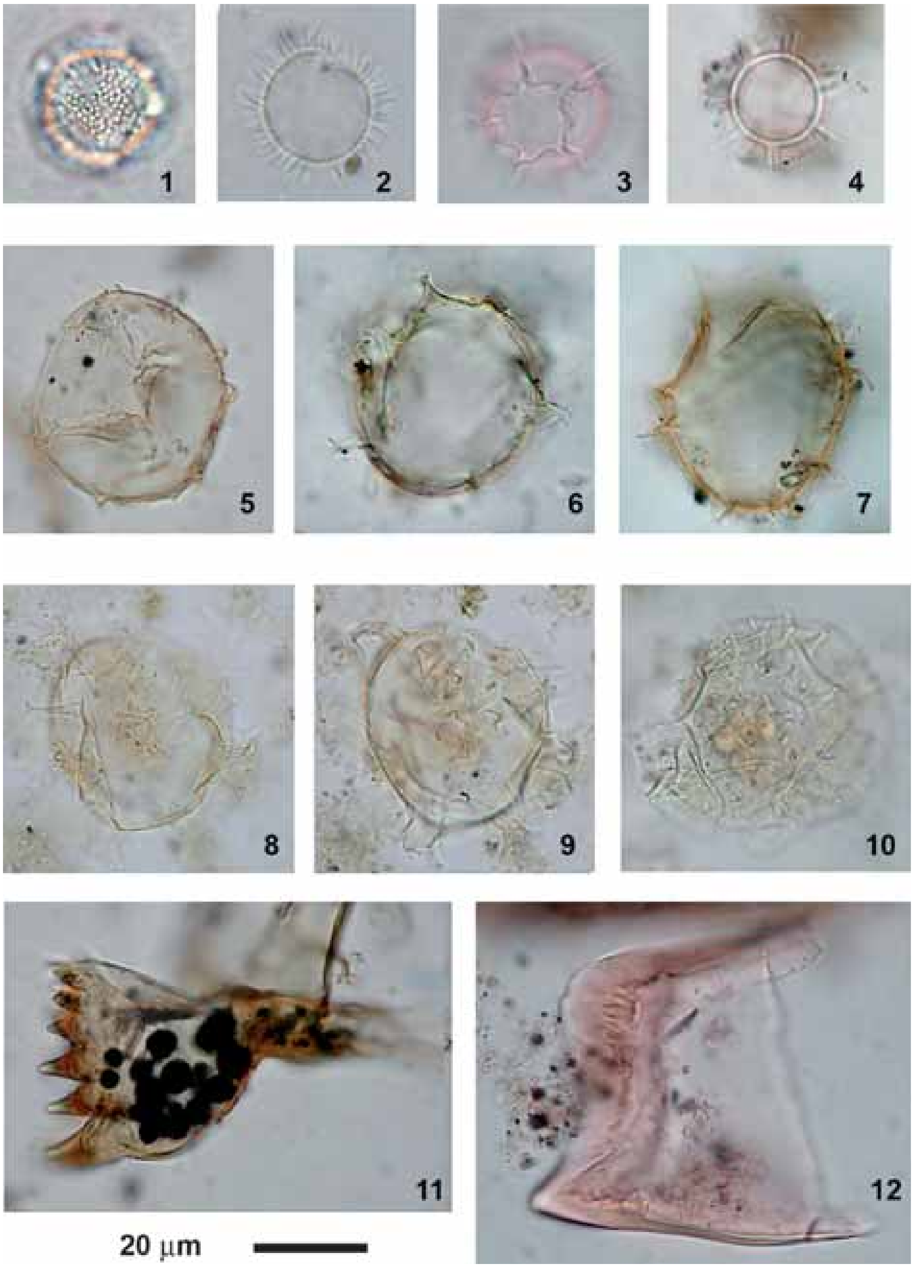

Plate 1: Photographs of palynomorphs of the Caspian Sea and the Kara-Bogaz Gol.

1. Incertae sedis 5b, fenestrate type of 5b, core SR94G05, I 70 cm.

2. Incertae sedis 5b, fenestrate type of 5b, other specimen, optical section, core SR94G05-I, 70 cm.

3. *Pterosperma*, core SR94CP14, 0–2,5 cm

4. *Pterosperma*, optical section, core SR94CP21, I 5 cm

5. *Impagidinium* caspienense, common type, core Gm2, 7–98 3,35 cm

6–7. *Impagidinium caspienense,* type with spiky processus, two different specimens, core SR94GS05, III 92 cm

8–9. *Spiniferites* belerius, core KBG8-01, 58–57 cm

10. *Lingulodinium machaerophorum* var. A, which is a form typical of the Kara-Bogaz Gol, core KBG8-01, 58–57 cm

11. Mandible of ostracod, core Gm2, 7–98 3,35 cm

12. Tooth of gastropod radula, core SR94CP14, 20 cm

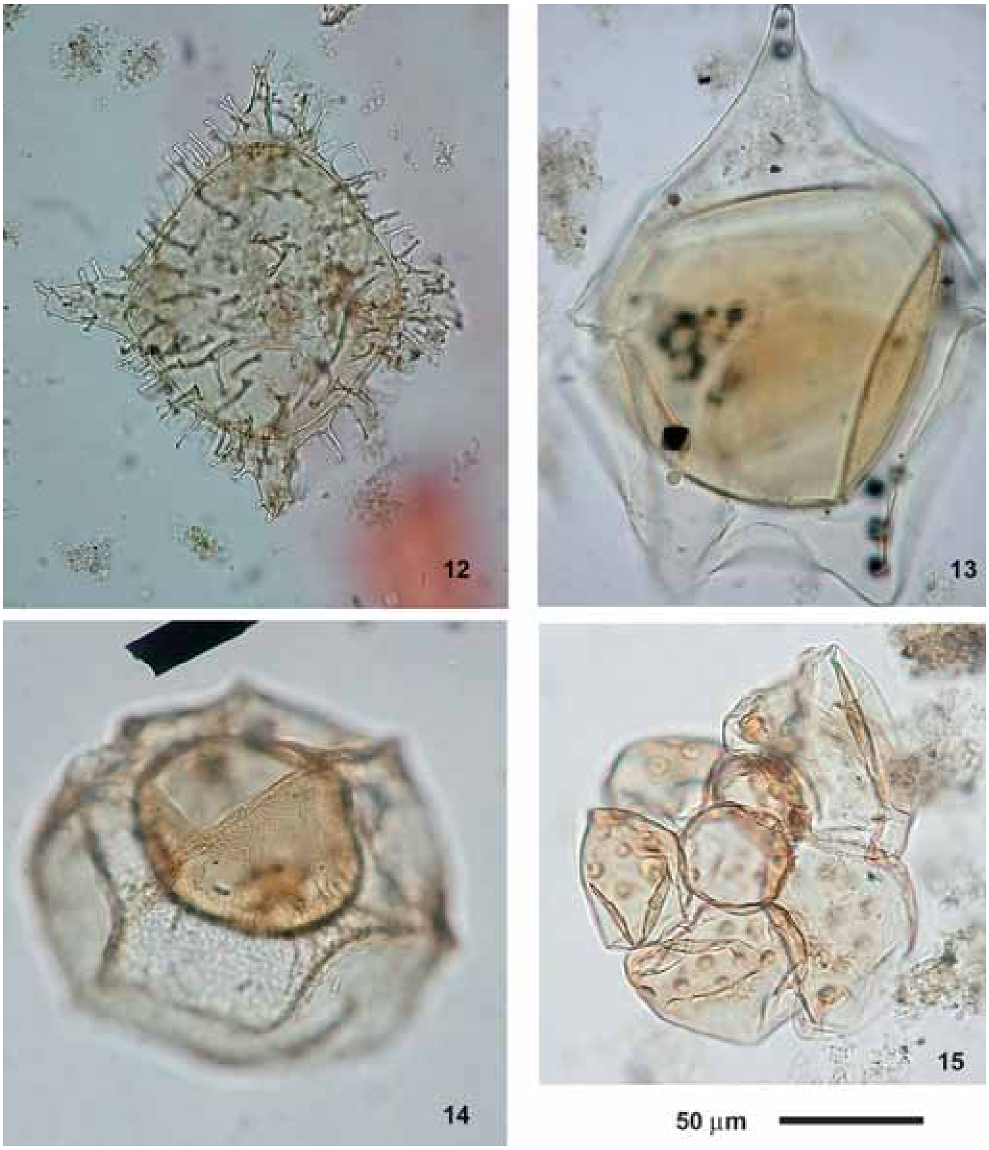

Plate 2: Photographs of palynomorphs of the Kara-Bogaz Gol.

15. Foraminifer lining, core KBG8-01, 18-19 cm

Reworked dinoflagellate cysts of the Karabogaz-Gol

12. Wetzeliella, core KBG8-01, 18–19 cm
13. Deflandria, core KBG8-01, 18–19 cm
14. Unidentified dinocyst, core KBG8-01, 17–18 cm

and allows 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 in 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 CO_2 [Higham, no date].

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]; and 345 to 384 yr in Karpytchev [1993]. 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 radionuclid method is the best, either ^{210}Pb alone or in combination with ^{137}Cs. The combination of radiocarbon and radionuclid methods however still leaves a gap between AD 1750, the most recent reliable radiocarbon ages due to a subsequent plateau, and AD 1860, the oldest age obtained by radionuclids.

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 ^{210}Pb) [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 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 (core CS03 off Anzali in the west and core CS10 off Babolsar in the centre) at water depths of 250 m [H. Lahijani, pers. comm.]. The sequences cover the last 200 years according to radionuclid 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 coastal lagoons of Anzali (core HCGA05, 170 cm long) and Amirkola (core HCGL02, 100 cm long) have been cored by the Iranian National Institute of Oceanography (INIO). The radiocarbon dates on shells combined with radionuclids indicate high but very varying sedimentations rates depending on locations. Palynological analyses of Anzali revealed the continuous existence of a slightly brackish lagoon over the last centuries and of Amirkola (analyses made jointly with M. Djamali) show the progressive closing up of the water body [Leroy et al., accepted]. Higher sea levels at the base of these two records have been related to the Little Ice Age. The strong influence of the Sefidrud River and other small rivers flowing from the Alburz Mountains, which carry huge volumes of sediment to the sea, is probably the main driver of these changes with sea level coming in second position.

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 [Leroy et al., 2007].

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, carrying to the Caspian Sea either meltwater from higher Eurasian latitudes or water from the Amu-Darya and the western Himalayas. 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 [Chali'@e et al., 1997]. Core GS05 from the south basin (museum number SR01GS9405) was taken in a slightly different coring station than core CP 14, i.e. in a more southerly location, but the two cores seem to overlap for a millennium. Core and core GS18 from the 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 corer penetration.

The pre-Holocene sediment of the long core from the south basin is silicate rich. Preliminary results suggest a very open landscape during the Lateglacial with intensive mechanical weathering in a cold climate and high water levels [Leroy et al., 2000; 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 9,5 cal. ka BP, 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 BP. Therefore the two basins did not have the same water level history giving 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 continuous fine-grained marine cores covering a whole climatic cycle with robust age-depth model are cruelly needed [Cordova et al., 2009].

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SOME FEATURES OF THE BLACK SEA SEASONAL THERMOHALINE VARIABILITY: MODERN VIEW

ABSTRACT
Results of statistical processing and physical analyses of the historical and recent hydrographic data set are presented. A seasonal thermohaline (hydrographic) variabilities of the Black Sea main baroclinic layer (0–200 m) are considered. In the upper 50-m layer, seasonal thermohaline variability is generated mainly by the heat and freshwater fluxes across the sea surface. In the main pycnocline between depths of 50 and 200 m it is caused by the flux of the wind-stress relative vorticity. Thermohaline effects of these processes are described.

KEY WORDS: The Black Sea, temperature, salinity, seasonal variability

INTRODUCTION

The Black Sea attracts considerable attention due to its natural originality, resource abundance, great historical value and vital importance to human societies of the vast region. Specifically, there has been modern increasing environmental concern over hydrocarbons transportation through the Black Sea by pipelines and ships.

The first large generalization of the earlier studies of the Black Sea physical oceanography performed in the 1890–1930s under the guidance of I.B. Shpindler, Yu.M. Shokalskii, and N.M. Knipovich was made in monographs [Knipovich, 1932], which describes the major part of the hydrographic (thermohaline) features of these seas that are known at present. Later, finer features of the thermohaline structure and related physical processes were discovered. In the middle of the 20th century we should note the monographs [Leonov, 1960, Filippov, 1968] devoted to the geographical and physical descriptions of the hydrographic regime of the Black Sea waters. The monograph [Blatov et al., 1984] presented a systematic quantitative description of the processes of the climatic, seasonal, inter-annual, synoptic, and short-period variabilities of the temperature and salinity of the Black Sea waters. Further refinements of the thermohaline regime of the Black Sea were generalized in [Simonov & Altman, 1991].

In this paper, we present the modern generalized view on the some large-scale features of the Black Sea seasonal thermohaline (temperature and salinity) variability. To a great degree, it define the condition and functioning of other components of the Black Sea ecosystem, in particular, the general circulation and chemical properties of the waters, marine flora and fauna. This study differs from the above mentioned monographs by a significantly (1,5–2-fold) greater amount of the measurement data used, an updated technology for their processing, and modern approach to interpretation of results.

DATA AND METHODS

The description is mainly based on the results of modern statistical processing and physical analysis of historical data set of the ship and coastal measurements of the water temperature and salinity vertical profiles, following the procedures and recommendations given in [Boyer & Levitus, 1994, Locarnini et al., 2006]. We processed and analyzed the data for a 50-year-long interval (1956–2005) with the highest measurement density. The total number of pairs of vertical temperature and salinity profiles in this period exceeded 90 000. Geographically, they are mostly concentrated in the near-shore areas and along standard sections. Meanwhile, it should be noted that the coverage of the entire area of the Black Sea is relatively good.

RESULTS AND DISCUSSION

The features of the thermohaline structure of the Black Sea waters in most are related to the very restricted water exchange of the Black Sea with the adjacent parts of the World Ocean (the Sea of Marmara and the Sea of Azov), because of which its external water budget is generally small [Simonov & Altman, 1991].

The fresh waters supplied to the Black Sea with the riverine runoff and precipitation are distributed by currents and turbulence over the upper mixed layer (UML) of the sea with a thickness of 5–10 m in the spring and summer and up to 40–60 m at the end of the winter. Usually, the water salinity in this layer is within the range 17,5–18,5 practical salinity units (psu). The saline (35–36 psu) waters of the Sea of Marmara flow in the southwestern part of the Black Sea through the Bosporus Strait at a level of 60 m and sink to the deeper layers. Thus, in the multi-annual mean (climatic) regime, the depth of 60 m represents the boundary of the direct influence of the surface fresh waters and the saline waters of the Sea of Marmara. They may be referred to as primary water masses [Mamayev et al., 1994], supplied to the Black Sea from outside, which have no direct contact in the Black Sea.

The Black Sea UML in the warm period of the year is underlain by the layer of the seasonal pycnocline (thermocline). This layer is also thin (10–20 m) but features high vertical gradients of temperature (0,2–0,3 °C m^{-1}) and, correspondingly, of water density (0,10–0,15 kg • m^{-4}). By the end of the winter, owing to the thermal convection, the thickness of the UML over the greater part of the area increases up to 30–60 m. At this time, the UML is limited from beneath by the layer of the main (constant) pycnocline (halocline) the depth range from 30–60 to 150–200 m of the Black Sea with vertical density gradients up to 0,03–0,04 kg • m^{-4}. In the near-mouth areas of the Black Sea, due to the high vertical gradients of the water salinity, the winter thickness of the UML comprises less than 10 m.

The absolute minimum of the water temperature in the Black Sea is usually encountered in the upper part of the main pycnocline (at a depth of 50–75 m) and has values of 6,5–7,5 °C. Only in severe winters is it located in the UML. The layer with a temperature lower than 8 °C is referred to as the cold intermediate layer (CIL). In the warm period of the year, it is "sandwiched" between the seasonal and main pycnoclines. Over the greater part of the area, at the end of the winter, the upper boundary of the CIL (the upper 8 °C isotherm) is exposed at the sea surface. At this time, the major part of the CIL is located inside the UML and only its lower part is related to the main pycnocline.

So, In the upper layer of the Black Sea approximately 40–60 m thick the principal thermal processes are represented by the winter renewal of CIL and by the spring formation and autumn destruction of the seasonal thermocline.

The seasonal signal of the Black Sea UML salinity is manifested by maximal values in February–March (from 18,4–18,7 psu in central area to 17,7–18,2 psu in coastal area) and minimal values in late spring – early summer (from 18,0–18,2 psu in central area to 17,0–17,7 psu in coastal area). Winter

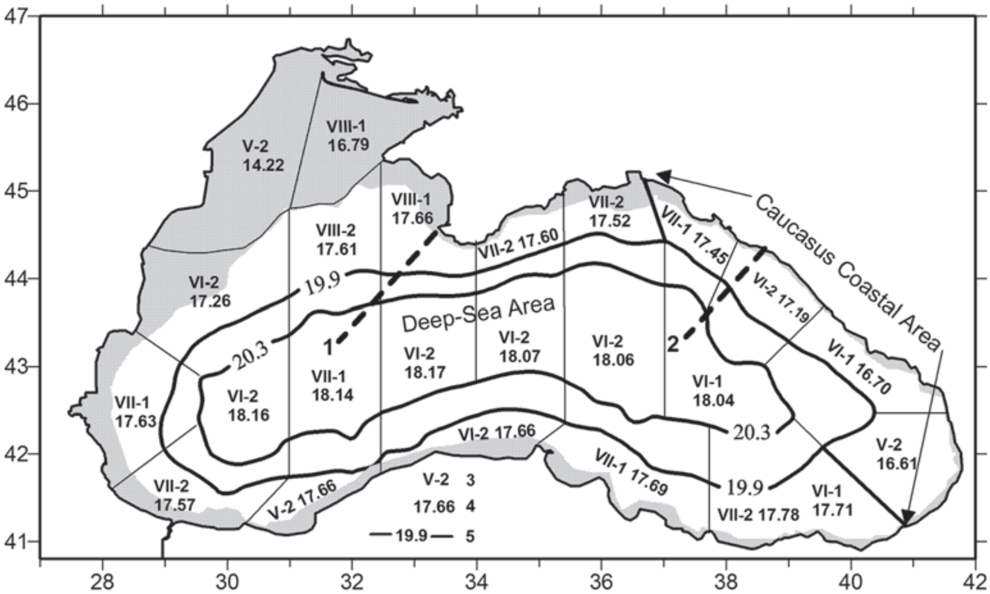

Fig. 1. Scheme of the Black Sea regions with homogeneous hydrographic conditions and distribution of annual salinity minimum value and phase: 1 and 2 – standard hydrographic sections southwestward from Sebastopol (1) and Tuapse (2), 3 – annual salinity minimum phase (half month) and 4 – value (psu), 5 – climatic annual mean isohalines at a depth of 100 m, delineated coastal (19,9 psu) and central (deep-sea, 20,3 psu) areas, and the main frontal zone between them. Shaded area with bottom depth less then 100 m

maximum exist despite the fact that the resulting winter freshwater runoff to the Black Sea (up to 40 км^3 per month, according to [Goryachkin & Ivanov, 2006]) is close to (only 25 % smaller than) the maximal spring runoff. The reason for this inconsistency lies in the intensive convective entrainment in the winter UML of the more saline underlying layers. Results of our calculations of climatic half-month sea surface salinity in 38 regions of the Black Sea show that spatial distribution of annual salinity minimum phases and values (Fig. 1) are more variable then ones of the salinity maximum.

Absolute salinity minimums (much less than 17 psu) take place in near-river-mouth north-western and south-eastern areas in 2-nd half of May. From them, tongues of freshened waters extend along the shores in the general cyclonic (anticlockwise) direction with progressive time delay and rising of salinity minimum value. In regions of the Black Sea central (deep-sea) area the annual salinity minimum value and phase are much more homogeneous (about 18,1 psu and 2-nd half of June, respectively, see Fig. 1). The reason for this is positive difference P-E (precipitation minus evaporation), lasting here from late autumn to June. The coastal water, diluted by river freshwater, diffuses into central area only after June, but its effect is compensated by high summer and early autumn evaporation.

The amplitudes of the Black Sea surface annual heating/cooling and freshening/salting rapidly decrease with depth down to a level of 30 m. Below 30 m, the principal seasonal process is the winter increase and the summer decrease of the dome height of the Black Sea main pycnocline. The first interpretation of this feature was suggested in [Blatov et al., 1984] from the point of view of the response of the large-scale potential vorticity of the Black Sea waters to the seasonal variations in the influx of the relative vorticity from the wind field over the sea surface, which has a cyclonic character in the winter and anticyclonic character in the summer.

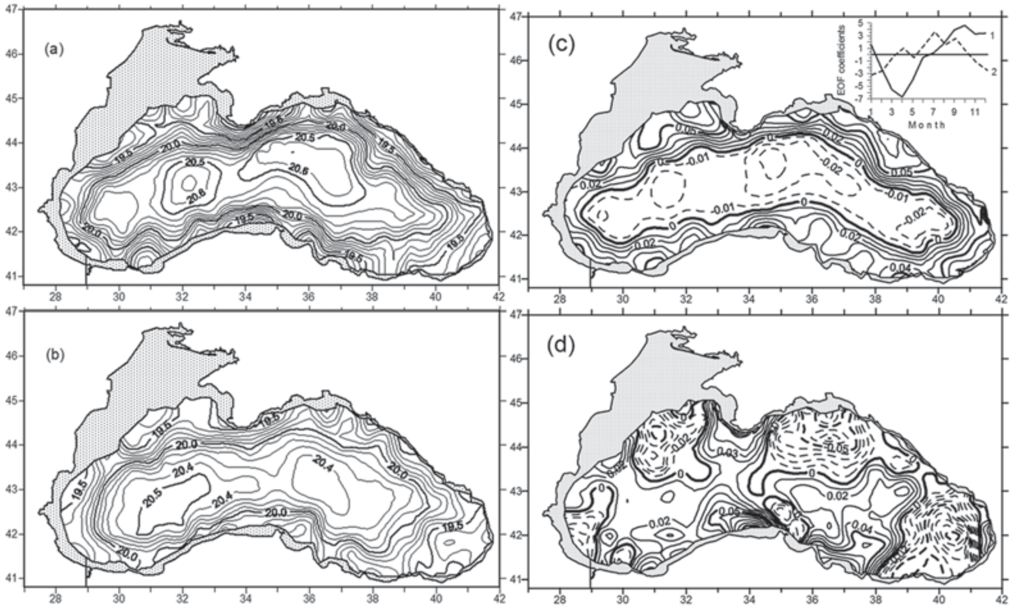

Fig. 2. Climatic monthly fields of the water salinity (psu) of the Black Sea at a depth of 100 m in February (a) and in August (b), and empirical orthogonal functions (EOF) of climatic salinity annual cycle at a depth of 100 m: the 1-st EOF (c) and the 2-nd EOF (d), and annual variations of its coefficients (inset in Fig. 2c)

In the course of this process, the seasonal changes in the temperature and salinity in the main pycnocline layer in the central and coastal areas of the Black Sea proceed in a opposite phases. The amplitudes of the corresponding oscillations reach their maximum at a depth of 100 m. The seasonal (from winter to summer) variability of the horizontal structure of the main pycnocline is especially clear manifested in the salinity field at the 100-m level (Fig. 2a, b). In all the seasons of the year, three types of structural elements are well recognized: the alongshore, the central area of the maximal salinity, the coastal area of the minimal salinity, and the Main frontal zone (MFZ) of high cross-shore salinity gradients. MFZ is closely related to the main element of the general water circulation in the upper 500-m layer of the Black Sea – the Main Black Sea Current [Blatov et al., 1984] or the Rim Current [Ozsoy & Unluata, 1997].

At the end of the winter – the beginning of the spring (from February to May), the MFZ is most intensive. The maximal cross-frontal salinity gradients are located closer to the inshore edge of the MFZ (Table 1). At the end of the summer – the beginning of the autumn (from August to October), these values decrease twofold over the entire Black

Table 1.

Section *N*	X_{max}**, km**	$(dS/dx)_{max}$ **, psu km**$^{-1}$	X_{off} **, km**	X_{in} **, km**
February				
1	65 ± 35	0.0165 ± 0.0039	128 ± 36	11 ± 39
2	35 ± 16	0.0169 ± 0.0064	83 ± 21	10 ± 5
August				
1	72 ± 53	0.0079 ± 0.0059	94 ± 44	31 ± 37
2	41 ± 23	0.0085 ± 0.0045	73 ± 24	18 ± 16

Sea area (see Fig. 2b and Table 1), while location of the maximal cross-frontal salinity gradients shifts toward the offshore edge of the MFZ, whose width decreases. This is caused by the winter–spring strengthening and the summer–autumn weakening in the Black Sea general circulation owing to the enhanced cyclonic activity in the autumn and winter and to the anticyclonic weather conditions in the spring and summer [Simonov, Altman, 1991]. The MFZ strengthens with a delay of approximately three months with respect to the maximum of the wind forcing, which is about one-fourth of the annual cycle; this kind of delay is characteristic of the processes in "forcing–response" systems.

For a more detailed study of the annual variability of the horizontal structure of the Black Sea main pycnocline, we decomposed climatic monthly salinity fields at a depth of 100 m over empirical orthogonal functions (EOF). The results showed that 80 % of the total dispersion of the annual variability in the salinity fields are described by five EOF; two of them are presented in Fig. 2c, d.

The 1st EOF (Fig. 2c), that is responsible for 46,1 % of the total dispersion, represents the most large-scale mode of the Black Sea main pycnocline response to external forcing. The annual variability of the corresponding coefficient (curve 1 in inset of Fig. 2c) shows that the maximal positive (negative) salinity anomalies in the central (coastal) areas of the Black Sea described by this mode are observed in April, when the main pycnocline dome is especially high. An opposite situation is observed a half-year later, in October, when the dome is most low.

The 2nd EOF (Fig. 2d) that describes 14,2 % of the total dispersion represents an alongshore quasi-periodical structure with a wavelength of 300–400 km and coastal trapping of amplitudes, which decreases with the distance from the coast. The annual cycle of the variability of the 2nd EOF coefficient (curve 2 in inset of Fig. 2c) is shifted by a quarter of the period with respect to the 1st EOF. This mode of the main pycnocline variability should be most clearly manifested in the summer in the salinity fields at a depth of 100 m.

The 3rd–5th EOF (not shown), each of which covers from 5,9 to 6,8 % of the total dispersion, also feature a wave structure trapped by the coast. One may suggest that they represent overtones of the 2nd EOF.

The combined effect of the 2nd and higher modes of the annual variability of the main pycnocline was obtained by extracting the contribution of the annual mean salinity field and 1st EOF from the monthly salinity fields at a depth of 100 m. The results for the first six months of the year are shown in Fig. 3.

The areas of the salinity anomalies of different signs shown in Fig. 3 have sub-basin sizes and a complicated spatial and temporal evolution. This is manifested in the cyclonic (anticlockwise) rotation of the pairs of anomalies of opposite signs (dipoles) with respect to their common centers and in the changes of their shapes, sizes, and intensities. While approaching to the coast, the anomalies fast spread about it. In the 2nd half of the year, the evolution of the anomalies is identical to that shown in Fig. 3, but with an opposite sign.

Hence, we can suggest that, at certain stages of their joint cyclonic rotation, salinity anomalies are trapped by the coast, fast spread along it, and then are issued to the open sea. The rapid increases and decreases in the sizes and intensities of the anomalies point to their wave origin. The wavelength along the trajectory of the centers of the anomalies that form a dipole pair comprises about 300–350 km, a mean phase speed of the cyclonic motion – 1,0–1,5 km day^{-1}. Within the alongshore segments of the trajectories, the phase speed of the anomalies is greater, while at the center of the sea it is slower.

The first evidence of sub-basin termohaline undulations with annual period in the Black Sea were received in [Eremeev et al., 1994] from harmonic analysis of climatic salinity

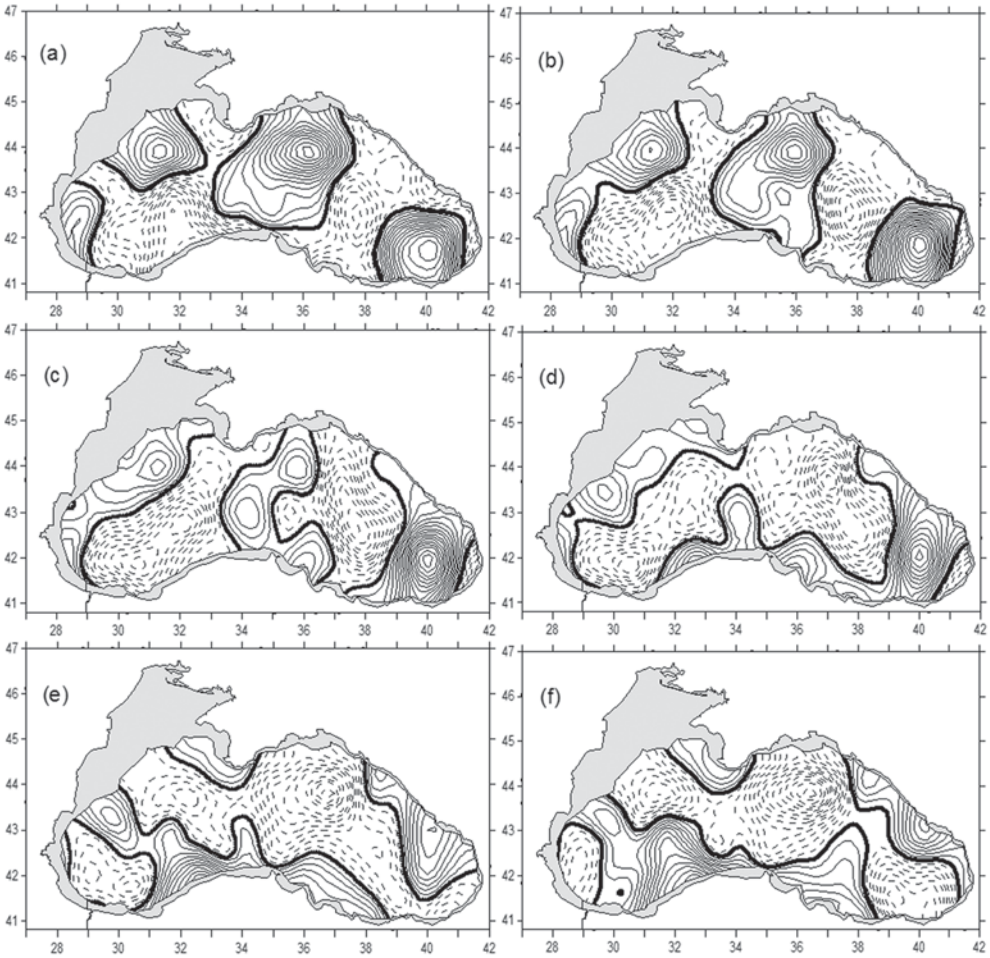

Fig. 3. Climatic fields of the Black Sea water salinity anomaly at a depth of 100 m received by subtraction the annual mean and 1-st EOF fields from climatic monthly salinity field in: (a) January, (b) February, (c) March, (d) April, (e) May, (f) June. Contour interval – 0,05 psu. Dashed lines – negative anomaly

fields. Some years later were received independent confirmations of this in space (ERS-1/2 and TOPEX/Poseidon) altimeter data [Stanev et al., 2000, Korotaev et al., 2001].

Model studies of the mesoscale water dynamics of the Black Sea waters [Rachev & Stanev, 1997, Stanev & Rachev, 1999] showed the possibility of the existence here of Rossby waves with a period about 0,5–1,0 year, a wavelength of 250–350 km, and a phase velocity of 1–2 km day^{-1}. The model Rossby waves were generated by the wind forcing in the southeastern part of the sea. While crossing the narrowest part of the Black Sea south of the Crimea, their phase speed, sizes, and intensities significantly decreased and their final dissipation occurred off the western continental slope. The topographic effects only slightly modified their evolution. Meanwhile, in [Rachev & Stanev, 1997, Stanev & Rachev, 1999] the authors reported manifestations of coastal trapped waves and discussed their possible interaction with the Rossby waves. This interaction resulting in the formation of hybrid Rossby–coastal trapped waves was obtained with the model of mesoscale water dynamics in a circular basin [Bokhove & Johnson, 1999]. The proportions of the properties of the coastal trapped waves and the Rossby waves in this model changed at different evolution stages of hybrid waves.

In our case, we may suggest that the response of the Black Sea main pycnocline to the external (wind) forcing of an annual periodicity is manifested in superposition of an annual basin-scale standing oscillation and sub-basin hybrid Rossby–coastal trapped waves, which form quasi-geostrophic cyclonic amphidromic systems (some analogous to tidal amphidromic systems).

Below the main pycnocline, where seasonal (and inter-annual) variability is indistinguishable, one finds the layer that is named sometimes generally as the deep layer. In the depth range from 200 to 1700 m, one observes a layer with a slow increase in the temperature (with the exception of an isothermal layer between 500 and 700 m) and salinity with depth sometimes broken by T, S-inversions with vertical scales about 10 m, which is typical of the fine T, S-structure of the waters [Murray et al., 1991]. The deep-water observations with conductivity-temperature-depth profilers performed in the Black Sea during the past two decades allowed one to distinguish the near-bottom mixed layer (NBML). A distinct upper boundary of the NBML is traced at depths from 1750 to 1800 m. Above it, up to a depth of 1700 m, one finds a layer with increased vertical gradients of water temperature, salinity, and density with a thickness about 100 m. It separates NBML from the deep stratified layer. In [Eremeev et al., 1997], it was shown that the observed parameters of the NBML in the Black Sea are defined by the buoyancy fluxes balance between the destabilizing geothermal heat flux and stabilizing salt flux supplied with the waters of the Sea of Marmara penetrating to great depths.

CONCLUSIONS

The generalization of the results of the studies of the Black Sea seasonal thermohaline variability presented in this paper allows us to make the following conclusions:

- the thermohaline structure of the Black Sea waters consists of a few characteristic layers with different thicknesses: the upper mixed layer (UML), the seasonal pycnocline (thermocline); the cold intermediate layer (CIL), the main pycnocline (halocline), the isothermal intermediate layer, the thickest deep layer with a slow temperature and salinity increase with depth, and the near-bottom mixed layer;
- the principal features of this structure are related to the very weak vertical turbulent exchange of the thermohaline properties between the freshened surface and the much more saline deep water mass;
- the seasonal variability of the UML, the seasonal pycnocline, and the CIL are caused by the corresponding variations in the heat and freshwater fluxes through the sea surface and in the riverine runoff;
- the seasonal variability of the main pycnocline are caused by the changes in the flux of the wind relative vorticity;
- the response of the Black Sea main pycnocline to the annual forcing by momentum and vorticity fluxes from the wind is manifested in the superposition of two principal modes – a basin-scale standing oscillation and sub-basin hybrid Rossby–coastal trapped waves, which form quasi-geostrophic cyclonic amphidromic systems.

Some of these conclusions are hypothetical in the meanwhile. The degree of their validity should be found out from further studies. ■

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ASSESSMENT OF HEAVY METAL POLLUTION OF SOILS IN INDUSTRIAL CITIES OF MONGOLIA

ABSTRACT

This paper presents qualitative and quantitative assessment of technogenic anomalies of heavy metals in urban soils of Ulaanbaatar, Darkhan, and Erdenet (Mongolia), including the assessment of background geochemical conditions of the study area and technological specialization of the cities. The research efforts concentrated on identifying spatial geochemical heterogeneity of urban soils depending upon their functional identity. The ecological status of the urban soils was evaluated based on standards accepted in Mongolia.

KEY WORDS: heavy metals, technogenic anomalies, pollution, urban soils, Mongolia

INTRODUCTION

Industrial development in Mongolia during recent decades has led to urban population growth and to aggravation of a number of environmental problems in its cities. Increasing technogenic pressure on the environment caused pollution of air and water, accumulation of pollutants in the soil cover, and deterioration of living conditions of urban residents. Socio-economic conditions that existed in the early 90's of the 20-th century in the cities of Mongolia have undergone significant changes [Gunin et al., 2003]. The purpose of this study was to establish qualitative and quantitative characteristics of technogenic geochemical anomalies of heavy metals (HM) which are the priority pollutants in the soils of three major industrial centers of Mongolia – Ulaanbaatar, Darkhan, and Erdenet.

These cities are located in intermontane valleys and depressions between hills and low mountains of the Hangayn-Hentiyn mountainous area in the Selenga river basin. Ulaanbaatar is the country's capital with a diverse industrial sector. Erdenet is the Mongolian largest production center of enrichment and primary processing of non-ferrous metals (copper and molybdenum). In Darkhan, the industrial sector includes primarily ferrous metallurgy and light and construction industries. The sources of pollution in all three cities are associated with thermal power plants (TPP) and ger districts. These entities use brown coal whose combustion products pollute the atmosphere [Kasimov et al., 1995].

The objectives of the research presented herein were to:

- characterize background geochemical parameters of soils in the study region, including the natural geochemical ore anomaly in Erdenet;
- assess general trends of technogenic transformation of micro-elemental composition of urban soils and specific features of soil pollution in different functional zones; and
- carry out environmental-geochemical assessment of HM pollution of the urban soils based on standards accepted in Mongolia.

These objectives were achieved through the ecological-geochemical concept. Basically, the content of chemical elements and their associations was determined in the landscape components (i.e., soil, snow cover, and vegetation) that serve as accumulating media for these chemical substances [Environment geochemistry, 1990; Glazovskaya, 1988; Kasimov, 1995] representing good indicators of pollution and ultimately of environmental change in urban settings.

MATERIALS AND METHODS

This study used the findings of the Joint Russian-Mongolian Complex Biological Expedition. Soil sampling[1] was conducted in Ulaanbaatar (99), Darkhan (46), and Erdenet (50) in December 2007. Mixed soil samples were taken by the "envelope" method (1m × 1m) from the top sod-humus layer (0–10 cm) at every 500–800 m in horizontal direction. In addition, samples of brown coal from three deposits near Ulaanbaatar (Nalaikh, Baganuur, and Chuluut) and of ash from the TPP-3 (provided by the Committee for Air Quality Monitoring of the Ministry of Environmental Protection of Mongolia) were collected.

The bulk content of Cu, Zn, Pb, Ni, Co, Cr, V, Mo, W, Sn, Ga, Ge, Ti, Mn, Y, Zr, Sn, and Ba in the soil samples was determined by an approximate quantitative spectral method with a spectrograph DFS-465S in the Alexandrov Geological and Geochemical Expedition Laboratory of the Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rare Elements (IMGRE). Concentrations of Hg were identified by a portable Zeeman mercury analyzer RA-915+. Basic physical and chemical properties of the soils were defined by routine methods [Orlov, 1985]. To check the accuracy of the approximate quantitative spectral method, the samples of soil, brown coal, and ash were analyzed by mass spectrometry and inductively coupled plasma mass spectrometry (ICP-MS) at the All-Russian Institute of Mineral Raw Materials (VIMS), using devices "Elan-6100" and Optima-4300 DV ("Perkin Elmer", USA). A satisfactory agreement between these methods in determining the concentrations of HM was established.

The analytical data obtained in the study were grouped by functional zones and processed statistically using Statistica 7 software (Mathsoft, 2004). Stable associations of elements in the soils were identified by cluster analysis (Complete Linkage

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[1] The number of samples is given in parentheses.

clustering); similarity of HM behavior was characterized by a correlation coefficient (*r*).

The clarkes of concentration (CC) and dispersion (CD) of HM in background soils were calculated with respect to the global Vinogradov's clarkes [Vinogradov, 1962] used because they occupy an intermediate position between the estimates of Greenwood and Earnshaw [2008] and Bowen [1979]. For the urban soils, the coefficients of concentration (C_c) and dispersion (C_d) of HM were calculated. Technogenic geochemical specialization of the urban soils was defined by a formula that included metals with C_c > 1,5 and whose values are subscribed next to the element symbols. Concentrations of elements in the soils of recreational landscapes in Darkhan and Erdenet were assumed to be reference; in Ulaanbaatar, background conditions were represented by the soils of the Natural Reserve Bogdhan uul and the soils of recreational landscapes.

Ecological-geochemical assessment of the urban soils was based on the integral index of soil pollution

$$Zc = \sum_{i=1}^{n} K_c - (n - 1),$$

where n – number of metals with $C_c > 1$ [3].

Different levels of soil pollution were described by the following values of Zc: minimum (or low) ($0 < Zc < 16$); medium ($16 < Zc < 32$); heavy ($32 < Zc < 64$); extremely heavy ($64 < Zc < 128$); and maximum ($Zc > 128$). Maps on Zc distribution in the urban soils were compiled using the ArcGIS IDW method.

The priority pollutants were identified by comparing the concentrations of elements in the soils with the maximum permissible concentrations (MPC) of elements adopted by the Mongolian National agency of Standards and Measurements [Soil quality, 2008]. Given a relatively even spacing of sampling locations, the percent of area under polluted soils was defined as the ratio of a number of sites where the content of elements exceeded MPC to the total number of tested sites within the city area.

CHARACTERISTICS OF RESEARCH OBJECTS

Natural conditions. The territory of Ulaanbaatar is located in a wide intermontane basin in the Hentiyn mountainous region with abs. elevations of 1300–1500 m. In the northwestern direction, there are Orkhon-Selenga midlands, where elevation falls in the northeasterly direction. This area has flowing forms of relief and broad intermontane valleys with average bottom elevations of 700–1200 m. There, the cities of Erdenet and Darkhan are located. The study region belongs to the Orhon river basin, the largest tributary of the Selenga river. Ulaanbaatar stretches along the Tuul river valley. The city of Darkhan is spread along the Kharaa river valley. Erdenet is located near the Hangalyn-gol river, which is a third-order tributary of the Selenga river. This region has a severely continental climate with large annual and daily fluctuations of air temperatures. The prevailing calm anticyclonic weather conditions in the cities cause temperature inversions in winter, which creates unfavorable ecological environment, specifically, the rise of concentrations of many toxic substances in the air. These toxic elements are gradually deposited into the snow cover and into the upper soil layers.

The light-textured Quaternary sediments with a low content of most trace elements (*CD* = 1,2÷1,5) represent the main parent material in the river valleys and intermontane basins [Bathishig, 1999]. In the intermontane depressions, the parent material consists of alluvial-proluvial loamy sediments and sandy loams with inclusions of break stone, gravel, and pebbles. Occasionally, there are outcrops of the Paleogene-Neogene deposits enriched with Fe, Mn, and Co (*CC* = 1,5÷2,6). In most cases, the parent bedrocks are composed of granosyenites or metamorphosed Devonian and Carboniferous extrusive-sedimentary rocks (shale rocks). The former are enriched with a complex of lithophylous elements and the latter have high concentrations (relative to the global clarke content) of Fe, Ti, Cu, Ni, and Cr (CC = 1,7÷2,8) and a lower content (close to the global clarke content) of Pb, Mo, and V [Bathishig, 1999]. The Erdenet molybdenum copper-porphyritic ore deposit has a high content of Ag and Re.

The region belongs to the ecotone (i.e., transitional zone) of Southern Siberia and Central Asia, where a unique landscape type, i.e., mountain expositional forest steppe, is widespread. This landscape is manifested on the slopes of the northern exposures (more cold and wet) by forests (often, typical sub-taiga) with the development of seasonally frozen mountain-sod forest soils. Warmer slopes of the southern exposure are occupied by shrub-dry-steppe and by meadow-steppe plant communities that are gradually replaced by dry steppes with sparse thin xerophilous grasslands on the mountainous chernozem and chestnut soils in transition to the flatland. Most of the soils have a low humus (up to 4 %), but a significant detrital content (and even stoniness) of all soil horizons [6]. Soils of the river valleys are the alluvial sod-lapideous-pebble soils covered with meadow communities and willows and, more rarely, with poplar-larch riparian forests. In the oxbow-shaped lakes, meadow-swampy soils are formed.

Urbanization has caused the destruction of natural vegetation, loss of the sod cover, and reduction of soil turfness leading eventually to the intensification of water and wind erosion, and to the increase of dust content in the atmosphere.

Industries and functional zoning of the cities. In Ulaanbaatar, the largest industrial center of Mongolia, the population exceeds one million; the population of Darkhan and Erdenet is 87 and 80 thousand, respectively. Ulaanbaatar has been developing more rapidly for the last 10 years, during which its population has grown 1.6 times and the number of cars has nearly tripled. The central part of Ulaanbaatar, located on the right bank of the river Tuul, is a place of modern many-storeyed residential, administrative, and commercial buildings. Most of its industrial enterprises and all TPPs are located in the western part of the city, which, in combination with the predominance of western and northwestern wind bearings, causes soil pollution in its eastern and southeastern parts. The ger districts surround the central districts of the city creeping up the slopes of southern, southwestern, and southeastern foothills of the Baga-Khentei Range.

Darkhan stretches along the river Kharaa valley for 12 miles from north to south. The industrial zone is located in the southern and southeastern parts of the city, where there are the TPP and the cement, wood processing, leather tanning, and iron-steel plants. The industrial zone is separated from the main (new) part of the city by an upland spur. The old part of the city with its railway station and the elevator is located in the north. The ger districts occupy the eastern, western, and northern outskirts of the city.

Erdenet (as well as Ulaanbaatar) is located in the intermontane basin that stretches from southwest to northeast. The principal industries of the city, i.e., a copper and molybdenum porphyritic ore mining and concentrating complex (MCC) and waste rock dumps, are located in its the eastern and northeastern parts. North of the mine, the extraction plant abuts a mining and concentrating factory, two TPPs, and a complex of industrial facilities. Further north in the valley of a tributary of the Hangalyn-gol river, there are sludge pits. The central part of modern residential districts and administrative buildings is located to the west of the industrial zone. The ger districts are in the southwestern part of the city on the upland slopes. Military bases and ranges are in the city's southwest part.

The TPPs and ger stoves, which burn brown coal, are the main sources of pollution. Analysis of micro-elemental composition of the brown coal and the TPP-3 ash in Ulaanbaatar, obtained by the ICP-MS method,

Table 1. Geochemical specialization of Mongolian coals and fly ash from the TPP-3

Study facilities	Relative to clarkes of lithospheric concentrations based on Vinogradov [12]	Relative to the average for world coals (*a*) and coal ash (*b*) [13]	Relative to TPP-3 fly ash
Ulaanbaatar coals (average)	$Se_{333}Sb_{13}Bi_{12}W_{2,1}Be_{2}Mo_{1,8}Pb_{1,6}$	$Pb_{23}Sb_{16}Se_{4,2}Cu_{3,6}Bi_{2,3}Ni_{1,3}$ (*a*)	$Sb_{3,4}Se_{2,6}Hg_{2,5}Bi_{1,8}Te_{1,6}$
TPP-3 fly ash	$Se_{128}W_{100}Be_{32}Mo_{13}Bi_{6,5}Th_{6,5}$As5 $Cd_{4}Sb_{3,7}Cu_{3,7}U_{3,1}Sr_{3}Co_{3}Sn_{1,8}Pb_{1,7}$	$W_{5}Th_{4,2}U_{2}Cu_{1,7}$ (*b*)	–

revealed a wide range of contaminants of the urban landscapes associated with thermal generation (Table 1). The brown coal deposits near Ulaanbaatar, as in the case of most sulfur coals, have a high content of chalcophylic elements (Se, Sb, Cu, Bi, Pb), and W, Be, and Mo, i.e., elements that characterize the geochemical specialization of a coal-bearing basin. The fly ash is rich in natural radioactive elements Th and U. The ratio of micro-elemental concentrations in the coals to these of the TPP-3 ash (Table 1) allowed us to identify elements that are depleted in the ash and that may be transitioning to the gaseous phase: Se, Sb, Hg, Te, Bi, and possibly, Pb. These elements do not accumulate in the solid phase and are spread into the atmosphere creating the direct negative impact on human health.

RESULTS AND DISCUSSION

Regional soil geochemical background conditions and their transformation in the major industrial centers. The extent of technogenic geochemical transformation of the urban soils was determined by analyzing chemical composition of dark chestnut soils in the natural and recreational landscapes and by constructing their geochemical spectra (Fig. 1, a). The reference characteristics for the three cities were close in respect to most metals; they tend to approach the global clarke concentrations for Zn, Mn, V, Ti, Cr, Zr, Hg, and Ba and are below the global clarke concentrations for Ge, Co, Y, and Ni (*CD* = 1,7÷8,4). In Ulaanbaatar, the significant accumulation above the clarke concentrations were noted only for W (*CC* = 1,5), and for Pb, Sn, Mo, and Ag (*CC* = 1,9÷1,5) in Darkhan. The ore-geochemical specialization of the area of the Erdenet copper-molybdenum deposit is manifested in high contents of Mo, Cu, and Ag (CC = 8,2÷2,8).

Industrial activity is the other main source of HM accumulation in the urban soils (Fig. 1, *b*). In Ulaanbaatar, a multi-elemental geochemical anomaly with relatively low clarke concentrations ($Ag_{3,0}Pb_{2,4}Sn_{2,1}Hg_{1,9}Ge_{1,7}Zn_{1,7}W_{1,5}$) was formed. Its formation may be attributed to the diversification of the city's industry and the predominance of light-textured soils with a low sorption capacity. Soil pollution in Darkhan ($Cr_{5,0}Hg_{3,1}W_{3,0}$) indicates its narrow industrial specialization, primarily in leather tanning, gold mining, and thermal power production. The soils of Erdenet accumulated $Mo_{2,2}Cu_{1,8}Sn_{1,5}Ge_{1,5}$. The sources of these elements are the MCC rock waste dumps blown by the wind and enriched with Cu and Mo and the combustion products of brown coal containing high content of Sn and Ge.

According to the results of the cluster analysis, the reference soils have the most stable associations of elements which reflect geochemical characteristics of the parent material: Cu–Zn–Pb, Mn–Ba, Cr–Ga, and Y–Zr. The first association combines cationgenic and chalcophylic elements of poor mobility in neutral and alkaline conditions that accumulate in the humus horizons. The second association includes Mn, which hydroxides represent the sorption barrier for Ba. The third and the fourth associations include complex-forming elements. Comparison of the HM associations in the three cities showed their considerable variability due to the differences in the natural and

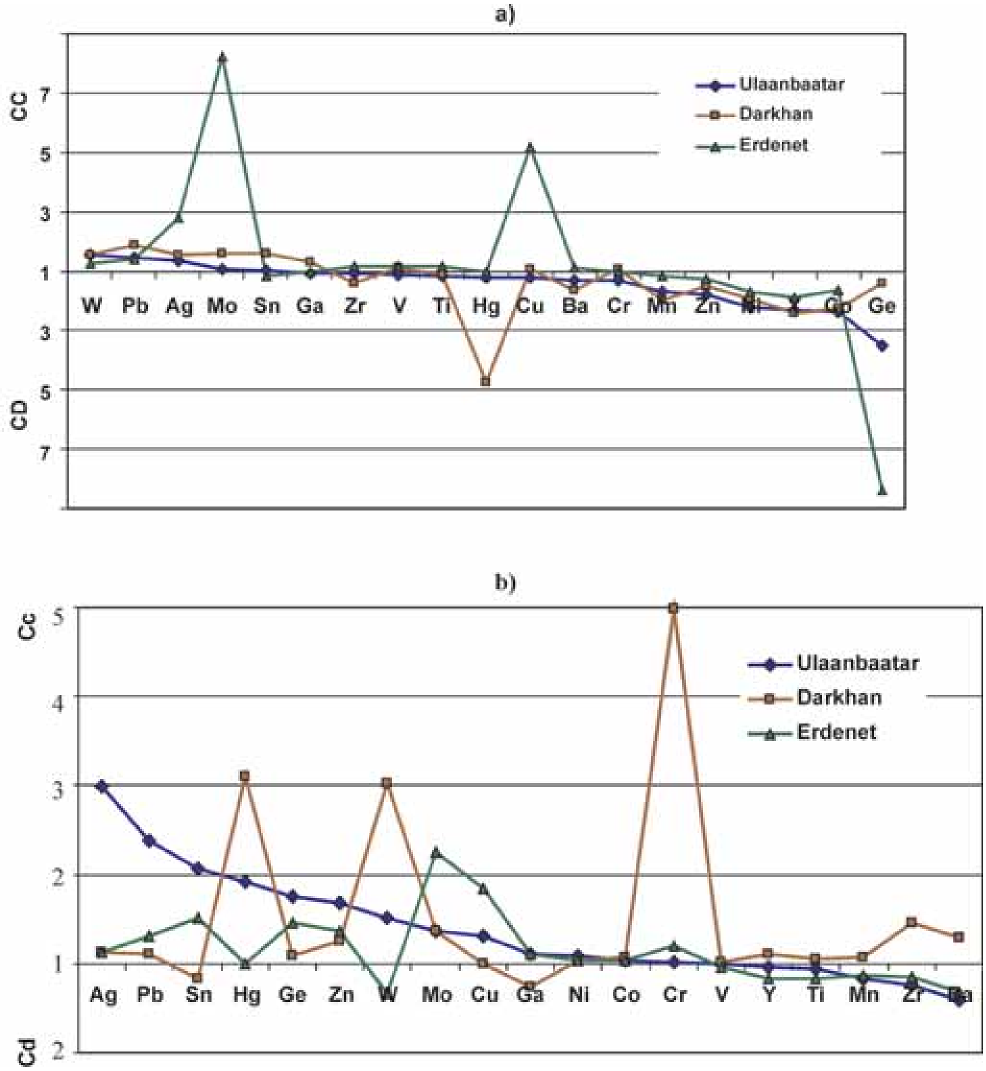

Figure 1. Geochemical specialization of the soils in Ulaanbaatar, Dakhan, and Erdent: background (a) and technogenic (b). The clarkes of concentration (CC) and dispersion (CD) in the background soils were estimated with respect to the Vinogradov's clarkes; the coefficients of concentration (Cc) and dispersion (Cd) were estimated with respect to the background soils.

anthropogenic conditions within the urban areas (Table 2).

The spatial geochemical heterogeneity of the urban soils. Geochemical heterogeneity of the urban soils is associated with the functional identity of the territories. The main elements of this functional composition are the highways, traditional ger districts, many-storeyed residential blocks, and recreational and industrial zones. For these sectors, the average concentrations of HM and the parameters of variability were calculated. In addition, the associations of elements were defined and geochemical spectra were plotted. Table 3 provides average concentrations of metals – the priority pollutants in the soils of these zones.

In Ulaanbaatar, the highest level of accumulation of many elements-pollutants is confined to the soils near the major highways and many-storeyed residential

Table 2. Associations of HM in the upper horizons of background and urban soils

Types of landscapes (number of samples)	Association, correlation coefficient (*r*)	No association	Significant *r* (*P* = 95 %)
Ulaanbaatar			
Background, recreational (10)	Cu, Pb, Zn, V, Sn, B (0,68–0,88); Cr, Li, Ni, Ga, Co (0,78–0,92); Mn, Y, Zr, Ba (0,85–0,97)	Ag, Mo, Hg, Ti, Sr	0,63
Residential, industrial, and traffic zones(83)	Cu, Zn, Pb (0,59–0,72); Ni, Co, Ga, B (0,48-0,81); Cr, V (0,73); Mn, Ti, Y (0,44–0,64); Sr, Ba, Zr (0,56–0,59)	Ag, Mo, Hg, Sn, Li	0,28
Darkhan			
Residential, industrial, and traffic zones (42)	Cu, Zn, Pb, Sn, Ga (0,57–0,83); Ni, V, B, Co, Ti (0,35–0,75); Mo, W, Ge (0,74–0,85); Zr, Y, B (0,33–0,63)	Cr, Ag, Mn, Hg, Li	0,31
Erdenet			
Background, recreational (8)	Cu, Ag, Ge, Zn, Pb (0,78–0,9); Cr , V, Ga (0,91–0,96); Mo, Sn (0,73); Mn, Ba (0,89); Ti, Y, Zr (0,68–0,87)	W, Co, Hg, Li, B	0,71
Residential, industrial, and traffic zones (39)	Cu, Ag, Mo (0,76–0,92); Pb, V, B, Ga, Ge, Zn (0,28–0,66); Ni, Co, Li (0,63–0,84); Mn, Ba, Ti, Y, Zr, Sn (0,29–0,77)	Cr, W, Hg	0,34

blocks in the old part of the city (Fig. 2), where high concentrations of Pb, Hg, Ag, Zn, W, Ge, Mo, Sn, and Cu (C_c = 3÷1,5) are present. In the industrial zone, the C_c is about 0,5 units lower due to a larger area of dispersion of emissions released from the pipes to the atmosphere at a considerable height. The least polluted areas are the ger districts on the slopes in the outlying parts of the city. Despite a relatively young age of development in these areas, there is a noticeable accumulation of Pb and Ge from the products of incomplete combustion of brown coal used for ger heating.

The most stable associations of elements traced in the soils of almost all functional zones of the city are Cu–Zn–Pb, Ni–Co–Ga, Cr–V, Mn–Ti, and Ba–Zr. The first association combines elements from the anthropogenic sources, primarily from motor vehicles. The second and the third associations include elements that accumulated in the clay and fine-silt fractions. Their variations depend upon the heterogeneity of soil texture. The fourth and the fifth associations mainly reflect geochemical features of the parent material of valleys and terraces common in the city's area.

In the soils of Darkhan, the widest spectrum of elements-pollutants ($W_{15}Cr_{8,8}Hg_{2,6}Ge_{1,9}Mo_{1,9}Zr_{1,5}$) was found in the industrial zone (see Fig. 2). The soils of the ger districts have the following formula of technogenic geochemical specialization: $W_{9,1}Zn_{1,8}Mo_{1,7}Hg_{1,5}$. There is a noticeable accumulation of $W_{8,6}Hg_{2,7}Ge_{1,5}Zn_{1,5}$ in the soils of new residential areas. Geochemical transformation of Darkhan soils is manifested in elemental associations, the most stable of which are: Cu–Zn–Pb, Mo–W–Ge, Sn–Ga, Zr–Y–Ba, Ni–V, and Co–Ti. Undoubtedly, the first three associations are of the technogenic origin from the area-source pollution. The most hazardous metals, i.e., Cr, Ag, and Hg, did not form stable associations, which can be explained by the point nature of pollution.

In the Erdenet soils, the most contrasting technogenic anomaly is confined to the traditional ger districts (see Fig. 2), where $Sn_{2,6}Ge_{2,4}Zn_{1,7}Cu_{1,6}Mo_{1,5}$ were accumulating. Soils of the industrial zone accumulated $Cu_{1,8}Mo_{1,5}$, while soils of the many-storeyed residential blocks accumulated $Ge_{2,2}Zn_{2,0}$. For the traffic zone, the accumulation of elements-pollutants was not identified,

Table 3. Average concentrations (mg/kg of soil) and MPC for HM [11] in the upper (1–10 cm) soil horizons in different functional zones in Ulaanbaatar. Darkhan. and Erdenet

Functional zone	Number of samples	Class of hazard of elements											
		I			II					III			Sn
		Hg	Zn	Pb	Ni	Co	Cr	Cu	Mo	W	Mn	V	
Ulaanbaatar													
Background	5	0.058	52.0	27.0	29.0	8.40	66.0	42.0	1.20	1.00	660	84.0	2.80
Recreational	5	0.080	42.0	19.4	23.0	6.80	60.0	36.0	1.14	3.00	520	78.0	2.40
Highways	9	0.170	82.2	55.6	31.1	8.44	70.0	60.0	1.96	3.67	544	91.1	4.22
Industrial	23	0.120	60.4	69.1	27.0	7.39	54.4	47.4	1.65	3.17	478	71.7	4.14
Ger districts	23	0.081	59.6	35.2	24.8	7.57	60.4	42.8	1.29	1.35	509	79.1	3.00
Many-storeyed residential areas	31	0.185	105	59.4	30.6	8.23	72.6	56.5	1.66	3.94	519	85.5	4.17
Darkhan													
Background	3	0.022	50.0	28.3	30.0	8.00	80.0	46.7	1.50	0.50	500	93.3	3.67
Recreational	3	0.083	56.7	40.0	23.3	5.67	80.0	40.0	1.93	3.67	400	80.0	3.00
Highways	25	0.056	63.6	29.2	32.0	8.92	704	50.8	2.78	7.48	560	104	3.24
Industrial	7	0.034	91.4	45.8	34.3	10.0	98.6	52.9	2.50	4.57	557	104	4.57
Ger districts	7	0.058	75.7	34.3	27.1	7.43	98.6	47.1	1.24	4.29	500	100	3.29
Erdenet													
Background	6	0.080	65.0	22.5	34.2	11.0	81.7	243	9.03	1.67	850	107	2.17
Recreational	3	0.037	76.7	21.7	30.0	9.33	60.0	96.7	1.50	1.67	533	103	2.33
Highways	18	0.101	62.2	24.7	35.0	11.9	113	450	13.6	0.889	822	98.3	2.33
Industrial	10	0.071	109	30.5	39.0	13.1	88.0	381	13.2	0.50	760	111	5.60
Ger districts	8	0.062	128	32.5	37.5	10.5	100	95.0	4.31	1.25	625	115	2.75
MPC. sandy soils		0.5	100	70	60	30	60	60	2	–	–	100	30
MPC. loam soils		1.0	150	50	100	40	100	80	3	–	–	130	40
MPC. clay soils		2.0	300	100	150	50	150	100	5	–	–	150	50

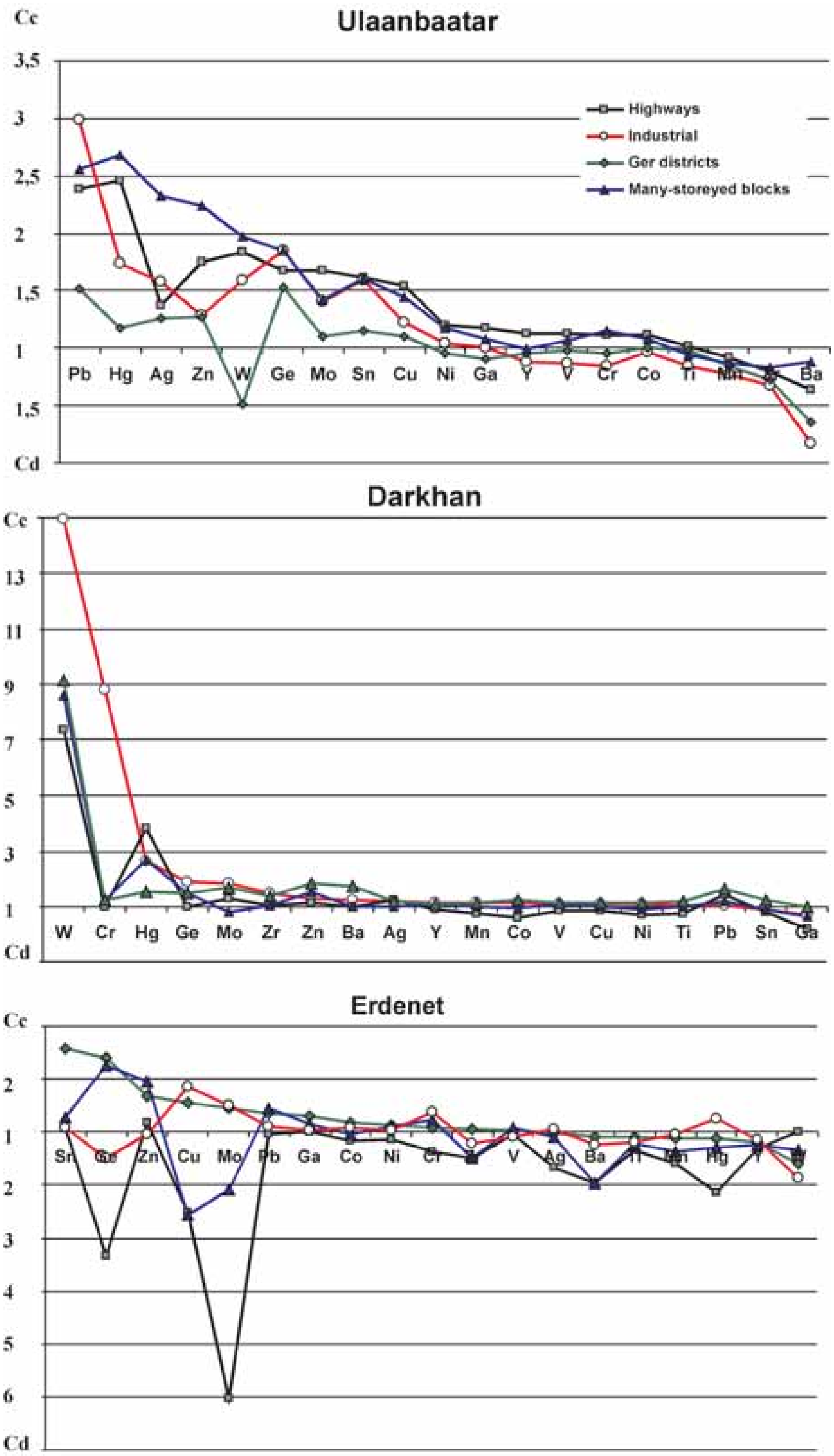

Figure 2. HM concentrations in the upper soil horizons of different functional zones in Ulaanbaatar, Darkhan, and Erdenet.

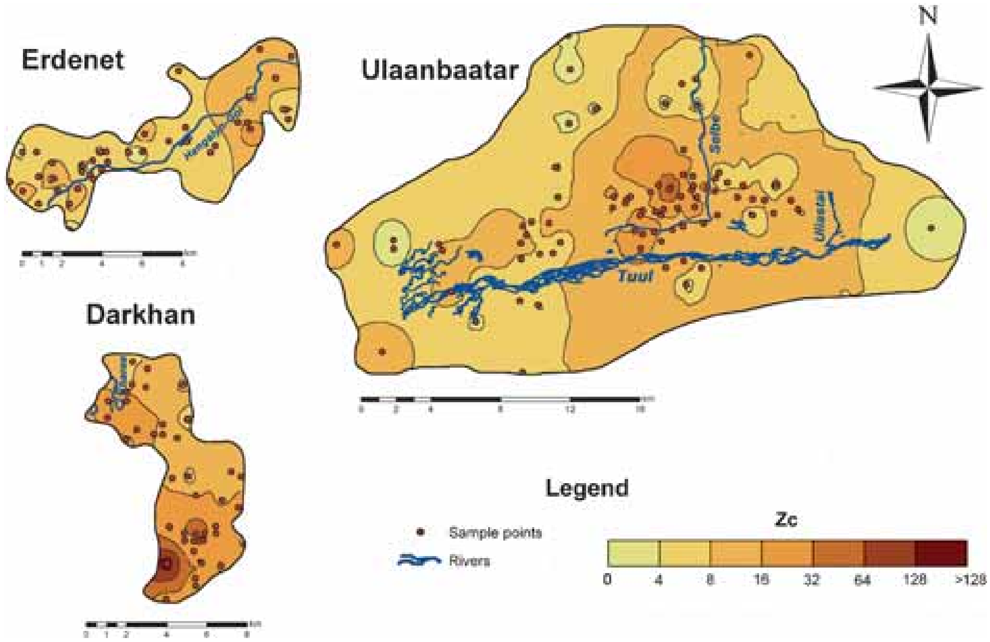

Figure 3. Maps of the integral index of soil pollution Zc for the soils in the cities of Ulaanbaatar, Darkhan, and Erdenet.

which may be attributed to the location of the highway system in the transitional geochemical environment, i.e., on the slopes of the river valley. Specific (for each functional zone) associations of elements characterize the geochemical heterogeneity of the Erdenet soils. The most stable associations are those that reflect the character of the parent material: Cu–Ag–Mo (ore body) and Mn–Ba–Ti–Y–Zr (granitoids). The industrial pollution is manifested in the Pb–Zn association.

The ecological-geochemical assessment of pollution of the urban soil. The values of the integral index of soil pollution Zc in Ulaanbaatar and Erdenet are low in all functional zones: in Ulaanbaatar, Zc varies from 5,6 (recreational zone) to 18 (many-storeyed residential blocks), while in Erdenet, it varies from 1,53 (major highways) to 8,2 (ger districts) due to enhanced reference concentrations of some HM. The highest values of Zc were found in the soils of Darkhan. In the residential and traffic zones, Zc ranges from 12,6 to 14,4, while in the industrial zone it reaches 27,7 which corresponds to the medium level of pollution.

The maps on Zc distribution (Fig. 3) demonstrate specific features of soil pollution in the urban areas studied. The bulk of the Ulaanbaatar soils belongs to the category of low-polluted soils (Zc < 16). In the city's center, in some locations, relatively high values of pollution were identified (Zc up to 40). In Edernet, the soils are less polluted (Zc < 16), with the exception of several locations near the MCC and in the ger district (Zc reaching 37). In Darkhan, the northern part with the residential blocks and some factories has a medium soil pollution level. In the central part of this city with the modern many-storeyed buildings, the level of pollution is low. In the southern part, i.e. in the industrial zone predominantly, Zc increases to 64 with some local maximums reaching 200.

The environmental risk of soil pollution in Ulaanbaatar, Darkhan, and Erdenet, was assessed by comparing the HM concentrations in the upper soil horizons with the rather stringent official Mongolian sanitary-hygienic standards [Soil quality, 2008] that vary depending upon soil texture

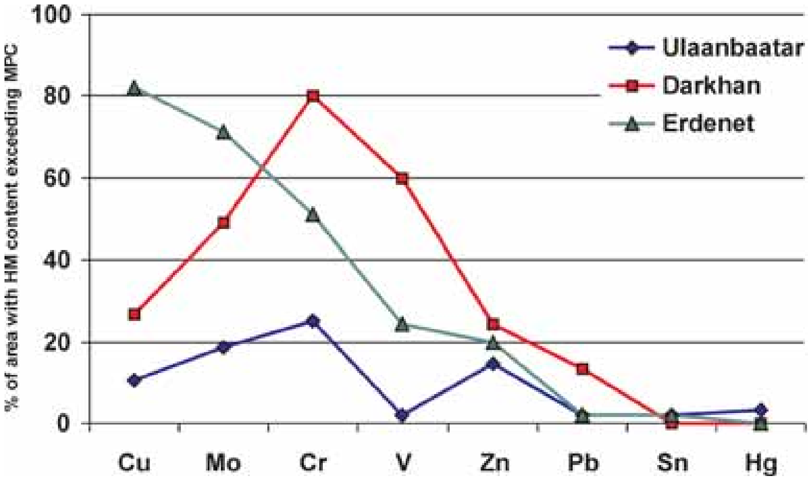

Figure 4. The assessment of ecological hazard from HM pollution in Ulaanbaatar, Darkhan, and Erdenet (% of area with HM content in soils exceeding MPC).

(see Table 3). It appeared that in Ulaanbaatar, the MPC values are exceeded only in the cases of Cr (on 25 % of the territory), Mo (19 %), Zn (15 %), and Cu (10 %) (Fig. 4). The areas of soil pollution are mostly confined to the residential (modern and ger districts alike) and traffic zones.

In two other cities, the share of soils affected by pollution (that exceeds MPC) is more significant: most hazardous pollutants in Darkhan are (in % of the total area of the city): Cr (80 %), V (60 %), Mo (49 %), Cu (27 %), Zn (24 %), and Pb (13 %); in Erdenet – Cu (82 %), Mo (71 %), Cr (51 %), V (24 %), and Zn (20 %). In Darkhan, the most polluted zones are the ger districts and the industrial zones, while in Erdenet the most polluted zones are the ger districts, many-storeyed residential blocks, and industrial zones.

CONCLUSIONS

1. The background geochemical specialization of the soils in the region is associated with close to or below the clarke values concentrations of most trace elements. The exceptions are: in Ulaanbaatar – W (*CC* = 1,5) and Pb, Sn, Mo, Ag, and W (*CC* = 1,9÷1,5) in Darkhan. The most pronounced natural geochemical anomaly was found in the soils of Erdenet: Mo (*CC* = 8,2), Cu (5,2), and Ag (2,8).

2. The technogenic geochemical specialization of Ulaanbaatar – $Ag_{3,0}$ $Pb_{2,4}Sn_{2,1}Hg_{1,9}Ge_{1,7}Zn_{1,7}W_{1,5}$ – reflects the influence of many different sources of soil pollution. The widest spectrum of elements-pollutants is present in the soils of the many-storeyed residential blocks and near the major highways. The geochemical specialization of Darkhan soils is the product of Cr5,0Hg3,1W3,0 pollution from leather tanning, gold mining, and TPP. Abnormally high levels of accumulation of W and Cr in the soils are confined to the industrial areas; the residential and traffic zones accumulate W and Hg. The anthropogenic accumulation of Mo2,2Cu1,8Sn1,5Ge1,5 in the soils of Erdenet is associated with mining of copper and molybdenum ores and burning of brown coal. The most pronounced technogenic anomaly of Sn, Ge, Zn, Cu, and Mo is present in the soils of the ger districts, while in the area of many-storeyed residential blocks, the excess over the reference values was observed only for Ge and Zn.

3. In Ulaanbaatar, the magnitude of technogenic geochemical anomalies manifested by Zc values, reaches its maximum (18,0) in the soils of many-storeyed residential blocks. The greatest expression of the anomalies was noted in Darkhan: *Zc* = 17,7 (industrial zone) and 12,6 and

14,5 (residential and traffic zones). In Erdent, almost everywhere, the Zc values do not exceed the value of 10 due to the elevated reference concentrations of some HM. The ecological conditions of the urban soils are characterized by the increase over the MPC levels for Cr, Mo, Zn, and Cu within 15–20 % of the Ulaanbaatar area. In the other two cities, the situation is more dangerous: 50–80 % of the Darkhan territory has Cr, V, and Mo concentrations in excess of the MPC; the concentrations of Cu, Mo, and Cr exceed the MPC in Erdenet.

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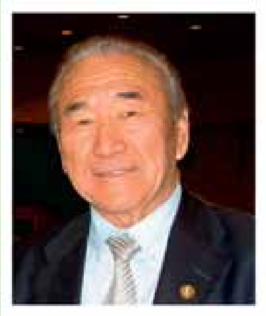

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ECOSYSTEM APPROACH FOR EVALUATING DEGRADATION PROCESSES AND NATURE PROTECTION IN INNER ASIA

ABSTRACT

The paper presents results of eco-biological assessment of Inner Asian ecosystems using the example of Mongolia as a case study. The comprehensive environmental analysis of changes in Mongolia's environment included approaches based on three principles: (1) formal, (2) administrative division, and (3) landscape-ecological. We analyzed ecosystems that have undergone at last three levels of alterations (moderate, heavy, and very heavy) due to anthropogenic factors. Based on our analysis of degradation processes that result in heavy and very heavy anthropogenic alteration of the natural environment, we isolated 5 groups of hazardous degradation processes: (1) rangeland overgrowth with shrubs, (2) deforestation of forest-steppe ecosystems, (3) desertification of ecosystems on light soils, (4) depletion of ecosystems of hydromorphic landscapes, and (5) narcotization of agrocenoses in modified ecosystems. The comprehensive assessment of adverse changes of natural habitats has enabled a revision of the state policy for the organization of the optimum network of wildlife reserves for conservation of floristic and faunistic diversity.

KEY WORDS: Inner Asia, Mongolia, ecosystem biodiversity, land degradation nature protection, degradation processes, ecosystem conservation

INTRODUCTION

Ecological problems both on the global and regional levels arising worldwide and the necessity of their preservation demand decisions based on the knowledge of protective and self-control mechanisms of individual ecosystems (such as vegetation, soils, and fauna), of ecosystems as a whole system, and of the threshold limits of their resistance to human impact.

Leading international organizations (UNEP, UNDP, World Meteorological Organization, World Health Organization, IUCN, etc.) have already started a transition from supporting specialized programs on the rational use of different components of natural resources to the development of comprehensive global programs, such as, for example, programs on biodiversity conservation and on control of desertification. One of the latest international documents that specifically address conservation of ecologically congenial conditions for humans and biota is *The Millennium Declaration* approved by more than 200 countries. This document stresses the general responsibility of nations to respect for nature. It states, "The present unresisting development models should be changed in the interest of our future welfare and well-being of our descendants".

The drylands of Asia occupy 11 930 119 km, from which 25,49 % belong to semiarid lands, 61,14 % – to arid lands, and 10,01 % – to extra-arid lands. About 70 % of these area have been affected by desertification. The United Nations Convention to Combat Desertification (UNCCD) adopted in 1994, defines desertification as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climate change and human activity".

BIOGEOGRAPHICAL FEATURES OF INNER ASIA AND MONGOLIA

Inner Asia, as well as other regions of Asia, has faced serious ecological threats at the end of the 90s of the 20th century. According to the assessments of N. Kharin & R. Tateishi [2000], by the beginning of the 21st century, more than 50 % of the region has been under intense or very intense disturbance. By now, a considerable area of Inner Asia requires urgent measures for ecosystem rehabilitation.

Inner Asia is a region that consists of a system of midland basins. This system includes completely drainless lacustrine basins (the Big Lakes Pane in Mongolia), basins of lakes in the Peoples' Republic of China (Ebii-Nor, Bagrashkel, Lop-Nor, Koko-Nor, Gashuun-Nor), lakes of the Tsajdam Hollow and the

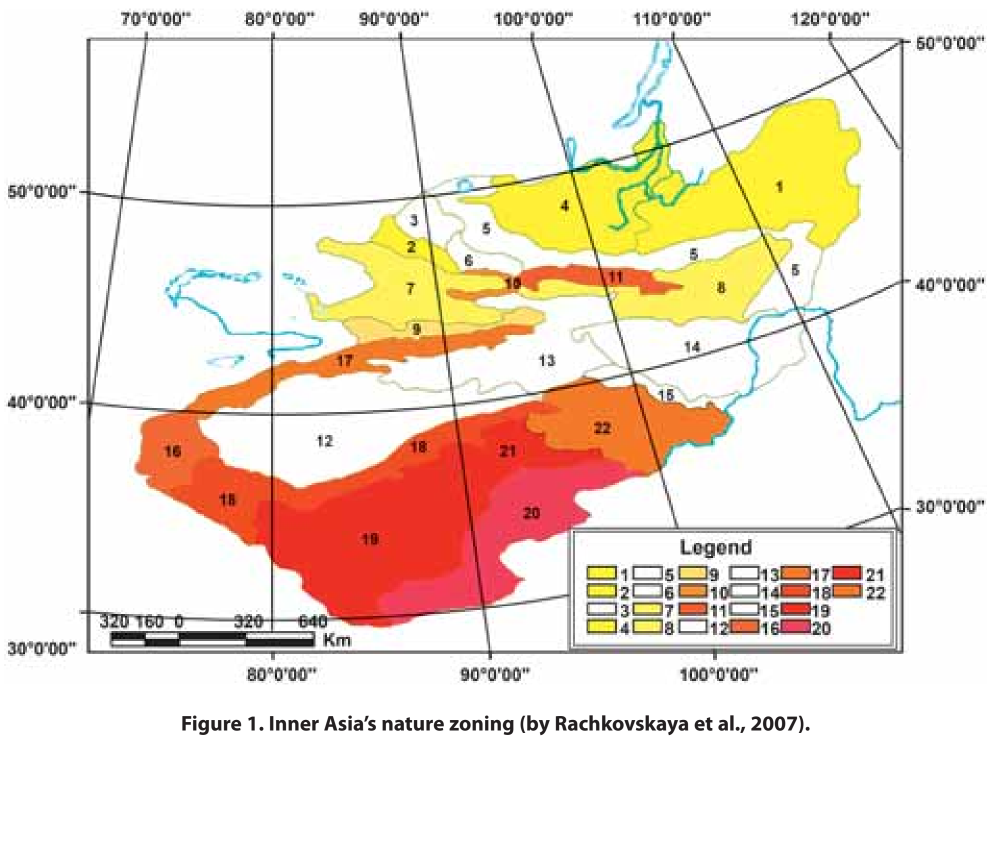

Figure 1. Inner Asia's nature zoning (by Rachkovskaya et al., 2007).

Table 1. The main nature regions of Inner Asia

Natural Zone	Relief	Region
Steppe	Plain	1. Mongolian
	Mountain	2. North-Western Mongol-Altai
		3. Northern Mongol-Altai
		4. Khangai
Semi desert	Plain	5. Sub-Gobi
	Mountain	6. Central Mongol-Altai
Desert, moderately cold	Plain	7. Dzhungarian
		8. Northern Gobi
	Mountain	9. Northern-East Tyan-Shan
		10. Mountain Dzhungarian
		11. Southern-Mongol-Gobi-Altai
Desert, moderately warm	Plain	12. Kashgarian
		13. Beishanian
		14. Alashan-Ordoss
		15. Korydor Hesi
	Mountain	16. Pamir
		17. South-Eastern Tyan-Shanian
		18. Kun-Lunian
		19. Tibet
		20. Eastern-Tibet
		21. Tsaidamian
		22. Nan-Shanian

northwest part of the Tibetan Plateau, and the basins with a particulate oceanic runoff (Lake Baikal, Bujr-Nur Lake, and Dalai Nor Lake) [Gunin et al., 1998; Gunin, Bazha, 2004].

The following main ecosystems comprise the ecological portrait of Inner Asia:

– steppes with a dominance of *Stipa krylovii, Cleistogenes squarrosa*, and *Caragana* shrubs;
– semidesert with a dominance of *Stipa gobica, S. glareosa, Allium polyrhizum, A. mongolicum;*
– various dwarf semi-shrub and shrub deserts;
– extremely arid deserts.

The functioning of these ecosystems is limited by the maximum of summer atmospheric precipitation due to the East-Asian monsoon and by the minimum of winter temperature associated with the Siberian anticyclone. These two primary features define the extreme ecological conditions in the region.

The most arid types of ecosystems are in the mountains: mountain desert, semi desert, and steppe (including high-mountain cryophilic steppe). Overall, in Inner Asia, there are 8 plain and 14 mountain provinces (See Figure 1; Table 1) [Rachkovskaya et al., 2005].

The anthropogenic impact alters natural processes eventually causing a "mutation" of ecosystems. Ecosystems existing under severe ecological conditions require special attention at all stages of management: investigation, use, and protection. They demand the development of ecologically sound interaction principles unified by a specially developed concept for nature management, including systems that combat desertification and promote ecosystem conservation in landscapes under severe ecological conditions. Such systems and approaches require the creation of territorial models based on key plots and they may have a significant methodological value.

METHODOLOGICAL APPROACHES

The assessment of comprehensive environmental investigation of changes in Mongolia's environment included approaches based on three principles: (1) formal, (2) administrative division, and (3) landscape-ecological. In the first approach, the boundaries of topographic divisions or grids serve as the study objects. The second approach is used when the objects of assessment are units of the region's political and administrative divisions. The third approach is applied when the main goal of assessment is an attempt to differentiate the biosphere into small and/or large scale mapping units (e.g., ecosystem types).

Landscape-ecological studies in Mongolia have been effective in cases where the soils and vegetation have been well studied and when specialized and integrated maps of the regions have already been available. The availability of such maps for Mongolia [Ecosystems of Mongolia, 1995] made it possible to use the landscape-ecological mapping units to determine spatial differentiation of the soils and vegetation and to define ecosystem conditions corresponding to elementary, local, or landscape levels of chorological classification of their structure [see, e.g., Vinogradov 1984; Vostokova et al., 1995]. In this study, we used the same method as was utilized in the compilation of the map *Ecosystems of Mongolia* [Gunin et al., 1995] where mesoecosystems represented basic level of units of the map. This approach provided for a much better inventory of the ecosystems and their classification based on natural characteristics and types of economic utilization (forestry and pastoral) for the entire Mongolian area.

Mongolia is one of the largest countries in the world. Its area is 1.564.116 sq. km. Mongolia includes almost all native zones of Inner Asia. It lies in the northern part of Inner Asia. Nearly half of Inner Asian biotic provinces and ecosystems are fully or partly located in Mongolia. One of the prominent features of Mongolian ecosystems is a unique type of the expositional mountain forest-steppe ecosystems.

Long-term investigations carried out by the Joint Russian-Mongolian Complex Biological Expedition of the Russian Academy of Sciences and the Mongolian Academy of Sciences provided a comprehensive assessment and mapping of the modern natural and anthropogenic-natural ecosystems. The principle activities were:

- *Complex environmental investigations;*
- *Inventory of the floristic and faunistic diversity including mapping of ecosystems at different scales;*
- *Identification of extreme ecological regimes;*
- *Compilation of ecological data bases;*
- *Definition of new properties of natural-anthropogenic systems;*
- *Optimization of the network of nature-protected territories.*

According to our analysis, the Mongolian territory has 430 varieties of middle-level ecosystems in total, 348 of which are automorphic and semi-hydromorphic, and 72 are hydromorphic ecosystems

Figure 2. The main types of Mongolian ecosystems.

(See Figures 2 and 3). The total number of contours exceeds 25.000 most of which are arid and semi arid ecosystems (13,310 contours). The average area of one contour is 117,5 sq. km.

Ecosystem diversity in Mongolia is extremely high. The zonal landscapes in their almost 1200 km north-to-south stretch cover most of the ecosystems of the Eurasian Moderate Belt (from typical mountain taiga to extra arid deserts). Thus, the taiga ecosystems are in direct and broad contact not only with steppes, but with the desert ecosystems too.

Ecosystem diversity depends on geological, geomorphological, and lithological conditions of formation of their ecotopes, as well as on their floristic diversity and their general biodiversity. According to the latest data published by R. V. Kamelin and N. Ulziykhutag [2005], the flora of Mongolia is rather rich and consist of 3.000 different plant species. This fact predetermines a high diversity of phytocenosises in all types of ecosystems.

Mongolian forest ecosystems occupy 119,0 thousand sq. km. The distribution of forests and their differentiation in the dominance of conifers (pine, larch, spruce, fir, and cedar) and parvifoliate (birch, aspen) species in various landscape-ecological conditions are regionally heterogenic. Despite their relatively small area (forest ecosystems occupy 7,6 % of the country's area), they are of exceptional importance to ecological stability and socio-economic development of the country. The forest ecosystems of Mongolia also have global ecological value. They serve as the global ecological barrier against the desertification processes in the Central and Northern Mongolia. Sub-taiga forests (larch and pine) are subject to the most severe impact (sites with high and very high level of disturbance comprise 85,7 % of the area of these ecosystems).

Steppes, semi-deserts, and deserts (most of which are grasslands) occupy the largest area in Mongolia (almost 1.230.000 sq. km or more than 90 % of the country's area). Hydromorphic ecosystems along lacustrine hollows and river valleys in arid and semi-arid zones of Mongolia experience the greatest disturbance. Such landscapes have a large number of water draw sites that attract livestock. The ecosystems under the moderate and heavy degrees of anthropogenic disturbance make more than 50 % of their combined area.

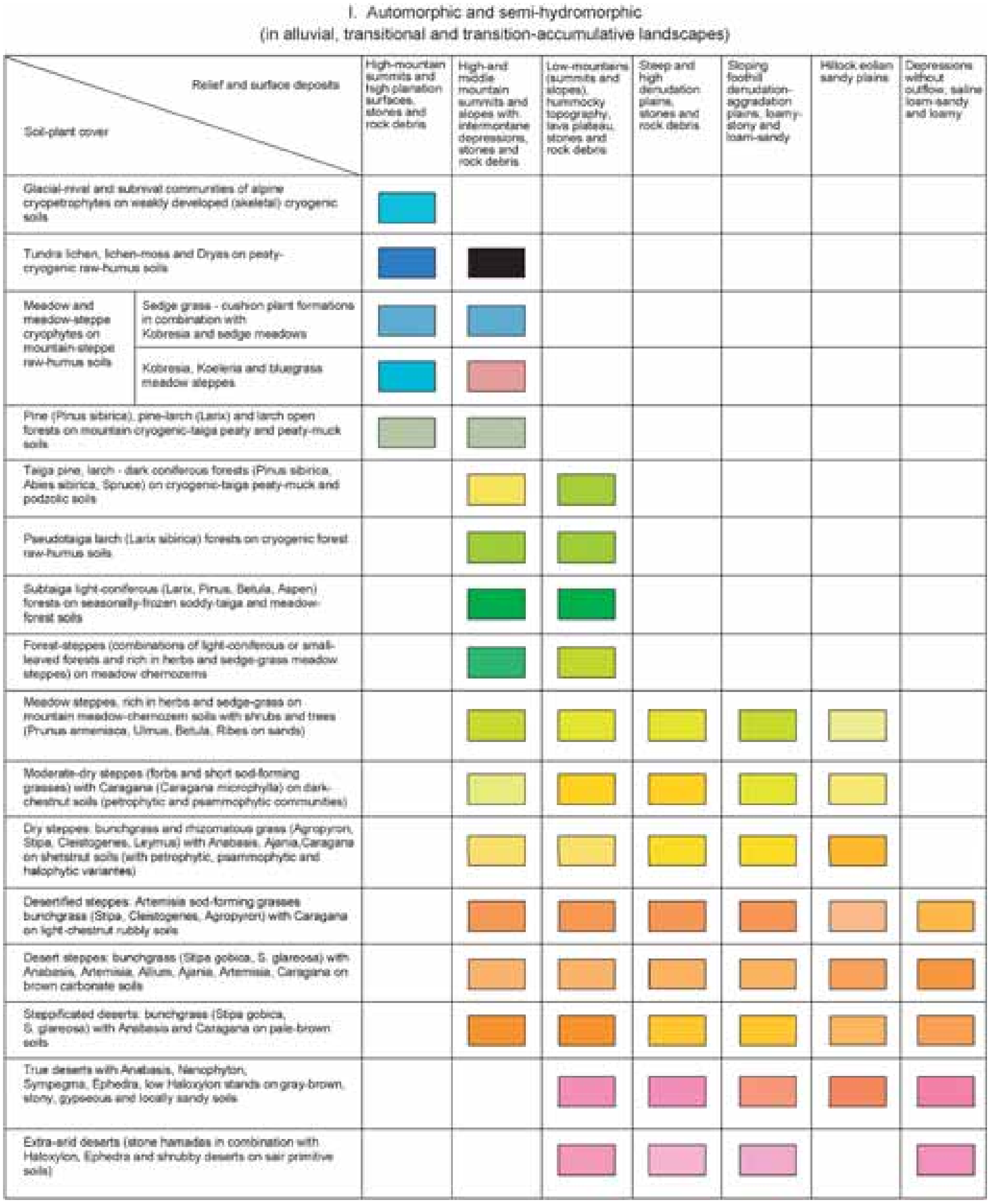

Figure 3. The main types of Mongolian ecosystems (fragment of the legend).

THE ECO−BIOLOGICAL ASSESSMENT OF THE ECOSYSTEMS CONDITIONS

The assessment of the ecosystems' status and of the anthropogenic impact on the ecosystems was based on quantitative indices of changes in particular ecosystem components (e.g., vegetation, soils, relief) and on the level of their alteration under the anthropogenic impact. These alteration levels were broken into major groups: absent, slight, moderate, heavy, very heavy, and into transitional categories between these groups [Gunin et al., 1999] (Table 2).

Specific differences in vegetation and its morphology represent reliable criteria for the assessment of anthropogenic impact on the ecosystems. The following parameters were used: changes (compared with the same plant communities of undisturbed plots) in projective cover, structure of grass stand,

Table 2. The qualitative scale for the assessment of the anthropogenic alteration of the ecosystems.

Alteration level	State of ecosystems
Absent (I)	Soil-plant cover is slightly modified; natural regeneration of slightly modified plots is possible.
Slight (II)	Satisfactory, the modification of ecosystems is observed where cattle are grazed; frequently, natural regeneration of the majority of modified plots is possible.
Moderate (III)	Moderate, there are more modified plots than at the preceding stage; natural regeneration is possible but difficult.
From moderate to heavy	Moderate, occasionally poor at forest plots; forest regeneration feasible with temporary bans on grazing, regulation of tree felling.
Heavy (IV)	Poor, soil-plant cover is occasionally modified irreversibly and natural regeneration is extremely difficult.
From heavy to very heavy	Poor, occasionally very poor; natural ecosystems have been virtually destroyed and natural regeneration is frequently impossible.
Very heavy (V)	Very poor, natural ecosystems have been replaced by man-made, or the plots represent an industrial badland (spoils, dirt piles, quarries, etc.); natural regeneration is impossible.

floristic composition, height of grass stands, sod thickness, weed species presence, and plant species abundance and viability. Morphological characteristics of soil profiles and agrochemical indices in the upper soil horizons were also taken into account.

We analyzed anthropogenic impact on the ecosystems of the alteration levels III, IV, and V. The anthropogenic factors can be divided into two groups: (1) factors leading to the destruction of natural vegetation and the disruption of natural links and the initial ecotype formation and (2) factors that allow indigenous vegetation and the ecotypes to largely recover after anthropogenic disturbances (immediately or in the course of successional replacement). The pattern of spatial distribution of disturbances is shown in Table 3.

The largest area in Mongolian ecosystems is occupied by rangelands, 23,3 % of which have moderate level of alteration (level III) and 3,6 % have heavy to very heavy level of alteration (levels IV and V). The forest ecosystems exposed to cuttings and anthropogenic fires comprise over 51,5 %

Table 3. The relationship between the types of anthropogenic impact and the levels of ecosystem alterations in Mongolia

Type of anthropogenic impact	Degradation extent by the levels of alteration (%)				
	I	II	III	IV	V
Overgrazing	20,23	52,89	23,26	3,55	0,07
Forest cutting	56,80	15,23	9,39	6,39	12,19
Forest fires	47,21	29,29	13,77	0,93	8,80
Land plowing	0,00	0,00	0,00	54,20	45,80
Urbanization	0,00	0,00	0,00	91,13	8,87
Complex effect	22,25	25,09	35,51	12,76	4,39

of all forest ecosystems; the impacted areas are concentrated in the northern parts of Mongolia. The share of cultivated lands is very small (0,75 % of the country's territory) and is currently represented by heavily degraded fallow lands (54, 2 % and 45,8 % of degradation levels IV and V, respectively). Other ecosystems (including hydromorphic ecosystems under integrated impact, ecosystems under technogenic impact, etc.) account for no more than 3,57 % of all lands, with approximately one-half in heavily altered categories.

THE IDENTIFICATION OF DEGRADATION/ DESERTIFICATION PROCESSES IN SUCCESSIONS OF PLANT COVER

Analyses of our own surveys performed over the last decade as well as analyses of the results obtained by other researchers who previously conducted geo-botanical surveys in Mongolia provided multi-temporal descriptions of the vegetation at the same plots. The sites were located mainly in the areas of stationary integrated observations at selected testing plots of the sub meridian transect Ulan-Ude – Ulaanbaatar – Hohhot. The analysis of the multi-temporal data allowed the identification and assessment of various degradation processes in the plant cover.

The categories of heavy and very heavy anthropogenic alterations of the natural environment contained five groups of hazardous degradation processes: (1) rangeland overgrowth with shrubs, (2) deforestation of forest-steppe ecosystems, (3) desertification of ecosystems on light soils, (4) depletion of ecosystems of hydromorphic landscapes, and (5) narcotization of agrocenoses in altered ecosystems [Gunin, Bazha, 2003].

Overgrowth of Rangeland Steppe Ecosystems with Shrubs. An important feature of the ecosystems studied, as well as of Asian steppes in general, was their overgrowth with various types of shrubs and dwarf semi-shrubs of the genera *Caragana, Artemisia, Spiraea, Armeniaca, Amygdalus, Dasiphora*, etc. It appeared that the participation of shrubs and dwarf semi-shrubs in the communities of the Eastern-Asian sector of the steppe zone increased with the increase of the anthropogenic pressure on the rangelands. Several species played significant role in degraded rangelands, including shrubs *Caragana microphylla*, *Caragana pygmaea* and dwarf semi-shrubs *Artemisia frigida*, *Thymus gobicu,s* and *Potentilla bifurca*; their abundance was directly proportional to a degree of the rangeland alteration.

Deforestation of Larch and Pine Forest Ecosystems. To investigate the process of deforestation of larch and pine forests, complete geobotanical and taxonomic descriptions of tree and shrub species were obtained. Tree evaluation included measurements of their height and trunk diameters. Shrub measurements included the count of trunks, height and diameter of the shrubs, and measurements of aboveground phytomass.

A complete succession series had 5 major stages: I – indigenous forests *(Pinus silvestris, Larix sibirica);* II – small leaved forests with a mixture of indigenous species (*Betula platyphylla*, *Populus tremula, Larix sibirica, Pinus silvestris*); III – small leaved forests without contribution of indigenous species, including undergrowth or thickets of shrubs with dead trees, or without undergrowth of arborous species (*Betula platyphylla*, *B. fusca, Populus tremula*, *Cotoneaster melanocarpa* and *Salix* sp.*);* IV – thickets of shrubs without involvement of any trees (*Cotoneaster melanocarpa*, *Spiraea aquilegifolia, Amygdalus pedunculata, Armeniaca sibirica, Betula fusca*, and *Salix* sp.*);* and V – steppe stage (*Carex korshinskyi* and *C. pediformis)*.
Desertification of Ecosystems with Soils of Light Granulometric Composition. One problem of desertification in Mongolia is associated with natural predisposition of fragile environment to degradation processes resulting from anthropogenic impact. We define the desertification process as the process when more arid elements penetrate into degraded ecosystems. Such elements included: (1)

the formation of barchan-like forms of relief on altered plots with sand soils, (2) the development of salinization processes in forest-steppes resulting from water erosion of salt-containing waste piles, and (3) the incorporation of dry steppe species typical of deserts into altered phytocenoses. The first species to advance through the disturbed habitats into the neighboring zones were pest anthropophillic species (*Caragana bungei*, *C. spinosa*, *Ephedra sinica*, *Corispermum mongolicum*, *Agriophyllum pungens*, *Peganum harmala*, *P. nigellastrum*, etc.) characteristic of sandy or salinized habitats.

Depletion of Rangelands of the Hydromorphic Landscapes. The rangelands of the hydromorphic landscapes are common in the river valleys and lake depressions. The major anthropogenic factors of long-term dynamics of plant communities are the concentration of the human population and livestock and unregulated human traffic. The phytocenoses of alteration stages III and IV in meadow steppe sod soils consisted of meso- and xeromorphic species *Carex duriuscula*, *Artemisia frigida*, *A. commutata*, *A. laciniata*, and *A. adam*sii. At the final stage of the succession series, iris species (*Iris lactea*, *I. bungei*) became the edifier perennial species that grew virtually everywhere (e.g., on the terraces and floodplains of meadow communities) and replaced initially different dominant species.

Narcotization of Agrocenoses in Fallow Lands and Highly Modified Ecosystems. We regard the current distribution of the *Cannabis* species in such a vast region as the north and central parts of Mongolia as the manifestation of a syngenetic succession. The distribution of *Cannabis* sp. is primarily promoted by their biological properties. Environment, i.e., the presence of conditions providing for the germination of seeds and seedlings' development is also very important. Furthermore, *Cannabis* has a high environment forming capacity, successfully competing with species that form phytocenoses into which it is incorporating. In the ecosystems studied, it frequently formed monocenoses from tall (1,5 m and higher) above ground phytomass with large mass providing up to 2,5 to 3,0 tons/ha of biomass in ruderal plant communities.

THE MAIN RECOMMENDATIONS FOR CONSERVING MONGOLIAN ECOSYSTEMS

Mongolia is an area of many unique natural objects, including residual populations of many endangered animal species. This fact stipulates a rather small disturbance of nature in the region as a whole: human population density remains still low within a large part of the territory; traditional ways of nature management prevail.

It is critical to enhance the status and implementation of regulations, boundaries, and goals for legally protected areas.

Specific efforts should be directed towards: i) defining the network of reserves and national parks; ii) enacting guidelines for cultivation of disturbed lands; and iii) establishing and evaluating ecologically and economically justified systems of ecosystem management. Collectively, these measures would promote conservation and recovery of plants, animals, ecosystems and plant regeneration successions while reducing the rate of vegetation degradation across the entire Mongolia.

The comprehensive evaluation of negative changes occurring in the natural habitats has enabled the revision of the state policy for the organization of an optimal network of wildlife reserves aimed at conservation of floristic and faunistic diversity. In 1993, under the initiative of the Ministry for Nature and Environment of Mongolia and under the support of international organizations within the framework of the UNDP-GEF project *Biodiversity Conservation and Sustainable Livelihood Options in the Grasslands of Eastern Mongolia* the long-term plan for the organization of protected areas (PAs) (*Component B. Conservation Areas/Wildlife*, 1993) was developed. This plan provided for the expansion of the area of the PAs (from 5,5 % to 25,0 %) and for the increase in their total number (from 21 to 60), including the organization of 12 transnational PAs (Mongolian – Russian and Mongolian – Chinese) [Gunin, 1993]. During the following decade (1994–2003), this plan was successfully realized in its significant part. Today, the state PAs in Mongolia include 48 natural reserves of different ranks (reservations, national parks, and natural reserves) which occupy 20,5 million ha (13,1 % of the country's area). Despite significant progress in the organization of a unique, to Asia, Mongolian PA system, the spatial distribution of PAs requires further development. For example, the dry steppes and semi-desert subzones in the central and eastern parts of Mongolia are least presented in the state PAs. Thus, they are completely absent in the Valley-Lacustrine region of the Central – Asian region. Only a small areas are occupied by the PAs in the Eastern Khalkha district of the Daur Mongolian region (0,81 % of the area) and in the Central Khalkha district of the Central Mongolian region (0,80 %). The percentage of area of the PAs in the Middle Gobi district of the Central Asian region is also relatively small (only 4,1 %), which is insufficient too. It is important to note, that the share of land under all PAs in the country is very small in general and that the PAs have currently a low nature protection status (Natural Reserves or Natural Monuments).

These conclusions and recommendations are of primary importance in achieving conservation and management of the landscapes and vegetation of Mongolia that will sustain the traditional grazing-based economic culture in Mongolia.

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THE EVOLUTION OF CLIMATE AND LANDSCAPES OF THE LOWER VOLGA REGION DURING THE HOLOCENE

ABSTRACT

The results of the palynological analysis and ^{14}C dating of the most complete sequences of the Holocene sediments were used for a detailed reconstruction of multi-cyclic alternations of climate phases and zonal and intrazonal plant formations that were taking place the Lower Volga region during the last ten thousand years. Twenty-six phases in evolution of the natural environment during the Holocene were distinguished. Landscape-climatic characteristics and chronological boundaries were identified for these phases. Reconstructed paleoclimatic stages were correlated to the Holocene transgressions and regressions in the Caspian Sea region. The model developed for periodization of climatic events may serve as a climato-stratigraphical framework for future paleogeographical studies of the Holocene in the Northern Caspian region.

KEY WORDS: the Lower Volga region, Holocene, pollen assemblages, ^{14}C dating, vegetation and climate reconstructions, paleo-environments, transgressions and regressions of the Caspian Sea

INTRODUCTION

Changes in landscape conditions that have been occurring in the northern Caspian Sea during the last 10,000 years are associated with climate change and fluctuations of the Caspian basin. Using data on geology, geomorphology history, archaeology, and malacology and results of radiocarbon (^{14}C) dating, experts have defined age, coastline hypsometry, and a hierarchy of multiple transgressions and regressions of the Caspian Sea in the Holocene [Leontiev et al., 1976; Lower Volga..., 2002; Rychagov, 1997; Svitoch, 2006; Varuschenko et al., 1987].

Climatic conditions and plant communities of the littoral areas of the Mangyshlak regression, of the maximum of the New Caspian transgression, and of different phases of the Late Atlantic period have been reconstructed from palynological analysis of the bottom sediments of the Caspian Sea and from analysis of lake, alluvial, and subaerial deposits of the northwestern and northeastern sectors of the Caspian region [Abramova, 1980; Abramova, 1985;

Vronsky, 1980; Vronsky, 1987; Yakhimovich et al., 1986 and many others]. For these paleogeographic stages, values of annual precipitation and values of annual, July, and January temperatures have been obtained with the help of mathematical methods to quantify paleoclimatic parameters of the spore-pollen assemblages [Abramova and Turmanina,1988; Bukreeva and Vronsky, 1995].

A holistic understanding of vegetation and climate evolution during the entire modern interglacial epoch has been hampered by a lack of data on the Caspian sequences with the full representation of the Holocene sediments, sufficient palynological characteristics, and a series of ^{14}C dates.

The first results of a comprehensive palynological study of sediments fully dated with ^{14}C method that allowed us to reconstruct a continuous sequence of changes in vegetation and climate of the Lower Volga during the Holocene were obtained in the late 1980's [Bolikhovskaya, 1990; Bolikhovskaya et al., 1989]. Using materials of our subsequent research, we compared climatic and vegetation Holocene successions of the Volga-Akhtuba floodplain and the Volga delta and identified the patterns of landscape and climatic changes that have been occurring in the study area during the last 10,000 years [Bolikhovskaya and Kasimov, 2010; Bolikhovskaya and Kasimov, 2008].

This paper presents the results of detailed reconstructions of changes in the zonal vegetation types and the transformation of the zonal and intrazonal plant communities in the Holocene landscapes of the Lower Volga region that occurred under the impact of global climate fluctuations and changes of edaphic conditions. These reconstructions were based on a comprehensive palynological analysis and radiocarbon dating of paleogeographic sequences that were the most informative in regards to the Holocene period. The reconstructed paleoclimatic events were correlated to the Caspian Sea transgressive-regressive phases in the Holocene. A detailed periodization scheme of individual paleoclimatic events has been developed. This scheme can serve as a framework for subsequent climato-stratigraphical and paleogeographical studies of the Northern Caspian region during the Holocene. The reconstructed chronological paleo-boundaries of vegetation, landscape, and climate change phases may serve as a climato-stratigraphical framework for subsequent paleogeographical studies of the Holocene of the Caspian basin. Furthermore, these findings may help to understand the magnitude of the transformation of the Holocene landscapes of the Northern Caspian region in various transgressive – regressive epochs.

MATERIALS AND METHODS. THE STUDY AREA

The main object of these research efforts was the Northern Caspian Sea region, specifically, the Volga-Akhtuba floodplain as it is the most indicative in palynological respect. Its vegetation (as shown by the results of this study) actively responded to climate change and the congruent Caspian Sea level fluctuations. The spore-pollen analysis of the sediments of two sections near the site Solenoye Zajmishche (47°54′ N, 46°10′ E; about – 19–20 m asl (i.e., above sea level); 5 km south of the city of Chernyi Yar, Astrakhanskaya oblast) was performed. Section 1 (S1) was a 5-meter thick layer uncovered by a well at a dry oxbow lake developed on the surface of a high floodplain. A detailed climato-stratigraphical interpretation was performed using palynological analysis of 50 samples taken at 10-cm intervals and ^{14}C dating of five samples (Table 1). It appeared that the process of accumulation of oxbow-lake clays continued through the entire Holocene. In the outcrop of the sediments, Section 2 (S2) uncovered a high floodplain towering 6–7 meters above the river's edge. Representative data have been obtained for the upper 3 m of the exposed sequence. On the base of pollen

Table 1. Radiocarbon and calendar dates for the Holocene sediments of the Sections at Solenoe Zajmishche.

Sample Number	Depth, m	14C dates, yrs BP	Calendar (calibrated) dates, BP. (ca. 14C yrs BP)
1	4,75–5,00	9560 ± 60	11060–10970
2	4,50–4,75	8500 ± 100	9500
3	2,25–2,50	3200 ± 60	3440–3400
4	2,00–2,25	2540 ± 130	2620
5	0,30–0,50	900 ± 60	900–800

assemblages, it may be dated to the late Subboreal and Subatlantic periods of the Holocene.

Palynological data were also derived for a 10-m thick layer penetrated by borehole N22 in the littoral area of the Volga Delta (45°43′ N, 47°55′ E) (–22 m asl) at the Damchik site of the Astrakhan Nature Reserve. The absolute age of this section's sediments identified by our colleagues in an international project from six ^{14}C AMS dates varied from 7287 ± 44 to 3316 ± 34 BP. [Kroonenberg and Hoogendoorn, 2008]. The Holocene geological record in the sequences of the Volga delta [Bolikhovskaya and Kasimov, 2008] is incomplete, which has been confirmed by rigorous palynological and algological investigation of four sections of the delta carried out by K. Richards [Richards and Bolikhovskaya, 2010].

Currently, the Lower Volga is the place with the most arid and continental climate in the territory of not only the Volga region itself, but also of Europe as a whole. The area where the study sites are located – the Volga-Akhtuba floodplain and the Volga delta – belong to the province of the Volga-Akhtuba semi-arid landscapes [Nikolayev, 2007]. In the area of Solenoe Zajmishche, the Volga-Akhtuba floodplain is adjacent to a semi-desert zone dominated by sagebrush-gramineous communities. The Volga-Akhtuba province, which stretches from north to south for more than 350 km, differs from other provinces in this zone by a gradual depletion, in the same direction, of tree, shrub, and herbaceous flora and by the greatest diversity of phytocoenoses. The Volga-Akhtuba floodplain is occupied by dense floodplain forests (mainly willow) and grassland communities (gramineous-herb, gramineous, gramineous-sedge, sagebrush-herb, etc.). Poplar, aspen, and maple grow in forests together with various types of willow. Oak (*Quercus robur*), ash (*Fraxinus excelsior*), elm (*Ulmus laevis*, *U. carpinifolia*), birch (*Betula pendula*, *B. pubescens*), and black alder (*Alnus glutinosa*) are less frequent. The dendroflora of the Volga delta is extremely poor: stands are formed mainly by white willow (*Salix alba*). Ash and elm can be found only occasionally in willow stands and only in the northern part of the delta. To the west and east, the Volga delta adjoins desert landscapes dominated by sagebrush (subgenera *Seriphidium* and *Dracunculus*). On the sands of the dunes, there are primarily tamarisk and dzhuzguna bushes. The vegetation of the littoral strip of the Caspian Sea consists mainly of halophytic and saltwort-sagebrush communities (*Halocnemum strobilaceum*, *Artemisia halophila*, *Suaeda altissima*, *S. confusa*). Thick growth of common reed grass (*Phragmites communis*) stretches along the sea. The poverty of the flora of the North Caspian Sea is the result of its development mainly during the Holocene.

We collected and studied samples from the modern alluvial and sub-aerial sediments in semiarid and arid areas of the Northern Caspian region. The results of the palynological studies clearly demonstrate that subrecent pollen assemblages of all samples analyzed adequately reflect the zonal type and structure of the pollen and

Table 2. Composition and percentage-share of dendroflora in pollen assemblages of the Sequences at Solenoe Zajmishche and Damchik-22 core

Section 1 Solenoe Zajmishche (Volga-Akhtuba floodplain)		Damchik-22 core (Volga delta)	
Taxa	**Conmnt during maxima, %**	**Taxa**	**Conmnt during maxima, %**
Abies sp.	3–5	*Abies* sp.	3–4
Picea sect. *Omorica*	22–48	*Picea* sect. *Omorica*	22–43
Picea sect. *Picea*		*Picea* sect. *Picea*	
Pinus subgenus Haploxylon	12–26	*Pinus* subgen. *Haploxylon*	1
Pinus sibirica		–	
Pinus sylvestris	45–58	*Pinus sylvestris*	45–55
Betula pendula	15–22	*Betula pendula*	46–67
B. pubescens		*B. pubescens*	
Betula sect. *Fruticosa*		*Betula* cf. *fruticosa*	
Betula cf. *nana*		*Betula* cf. *nana*	
Salix sp.	42–46	*Salix* sp.	63–75
Alnus glutinosa	4–11	*Alnus glutinosa*	12–20
A. incana		*A. incana*	
Corylus avellana	21–31%	*Corylus avellana*	13–20%
Corylus colurna		–	
Fagus sylvatica		–	
Fagus orientalis		*Fagus orientalis*	
Quercus robur		*Quercus robur*	
Quercus petraea		*Quercus petraea*	
Carpinus betulus		*Carpinus betulus*	
Carpinus caucasica		–	
Carpinus orientalis		*Carpinus orientalis*	
Tilia cordata		*Tilia cordata*	
Tilia platyphyllos		–	
Tilia tomentosa /argentea/		*Tilia tomentosa / argentea*	
Tilia dasystyla		–	
Ulmus laevis		*Ulmus laevis*	
Ulmus carpinifolia / foliaceae/		*Ulmus carpinifolia*	
Ulmus glabra /scabra/		–	
–		*Ulmus* cf. *pumila*	
Fraxinus sp.		*Fraxinus* sp.	
cf. Morus sp.		*cf. Morus* sp.	
Tamarix sp.		*cf. Tamarix* sp.	
–		*Elaeagnus*	
Euonymus sp.		*Euonymus*	
Caprifoliaceae		–	
Juniperus sp.		*Juniperus* sp.	
–		*Juniperus* cf. *foetidissima*	
Total number of taxa	35	Total number of taxa	30

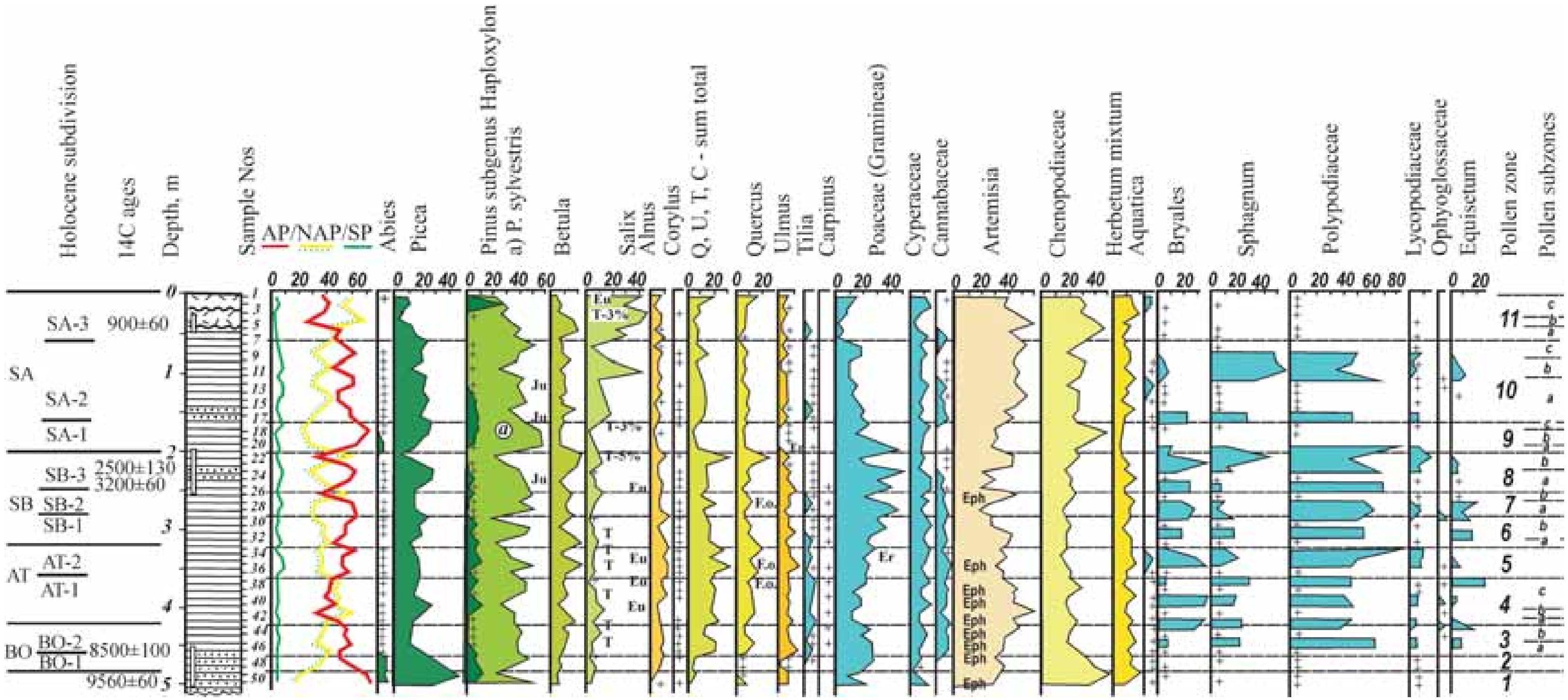

Figure 1. Pollen-spore percentage diagram of Section 1 near the site Solenoye Zajmishche.
1 – sample locations for radiocarbon dating (^{14}C); 2 – arboreal pollen (AP); 3 – non-arboreal pollen (NAP); 4 – spores (SP); 5 – pollen content less than 2 %; 6 – *Juniperus*; **7 –** *Tamarix*; **8 –** *Euonymus*; **9 –** *Fagus sylvatica*; **10 –** *Fagus orientalis*; **11 –** *Fraxinus*; **12 –** *Ericales*; **13 –** *Ephedra*

spore producing plant communities. Detailed descriptions of the pollen assemblages and reconstructed paleophytocenoses, as well as the methodological background of performed reconstructions, are given in a number of our previous publications [Bolikhovskaya, 1990; Bolikhovskaya and Kasimov, 2010; Bolikhovskaya and Kasimov, 2008].

Here, referring to the methodological aspects, we emphasize that climatological and stratigraphical interpretations of the fossil assemblages from the delta deposits were based on characteristic features of the pollen records of Solenoe Zajmishche, i.e., the chronology of peaks of pollen of dark coniferous trees, broadleaf trees, grass and xerophytic shrub communities, etc. Comparison of the composition and degree of participation of arboreal pollen in the assemblages of Solenoe Zajmishche and Damchik confirms the promising prospect of using the delta sequences for the investigation of vegetation and climate change in the littoral Caspian region and, consequently, of arriving at conclusions on sea level fluctuations. First, it appears that tree and shrub species of Damchik palynoflora, which consists of 30 taxa, is close to the arboreal pollen of Solenoe Zajmishche, which contains 35 taxa (Table 2). The maximums of percentages of coniferous pollen (i.e., fir *Abies* sp.), spruce (*Picea* sect. *Picea*), and common pine (*Pinus sylvestris*)) in the dendroflora are also similar. However, systematic differences are also clearly seen, undoubtedly due to the differences in geography and paleozonal position of the sequences, as well as to the differences in edaphic conditions of growing trees in the floodplain and littoral areas. The following species are absent in the fossil Damchik dendroflora: Siberian pine (*Pinus sibirica*), common beech (*Fagus sylvatica*), some types of linden (*Tilia platyphyllos*, *Tilia dasystyla*), rough elm (*Ulmus glabra /scabra/*), and some representatives of the Caucasian forests, i.e., Caucasian hornbeam (*Carpinus caucasica*), hazelnut- tree or bearnut-tree (*Corylus colurna*). In addition, peaks of pollen of birch (*Betula pendula*, *B. pubescens*), alder (*Alnus glutinosa*, *A. incana*), willow (*Salix* spp.), and of a complex of deciduous trees (*Quercetum mixtum*) are also markedly different.

The most dynamic components of the pollen assemblages of the Solenoe Zajmishche sequences were the pollen of Scots pine, cedar, spruce, deciduous trees (beech, oak, hornbeam, linden, elm, etc.), gramineous grasses, sagebrush, goosefoot, and spores of ferns and green and sphagnum mosses. Eleven spore-pollen zones were isolated on the spore-pollen diagrams based on the dynamics of major components and the stratigraphical-paleogeographical palynoflora characteristics (Figs. 1 and 2). Most of these zones were subdivided into a number of subzones and smaller palynostratigraphical units, which reflect successive changes of climate and the structure of zonal and local vegetation during the Holocene.

THE RESULTS OF LANDSCAPE AND CLIMATE RECONSTRUCTIONS

A detailed stratigraphical interpretation of the sediments studied and a description of 26 phases in the development of vegetation and climate during the Holocene in the Lower Volga region were performed using the palynological data and results of ^{14}C dating obtained in this study (Table 3).

We correlated the reconstructed paleoclimatic events to the Caspian Sea level fluctuations defined according to geological, geomorphological, malacological, and other studies (Fig. 3).

PRE-BOREAL PERIOD (~10500/10300 – 9500/9200 BP)

The oldest sediments of Solenoe Zajmishche (4,8–5 m), dated to pollen zone 1 (see Fig. 1), are characterized by the dominance of tree pollen, mainly coniferous species (fir, spruce, cedar pine, and common pine). It is precisely here, that the maximal, for the Holocene sediments, pollen content of spruce (48 %) was found. In general, the amount

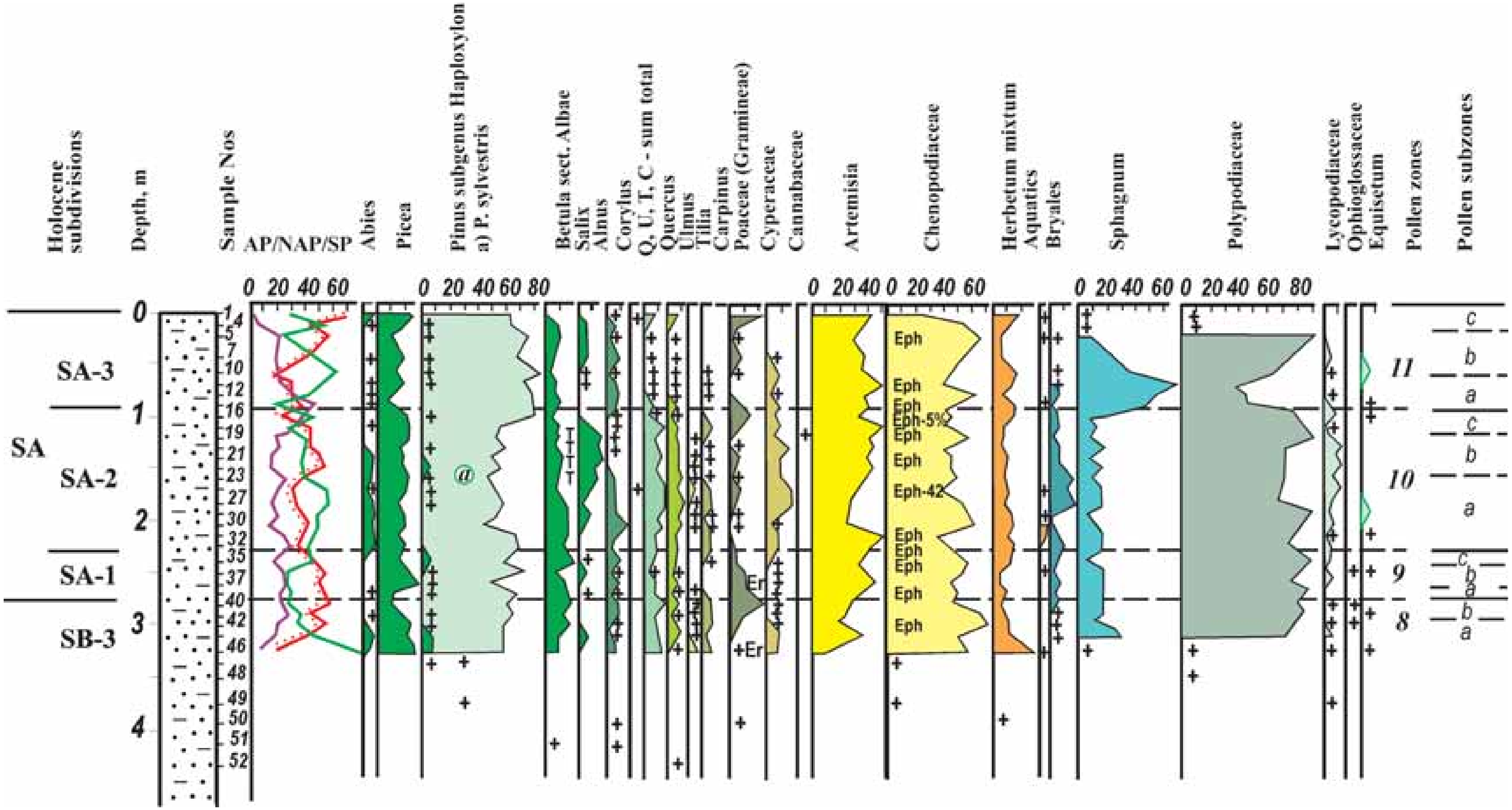

Figure 2. Pollen-spore percentage diagram of Section 2 near the site Solenoye Zajmishche (symbols are the same as in Figure 1).

Table 3. Climatic stages of the Holocene in the Lower Volga Region, their characteristic and ages according to pollen analysis and 14C dating of the deposits from the Solenoe Zajmishche

Holocene ubdivisions	^{14}C ages of climatic stages, years BP		Zonal vegetation	Climate
	Conventional	Calibrated		
SA-3	200–0	250–0	Semi-desert	Relatively warm and arid
	400–200	500–250	Semi-desert	Temperature fall, humidification
	700–400	670–500	Semi-desert	Temperature rise, humidification
	900–700	840–670	Semi-desert	Temperature fall, aridization
	1100–900	1030–840	Dry steppe	Cool and arid
SA-2	1300–1100	1270–1030	Steppe	Temperature rise, humidification
	1500–1300	1400–1270	Dry steppe	Temperature fall, aridization
	1700–1500	1600–1400	Steppe	Relatively warm and relatively humid
	1800–1700	1720–1600	Steppe	Warm and arid
	2100–1800	2080–1720	Steppe	Relatively warm and relatively humid
SA-1	2300–2100	2340–2080	Dry steppe	Temperature fall, continentalization
	2500–2300	2600–2340	Steppe	Temperature fall, humidification
SB-3	2700–2500	2780–2600	Steppe	Relatively warm and arid
	3500–2700	3770–2780	Forest-steppe	Relatively warm, humidification
SB-2	3700–3500	4040–3770	Dry steppe and semi-desert with Chenopodiaceae – Artemisia assemblages	Temperature fall, aridization
	4200–3700	4770–4040	Forest-steppe; mixed forests with broadleaved , birch and conifer stands	Warm and humid climate (III climatic optimum)
SB-1	4800–4200	5540–4770	Forest-steppe	Temperature fall and humidification rise
	5000–4800	5740–5540	Forest-steppe	Temperature fall, aridization
AT-2	6100–5000	6970–5740	Forest-steppe; mixed forests with hornbeam, beech, elm, lime, birch and conifer stands	Warm and humid (II – main – climatic optimum)
AT-1	7400–6100	8240–6970	Steppe	Warm and relatively arid
	7600–7400	8400–8240	Dry steppe with Chenopodiaceae – Artemisia assemblages	Temperature fall, aridization
	8000–7600	8900–8400	Steppe	Warm and relatively humid

Holocene ubdivisions	^{14}C ages of climatic stages, years BP		Zonal vegetation	Climate
	Conventional	Calibrated		
BO-2	8300–8000	9350–8900	Steppe	Temperature fall, continentalization
	8500–8300	9500–9350	Forest-steppe; mixed forests with hornbeam, elm, lime, birch and conifer	Warm and humid (I climatic optimum)
BO-1	9200–8500	10350–9500	Steppe with Chenopodiaceae assemblages, park pine forests	Cool, continentalization
PB-2	10000–9200	11500–10320	Forest-steppe dominated by *Picea*, *Pinus*, *Abies*	Relatively cool and humid

of microfossils of dark-coniferous species (fir, spruce, and cedar pine) approached 60 %; the pollen of deciduous trees, i.e., the grains of oak and elm, comprised 6–7 %. In the group of grasses and small-shrubs, the pollen grains of xerophytes, i.e., goosefoot, sagebrush, and ephedra, dominated. The spore-group contained the grains of boreal forest clubmoss species (*Lycopodium annotinum* L., *L. lagopus* (Laest.) Zinzerl.), and fern *Athyrium filix-femina* (L.) Roth).

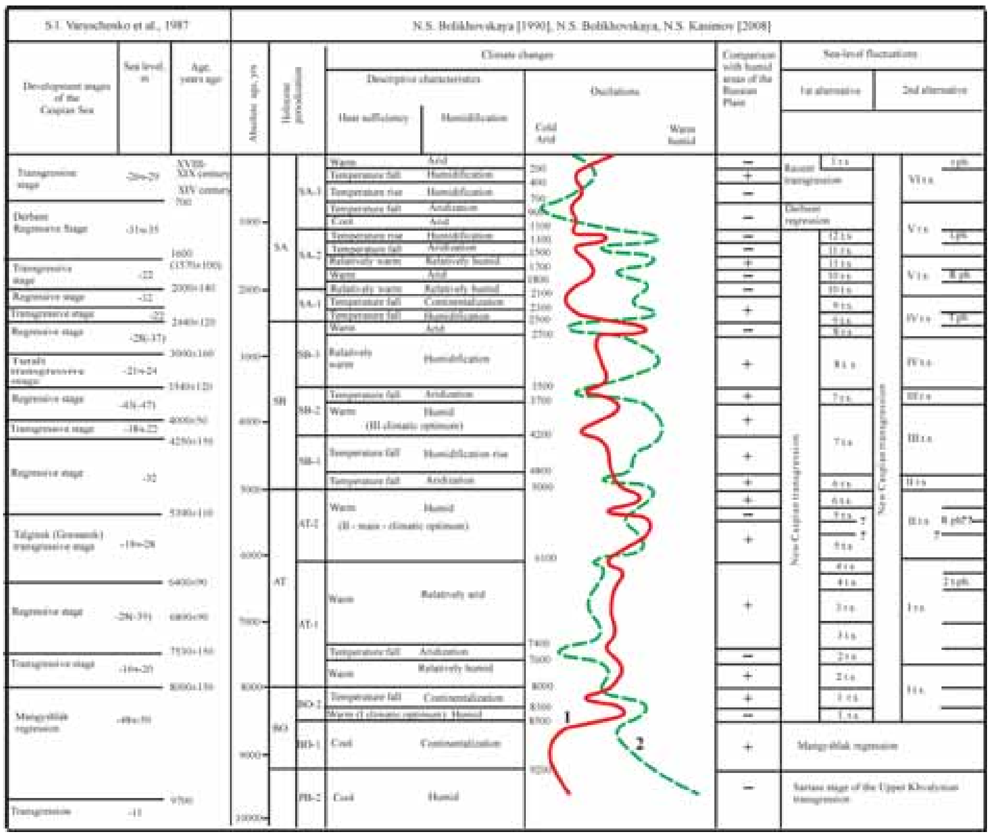

Figure 3. Reconstruction of climate changes in the Lower Volga Region during the Holocene and their correlation with transgressive and regressive stages of the Caspian Sea.
1 – curve of fluctuations of heat supply; 2 – curve of fluctuations of moisture availability

These deposits may be dated to the second half of the Pre-Boreal period (PB-2) of the Holocene. This dating was based on the climato-stratigraphical and climato-phytocenotical reconstructions, the location in the section, and the ^{14}C date of 9560 ± ± 60 BP at the depth of 4,75–5,0 m. It may be determined from interpolation calculations that these deposits were formed in the interval ~10000–9200 BP. We correlated this period to the Pereslavl cooling in the central regions of the East European Plain and to the final phase of the Sartass transgressive stage of the Late Khvalynian transgression of the Caspian Sea. The age of this stage is defined by the dates of 9700 ± 190 and 13110 ± ± 490 BP based on ^{14}C dating of the Sartass sediments of Dagestan [Leontiev et al, 1976]; sea level of this stage was identified at –10 to –12 m asl from the data on sections of ancient beach ridges [Rychagov, 1997; and others].

At that time, in a cold and relatively humid continental climate, the Lower Volga region was dominated by forest-steppe landscapes with the extensive development of dark coniferous forests. Spruce forests occupied the most favorable habitats of the Volga floodplain, i.e., leached depressions of the inner floodplain rich in loamy sediments, depressions adjacent to the terraces, and the slopes facing the river. There, spruce grew together with fir, cedar pine, oak, and elm. Grass cover of these park forests consisted of scattered turf grass patches, ferns, clubmoss, horsetail, and herbs. Eroded sites (with sparse xerophytic shrubs and small-shrubs) and salinized substrates (with halophytic communities), developed during the earlier arid climatic phase, prevailed in open landscapes. Sites with reworked sands, i.e., natural storage reservoirs of fresh water, were the areas of sparse pine forest growth.

The palynological analysis of the Sartass marine sediments from the boreholes in the Northern Caspian region performed by V.A. Vronsky [Bukreeva and Vronsky, 1995] showed that during their formation in the littoral areas they were dominated by arid steppe vegetation with some wooded sites.

BOREAL PERIOD (~ 9500/9200–8000 BP)

Pollen zones 2 (4,6–4,8 m) and 3 (4,2–4,6 m) represent the deposits of the Boreal period (BO) and suggest that, during this Holocene phase, the study area was the zone of development of steppe and forest-steppe landscapes. Under the influence of climate fluctuations, significant changes in plant formations continued to occur there for over 800 years.

During the Early Boreal period (BO-1; pollen zone 2), when the climate cooled down and its continentality increased, steppes with the predominance of herb-gramineous and clubmoss-sagebrush formations became the dominant vegetation type in the Lower Volga region. Biotopes with the most favorable edaphic conditions were occupied by sparse spruce-pine stands with some fir, cedar pine, and isolated trees of oak and elm. The composition of palynoflora, reconstructed paleovegetation, and ^{14}C age of 8500 ± 100 BP (4,5–4,75 m) allowed us to correlate this sub-period to the Mangyshlak regressive stage of the Caspian sea, identified by most researchers in the range of ~ 9000–8000 yr BP [Leontiev and Rychagov, 1982; Varuschenko et al, 1987; Leontiev et al., 1976; etc.]. Semi-desert and desert landscapes dominated the dry shelf that was free of the Caspian Sea, which level dropped to the marks of no less than – 50 m during the Mangyshlak regression [Abramova, 1980; Vronsky, 1987]. The palynological analysis of the continental Mangyshlak sediments exposed in the boreholes in the northern Caspian Sea and analysis of marine sediments of the Mangyshlak regression from deep columns of the Middle Caspian that completely lacked woody vegetation, showed that the littoral area was inhabited only by the clubmoss family species, i.e., salt grass, glasswort, sarzasan, and other plants of salinized littoral zones [Bukreeva and Vronsky, 1995].

The sediments of the second part of the Boreal period of the Holocene (BO-2) were deposited during the first climatic phase of the emerging New Caspian transgression of the Caspian Sea.

The Mid Boreal phase (pollen subzone 3*a*, Fig. 1) marks the beginning of a long-term invasion of deciduous dendroflora into the study region, most vividly expressed in the dominance of or a significant presence of broad-leaved forest formations in several forest-steppe and steppe phases of the subsequent Atlantic and Subboreal periods. Through interpolation, the age of this phase was estimated at ~ 8500–8300 BP. We can conclude, therefore, that the chronological framework of the preceding (Mangyshlak) regression was narrower than previously thought. Probably, the maximum decrease in the level of the Caspian Sea during the Mangyshlak regression occurred in the interval of ~ 9200–8500 BP.

We correlated the phase of the dominance of forest-steppe landscapes under significant warming and moistening of climate to the first Holocene climatic optimum of the Caspian, when the stands of riparian forests were dominated by deciduous trees: oak, common hornbeam (*Carpinus betulus*), elm, and linden. Oak and elm (*Quercus robur*, *Q. petraea*, *Ulmus laevis*, *U. foliacea*) were the edificatory species; the undergrowth contained oriental hornbeam (*Carpinus orientalis*) and hazel. The grass cover of forest communities was dominated by gramineous plants and grasses. Open spaces were occupied mainly by herb-granineous formations. In this case, the heterogeneity of edaphic conditions determined the diverse composition of grass-shrub cover of steppes expressed by the development, along with these formations, of xerophytic and halophytic cenoses.

The final steppe phase of the Boreal period (3*b*) marked a short-term climate cooling dated to ~8300–8000 BP. The paleolandscapes of the Lower Volga region had greater presence of spruce and pine formations. The area of deciduous forests decreased; the share of mesophytic species, i.e., ordinary hornbeam and linden, also decreased in these formations. Oak and elm continued to play the dominant role only in the floodplain forests. Willow stands spread into the floodplain sites. Published sources indicate that cooling at the boundary of the Boreal and Atlantic periods of the Holocene also occurred in many neighboring and remote regions of Northern Eurasia (the Lower Don, Ulyanovsk Volga Region, Bashkortostan, Eastern Transcaucasia, etc.) [Blagoveschenskaya, 1986; Klimanov and Nemkova, 1988; Mamedov and Veliyev, 1988; Spiridonova, 1991; etc.].

ATLANTIC PERIOD (~ 8000−5000 BP)

Vegetation and climate change that occurred in the Lower Volga region during the Atlantic period are reflected in the assemblages of pollen zones 4 and 5 (see Fig. 1).

Three phases in the evolution of steppe landscapes that dominated throughout the Early Atlantic time (AT-1) are represented by pollen zones 4*a*, 4*b* and 4*c* (3,6–4,2 m).

Climatic conditions and vegetation cover of the early phase of the Atlantic period (4*a*) with a significant expansion of deciduous forest formations dated to ~ 8000–7600 BP were close to a relatively humid forest-steppe phase (3*a*) of the Mid Boreal warming. Therefore, we have concluded that there was an extended phase of climate warming and humidization during ~ 8500–7600 BP interrupted briefly by the Late Boreal cooling. This was the climatic phase that corresponds to the early transgressive stage of the New Caspian basin, for which S.I. Varuschenko et al. [1987] indicate the ^{14}C age within the range of 8000 ± 150 and 7530 ± 150 BP and the rise of sea level to −16 to −20 m asl. G.I. Rychagov [1997] considers this phase to be the maximal (according to him, the coastline was on −19 to −20 m asl) and dates it to ~ 8000–7000 based on the results of the study of coastal forms, terraces, and marine sediments of the Western Caspian Sea region (see Figure 2, 3. in [Lower Volga..., 2002]).

In the range of ~7600–7400 BP, pollen subzone 4*b* marks a short-term phase of aridization and cooling of climate with a reduction of deciduous forests and the expanse of the area of turf-free ecotopes. The pollen of this period is dominated by grass and shrubs, the maximal (for the sediments of the Atlantic period) peak of sagebrush, by a declining share of linden, and by a greater role of willow.

The next phase in the development of vegetation and climate, reconstructed from the spectra of pollen subzone 4*c*, reflects relatively long warming in the range of ~ 7400–6100 BP. It was a period of not only warm but also of a relatively dry climate. Given the climatic features of the last arid phase, we assume that the lowering of the New Caspian basin could have occurred not only in 7600–7400 BP but even later, i.e., in ~ 7600–6100 BP. This regressive phase corresponds to the regressive phase dated by ^{14}C to 6800 ± 90 and 6400 ± 90 BP with –28 (–39) m asl [Varuschenko et al., 1987].

Steppe remained the zonal vegetation type of the Lower Volga region in 7400–6100 BP. Global warming led to the growing contrast between zonal and intrazonal landscapes and between their plant formations. On watersheds, the area of open landscapes with grass-shrub communities expanded and their differentiation increased. Within the Volga-Akhtuba Valley, improved site conditions contributed to the enrichment of the composition of the deciduous forests. There were many other species in the mixed oak forests of the central part of the floodplain, e.g., linden (*Tilia cordata*, *T. dasystyla*), elm (*Ulmus laevis*), field elm (*U. carpinifolia*), common hornbeam (*Carpinus betulus*), oriental beech (*Fagus orientalis*), alder, etc. Species-depleted forest communities of less favorable habitats were composed of oak-elm, elm, alder, and willow stands. The undergrowth was represented by hazel (*Corylus avellana*), euonymus (*Euonymus* sp.), and willow. The grass cover was dominated by gramineous plants and herbs. Tree trunks were covered with vines of hops (*Humulus lupulus*), which was constantly present, since the Mid Boreal period and until the end of the Subboreal time, in the Volga-Akhtuba forests.

The vegetation cover of the Late Atlantic period is reflected by pollen zone 5 (3,2–3,6 m). Its taxa composition is close to that of pollen zone 4. However, it differs from the latter in the dominance of the tree and shrub pollen, in increased (up to 31 %) amount of thermophilic dendroflora pollen, in the presence of Caucasian hornbeam (*Carpinus caucasica*), and in a greater role of pollen of alder, grasses, *Ericales*, and fern spores (see Fig. 1).

The late Atlantic interval (AT-2), which lasted from 6100 to 5000 BP, is characterized by the dominance of steppe vegetation and the highest, in the Holocene, number of thermophilic and moisture-loving species. This was the major Holocene climatic optimum within the study area in terms of the intensity and balance of heat supply and moisture availability for vegetation.

We associated the entire Late Atlantic period with the transgressive phase of the New Caspian basin (–18 to –28 m asl [Varuschenko et al, 1987] and -21 m asl [Rychagov, 1997]) and the ^{14}C age of 5940 ± 100, 5540 ± 110, and 5390 ± 110 BP). Using the palynological data, we identified the relative momentum of climate continentalization within this phase, which could have caused a short-term drop in sea level [Bolikhovskaya, 1990] ~5500–5400 BP.

Our reconstructions showed that during the Late Atlantic time, the forest belt of the Lower Volga Valley consisted of mixed oak forests with common and Caucasian hornbeam, oriental beech, and various types of elm, linden, birch and other trees. There were also oak-elm, elm, and pine stands. The spore assemblages of the ferns *Athyrium filix-femina*, *Botrychium matrycarifolium*, of the clubmoss *Diphazium complanatum*, and of other species are indicative of meadow and moisture-loving species in the grass cover of the forests and the forest fringes. The stands of island placoric forests, confined to narrow valleys, steppe "saucers", estuaries, and other depressions with a low level of groundwater, were the habitats of species less demanding for moisture, i.e., pine, birch, elm, English oak, etc.

Furthermore, the palynological studies of the Holocene sediments of the lower reaches of the river Ural found that, during the phase of the maximum Holocene warming and humidization in the Northern Caspian Sea region, there was the dominance of steppes with pine and deciduous species of oak, hornbeam, linden, and ash [Yakhimovich et al., 1986].

SUBBOREAL PERIOD (~5000–2500 BP)

The variability of the sediments of the Subboreal period (SB) (2,0–3,2 m) was increasing upward in the stratigraphy. Three pollen zones were isolated there; each zone was in turn subdivided into two pollen subzones. This fact indicates more frequent alternations of landscape-climatic conditions in the SB period compared to the Atlantic period.

Pollen zone 6 (2,8–3,2 m) allowed us to reconstruct the landscapes of the first one-third of the Subboreal period (SB-1) transformed under the influence of climate cooling, which began ~ 5000–4200 BP. This is manifested in the spore-pollen assemblages by decrease of the share (to 15–18 %) of the thermophilic tree pollen (due to decrease of the oak, elm, and linden pollen content and disappearance of the beech pollen). There is no reason to assume a fundamental change in the boundaries of the natural zones, but deterioration of climatic conditions led to a reduction in the forest cover and degradation of broad-leaved forest stands in still prevalent forest-steppe landscapes. By their very structure, the forests of the Volga-Akhtuba floodplain were close to the forests of the second half of the Early Subatlantic period. Clay-sediment formation in the oxbow lake during the first phase of the Early Subboreal time took place in conditions of both cooling and aridization of climate, since in the lower part of the examined layer (pollen subzone 6*a*), the pollen of grass-shrub plants (where xerophytic species dominated) reached 45 %. The amount of arboreal (including spruce), shrub, grass, and sedge pollen grew upward in the stratigraphy (pollen subzone 6*b*).

The cooling, in combination with the aridization of climate on the turn of the Atlantic and Subboreal periods, caused the next regressive phase of the New Caspian basin, which, according to the pollen data, was of a short duration (approx. from 5000 to 4800 BP). The data obtained confirmed the assumption made earlier by A.N. Varuschenko et al. [1980] that the most likely period of regression to −32 m (Izberbash) was 3100–2400 BP (~ 5000–4400 BP). Later (~ 4800–4200 BP) and until the end of the Early Subboreal period, this cooling was accompanied by climate humidization and, possibly, by a gradual rise in sea level.

Pollen zone 7 (2,5–2,8 m) describes the Mid Subboreal warming (SB-2) that took place in the interval ~4200–3500 BP. The assemblages of pollen subzone 7*a* were dominated by the pollen of broadleaf species (up to 21 %), coniferous trees (mainly pine and spruce), gramineous plants (in grass-shrub formations), and by the pollen of a variety of herbaceous species. This fact suggests that the vegetation of the early phase was developing in a warm and relatively humid climate. At that time, prevailing forest-steppe landscapes had oak and oak-elm forests mixed with beech, hornbeam, linden, and elm (*Quercus robur*, *Fagus orientalis*, *Carpinus betulus*, *Tilia cordata*, *T. dasystyla*, *T. tomentosa*, *T. rubra*, *Ulmus laevis*, *U. glabra*, *U. carpinifolia*), spruce-pine forests, and herb-gramineous steppe formations. This period of warming and humidization (~ 4200–3700 BP), i.e., the third Holocene optimum of the Northern Caspian region, was inferior to the main (the second, Late-Atlantic) optimum in duration and thermal characteristics. It corresponds to the transgressive phase of sea level rise to −18 to −22 m asl in the ^{14}C dated interval of 4250 ± 150 and 4000 ± 50 BP isolated by S.I. Varuschenko et al. [1987].

This sub-period ended with a pulse climate drying ~ 3700–3500 BP (pollen subzone 7*b*), which led to the dominance of the steppe and semidesert communities on watersheds, to the degradation of herb-gramineous steppes and riparian deciduous forests, and to the expanse of the area of eroded sites with sparse cover of sagebrush, *Ephedra*, and other xerophytes. This phase corresponds to the regressive Caspian stage in the interval from 4000 ± 50 to 3540 ± 120 BP [Varuschenko et al., 1987].

Changes in phytocenotic and climatic conditions during the Late Subboreal phase (SB-3) (~ 3500–2500 BP) are reflected by pollen zone 8 (2,0–2,5 m). The dominance of arboreal pollen (spruce, pine, and broadleaf species), the dominance of the pollen of gramineous plants, forbs, and grasses, and the dominance of ferns in the spore-grain assemblages indicate that the Late Subboreal phase began with the humidization of climate that lasted approximately from 3500 to 2700 BP. This humidization led to the southern shift of dark-coniferous species boundary, to the return of steppes to the Lower Volga territory, to the emergence of elm (*Ulmus laevis*, *U. glabra*, *U. carpinifolia*) as the dominant species in the riparian deciduous forests, to a mesophication of grass cover of the Volga-Akhtuba floodplain, and to the dominance of herb-gramineous and gramineous cenoses.

The phase of climate humidization corresponds to the Late Subboreal cooling of the central regions of the Eastern European Plain and to the fourth (to −23 to −23 m asl, according to Rychagov [1997]) or to the Turalinskaya (according to Varuschenko et al. [1980]) transgressive phase of the New Caspian basin.

In the upper part of the section, the grass-small-shrub xerophytic pollen is prevalent in the assemblages of pollen subzone 8*b*. The share of spruce and pine pollen falls dramatically. The pollen of small leaf and broadleaf trees begins to dominate. The amount of pollen of thermophilic arboreal elements reaches 30 %. The palynological data indicate that during the final phase of the Subboreal period, warming and increased dryness of climate, which lasted roughly from 2700 to 2500 BP, caused a new wave of steppification of the vegetation cover. In the open steppe landscapes of the Lower Volga region, goosefoot-sagebrush associated with gramineous formations. The composition of arboreal species was substantially depleted: conifer stands degraded almost entirely and hornbeam disappeared. At the same time, the area of forests consisting of oak and oak-elm with admixture of linden and beech (*Fagus sylvatica* L.) increased significantly. These forests were prevalent among the riparian forest formations of the Volga-Akhtuba and grew together with small leaf stands (birch, alder, and willow) and thickets of halophilic tamarisk (*Tamarix* sp.). In the grass-small-shrub layer, graminoues grasses, sedges, and sagebrush dominated. The reduction in the area of the oxbow paleo-lake caused the waterlogging of its shoreline zone and the overgrowing of sphagnum moss. Judging from the palynological records, during all subsequent phases of the evolution of the Holocene vegetation of the Lower Volga, broad-leaved forests were significantly less common.

We correlated this phase of a relatively short-term aridization and warming of climate to the Alexandrbajskaya phase isolated by A.N. Varuschenko et al [1980], i.e., the regressive stage (sea level drop to −37 m asl).

SUBATLANTIC PERIOD (~2500 BP TO THE PRESENT TIME)

The results of ^{14}C dating (Table 1), the spore-pollen records of the upper 2-m thick clay layer from the oxbow lake (see Fig. 1), and the records of the floodplain alluvium of S2 (Fig. 2) indicate that, for the past 2500 years, the study area of the Northern Caspian region was initially dominated by steppes (~from 2500 to 900 BP). These steppes were replaced later (from 900 BP to the present time) by semi-desert landscapes. The climate was generally colder and more continental than the climate of the Atlantic and Subboreal periods. The assemblages of pollen zones 9, 10, and 11, each subdivided into several palynostratigraphical units, suggest multiple changes of climatic conditions and the transformation of vegetation during the Subatlantic period.

The assemblages of the Early Subatlantic (SA-1) interval (~2500–2100/2000 BP are mainly of the steppe type (pollen zone 9: 1,6–2,0 m in S1 and 2,3–2,75 m in S2). During cooling and humidization of climate, the initial phase (~ 2500–2300 BP) was dominated by open steppe and meadow-steppe (mainly gramineous) communities with patches of spruce-pine forests mixed with oak, ash *(Fraxinus* sp.), and linden (pollen subzone 9*a*). During the next phase (~2300–2100 BP), under the influence of climate continentalization and cooling, the deciduous stands almost completely disappeared from the vegetation of the Lower Volga Valley; they were replaced by pine park forests with admixture of spruce (pollen subzone 9*b*). Xerophytes dominated in the sparse grass-small-shrub cover of dry steppes that prevailed at that time. The Early Subatlantic interval ended with the emerging phase of climate humidization (~2100–2000 BP), which led to a greater spread of dark coniferous and broadleaf species in the forests and gramineous plants, sedges, and mesophilic species in the grass cover (pollen subzone 9*c*).

As shown by the assemblages of pollen zone 10 (0,6–1,6 m in S1 and 0,65–2,3 m in S2), the evolution of vegetation of a long-lasting Mid Subatlantic (SA-2) sub-period (~ 2100/2000–1100 BP) was influenced mainly by the continuing mitigation of climate continentality. The amount of arboreal thermophilic pollen increased in the assemblage of pollen subzone 10*a* (oak, elm, and linden together, up to 14 %), while steppe remained the zonal vegetation type of the initial phase. Warming promoted an even greater spread of mixed oak forests (English and sessile oak *Quercus robur* and *Q. petraea*, elm *Ulmus carpinifolia / foliaceae /*, rough elm *Ulmus glabra /scabra/*, cardiophyllous linden *Tilia cordata*, etc.) and the growth of hazel in the undergrowth of the wooded areas in river valleys, ravines, and depressions. The grass-small-shrub cover of the steppe coenoses was composed of herb-gramineous and haze-sagebrush communities. This long phase of warming and humidization of climate, dated to the interval ~2000–1500 BP corresponds to the Ulluchayskaya transgressive stage of the Caspian Sea that is ^{14}C dated to the interval 2000 ± 140 – 1570 ± 100 BP according to S.I. Varuschenko et al. [22]. Perhaps within this trangressive stage ~1800–1700 BP, there was a short-term sea level drop caused by decrease in precipitation.

The next phase in the landscape development is reflected in the assemblages of pollen subzone 10*b* (0,8–1,05 m in S1 and 1,15–1,55 m in S2) with the overall reduced amount of the tree and shrub pollen (including spruce, pine, and broadleaf species) and the dominance of willow pollen. The grains of sagebrush and the *Chenopodiaceae* family dominate in the pollen of grass and shrub assemblages, while sphagnum moss prevails among the spores. These and other palynological characteristics indicate that cooling and aridization of climate in the interval ~1500–1300 BP significantly reduced the role of coniferous and broadleaf trees in the forests of the Volga Valley and promoted the development of willow species in the riparian stands. On placoric sites, the area of steppe communities with the prevalence of sagebrush and some species of the *Chenopodiaceae* family (as subdominants) expanded. Decrease in the mirrors of oxbow lakes led to the waterlogging and to the growth of the eutrophic sphagnum moss, horsetail, and other plants of wet floodplain ecotopes. It is possible that this stage of cooling and aridization of climate in the interval ~1500–1300 BP corresponds to the first phase of the Derbent regression of the Caspian Sea.

New warming and humidization of climate is reflected in the interval ~1300–1100 BP by the assemblages of pollen subzone 10*c* (0,6–0,8 m in S1 and 0,95–1,15 m in S2). During this phase, the floodplain forests were dominated by spruce-pine, oak, and oak-elm stands. At the same time, the role of gramineous plants and sedges increased in the grass-shrub cover dominated by sagebrush.

Throughout the Late Subatlantic period (SA-3), i.e., during the last ~ 1100 years, the study area remained under unstable climatic conditions (pollen zone 11, 0,0–0,6 m in S1 and 0,0–0,95 m in S2). The initial phase of modern vegetation development is characterized by pollen subzone 11*a*. Amid the growing role of the pollen of grass-small-shrub communities (judging from the high content of the *Chenopodiaceae* grains), the amount of spruce, pine, and oak pollen decreased dramatically during that time while the role of small leaf tree pollen (i.e., willow (*Salix* sp.) and birch (*Betula pendula*, *B. pubescens*)) increased. Climatic and phytocoenotic conditions of this dry-phase that reflects climate cooling and aridization ~1100–900 BP were close to the interval of cooling and aridization of the interval 1500–1300 BP. The maximum of the Late Subatlantic climate cooling and aridization in the interval ~900–700 BP was marked by the absolute prevalence of the semidesert and desert associations and almost complete disappearance of broadleaf species from the Volga-Akhtuba forest belt composed primarily of willow stands (pollen subzone 11*b* – 0,3–0,4 m in S1 and 0,2–0,65 m in S2).

The combined assemblages of pollen subzones 10*b*, 10*c*, 11*a*, and 11*b* suggest that the Derbent regressive stage of the Caspian basin (isolated by D.C. Leontiev and G.I. Rychagov [1982] in the interval 1400–800 BP and by S.I. Varuschenko et al. [1987] from the middle of the V century to the XIV century (~1550–700 BP)) was probably aggravated by rising sea levels caused by climate warming and humidization ~1300–1100 BP; it is possible the regression to the lowest level of −34 to −35 m asl occurred ~ 900–700 BP.

Since the time level specified by the radiocarbon date of 900 ± 60 yr BP (cal. 900–800 BP) the Volga-Akhtuba region has been occupied by the arid semi-desert landscapes that are close to the modern autonomic semi-desert landscapes of the studied territory. This conclusion was reached based on analysis of the assemblages of pollen subzone 11*c*. The pollen assemblages from Sample 2 in S1 and Sample 4 in S2, where the amount of pollen of trees and shrubs increased (in the arboreal group, due to the cedar pine pollen), reflect cooling and humidization of climate in the interval ~ 400–200 BP and the greater expansion of coniferous species into the floodplain forests in the Northern Caspian region.

CONCLUSIONS

The research presented herein established the following dependencies in landscape-climatic changes in the Lower Volga region and in climate-dependent sea level fluctuations of the Caspian Sea during the Holocene.

1. Over the past 10,000 years, there were several changes in the vegetation cover and climate of the Lower Volga region. Palynological data indicate at least 26 phases in the evolution of the Holocene landscapes and climate of this territory. During the Early and Middle Holocene, in the interval ~ 10000–2500 BP, forest-steppe and steppe landscapes dominated under a more favorable and humid (compared to the modern time) climate in the study area. These landscapes underwent seven forest-steppe and seven steppe non-consecutive phases during their development. In the Late Holocene, in the interval ~ 2500–900 BP, there were eight phases that reflect the transformation of zonal and intrazonal phytocoenoses. During the last 900 years, the territory of the Lower Volga became the area of development of desert-steppe and desert landscapes, for which at least four climato-phytocoenotic alternations were identified; these phases reflected fluctuations of heat and moisture availability (see Fig. 3).

2. The main feature of the evolution of climatic processes in this region during the Holocene was expressed in the distinct climatic optimums that corresponded to the maximums of heat and moisture supply.

The Late Atlantic optimum (~ 6100–5000 BP) was the main optimum and the time of development of forest-steppe landscapes. The amount of thermophilic arboreal pollen in the pollen assemblages that represent this period reached 31 %. Mixed oak forest with admixture of common and Caucasian hornbeam (*Carpinus betulus*, *C. caucasica*), oriental beech (*Fagus orientalis*), different species of elm (*Ulmus laevis*, *U. foliacea*), linden (*Tilia cordata*), birch, and other trees, and coniferous forests comprised the forest belt of the Lower Volga floodplain. The Late Boreal (~ 8500–8300 BP) and the Middle Subboreal (~ 4200–3700 BP) optimums were close in character and were characterized by a lesser heat availability and greater moisture supply. They were both marked by the dominance of forest-steppe and, in some phases, of steppe landscapes. However, they differed from the Atlantic optimum by less favorable, for the growth of broad-leaved tree stands, conditions and by lesser participation of the broadleaf species in forests. The amount of pollen of broadleaf species in the pollen assemblages that describe these periods did not exceed 21–23 %.

It is possible to correlate these three phases to the maximal transgressive stages of the New Caspian basin with a high degree of confidence.

3. The fact of existence of the transgressive stages of the Caspian Sea is also supported by the phases of cold and relatively humid climate. First, this is expressed in the presence of the forest-steppe phase in the interval ~ 10000–9200 BP, which corresponds to the Sartass stage when, within the part of the Northern Caspian region free from the sea, there were wide-spread sparse pine forests and isolated forest stands dominated by spruce and fir. The phases of cooling and humidization were also identified in the intervals ~ 4800–4200, 2500–2300, and 400–200 BP. The trasgressive stages of the sea correlate also with the phases of warming and humidization of climate in the intervals ~8000–7600, 3500–2700, 2100–1800, 1700–1500, 1300–1100, and 700–400 years BP.

4. Regressions of different ranks may correspond to the reconstructed minimums of heat and moisture (the periods of cold and dry climate), as well as to the intervals of significant warming and aridization (the periods of relatively warm and dry climate).

Two of the most significant minimums of heat and moisture availability correlate with the Early Subboreal sub-period and to the first one-half of the Late Subatlantic sub-period. The first minimum corresponds to the time of the Mangyshlak regression of the Caspian Sea (~ 9200–8500 BP), while the second minimum corresponds to the Derbent regression (1500–700 BP).

Within the interval 8500–1500 BP, there was one phase of rapid warming and aridization of climate (~ 2700–2500 BP) and five phases of sharp cooling and aridization of climate (in the intervals ~ 8300–8000, 7600–7400, 5000–4800, 3700–3500, and 2300–2100 BP) that may correspond to a short-term but pronounced drop in the Caspian Sea level. The most significant decrease relates to the intervals ~ 7600–7400 and 3700–3500 BP. All phases of cooling and aridization of climate were marked by the prevalence of dry steppes and semideserts within the study region; there, xerophitic sagebrush and haze communities dominated the vegetation.

5. The comparison of landscape and climatic stages identified herein with the stages of development of natural humid areas of the Russian Plain that feed the Caspian Sea with water indicates multidirectional evolution of climate during the intervals of ~ 9700–9200, 8500–8300, 7600–7400, 5500–5400, 2700–2500, 2100–1700, and 1500–400 BP, as well as during the last century (see Fig. 3).

6. Based on the reconstructed climatic and vegetation successions, two paleogeographic models of the Caspian Sea in the post Mangyshlak time may be proposed (see Fig. 3). The first model is based on the fact that the Late Subatlantic interval, characterized by the dominance of semidesert and desert landscapes, is very different in phytocenological and climatical respect (with the exception of the last phase of the Subboreal period ~ 2700–2500 BP.) from the entire preceding part of the Holocene. It should be also noted that the last (the newest) 700-year-long phase of the development of the Caspian basin is close to regressive and not to transgressive phases in paleo-climatic respect. The alternative model is close to the models developed by O.K. Leontiev and G.I. Rychagov [1982], and A.N. Varuschenko et al. [1980], except for the interpretation of a regressive phase in the interval of ~ 5000–3500 BP. We suggest that this phase was developing as a pulse regressive phase (as determined from the palynological data) ~5000–4800 BP. This phase was replaced by a transgressive phase ~ 4800–3700 BP followed by a new pronounced pulse decrease in the Caspian Sea level ~ 3700–3500 BP.

7. The vast majority of subrecent pollen assemblages of the Volga Akhtuba region [Bolikhovskaya and Kasimov, 2008] indicate that in the last century, there were the most optimal thermal conditions (for the last thousand years) to support broadleaf species in the floodplain forests of the Lower Volga floodplain.

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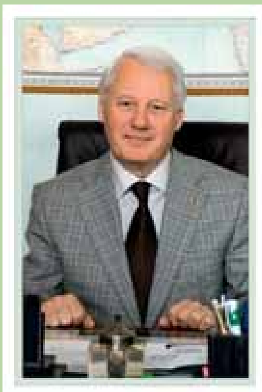

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CADASTRAL ASSESSMENT OF CRIMEAN BEACHES AS AN INSTRUMENT FOR SUSTAINABLE COASTAL DEVELOPMENT

ABSTRACT

One of the important steps towards sustainable development of territories is the assessment of the reserves and rate of consumption of natural resources. Such assessments are also supported at the international level. The recreational resources represent the most important type of natural resources for the coastal zone of Crimea. They are the basis for recreational tourism and, therefore, determine the economic status of the peninsula as a whole. Currently, however, the coastal zone of Crimea is being developed quite chaotically. The need for a specialized information system capable of timely reflecting natural and manmade changes in the coastal zones is widely recognized.

The paper presents a system that was developed using ESRI ArcGIS formats capable of not only capturing changes occurring in the environment, but to also identifying options for a more efficient use of the recreational resources of the peninsula. The approach and unique algorithms developed by the authors of this paper were applied to four Crimean beaches.

KEY WORDS: cadastre, beaches, recreational resources, geographic information systems

INTRODUCTION

Assessment of natural resources and environmental management is crucial for sustainable development of territories. At the same time, it represents one of the most important areas of scientific research. Regions where the use of natural resources is a priority for economic development are of a particular importance. One of such regions is the Crimean peninsula. Infrastructure development that facilitates the use of the natural recreational potential represents a crucial economic goal for the region.

In this paper, the recreational potential means an aggregate of natural, cultural, historical, and socio-economic conditions important for organization of recreational activities in a given area [Mironenko and Tverdokhlebov, 1981]. The recreational potential of Crimea, as well as any other type of natural resources, should be zoned and quantified to identify integral resources and recommendations for their most effective utilization. The main difficulty of this endeavor is associated with diverse forms of the recreational potential and its impact on the human body. The particular impacts of individual components, however, have been studied insufficiently.

The solution may be found in the development of a specialized geographic information system (GIS) that specifically targets the recreational potential of Crimea. This GIS should include a detailed and most precise quantitative description of the individual components of the recreational potential of different parts of the peninsula. The most popular recreation objects, i.e., beaches, should be the first priority of the investigation. Such GIS should be a consistently updated and maximally visual cadastre of the recreational resources of Crimea. It should include natural (geomorphological), ecological, climatic, economic, and sociological components. This GIS would aid in future certification of beaches, development of map documents, and various advertisement media.

COMPONENTS OF THE RECREATIONAL POTENTIAL

The most important components of the recreational potential are recreational resources, i.e., components of the environment and objects of human activity that can be used for various types and forms of recreational activities – leisure, tourism, health improvement, etc., due to such qualities as uniqueness, historical or artistic value, originality, aesthetic appeal, and health-improving value [Geography..., 1980]. This recreational potential includes the following elements:

- therapeutic resources (climate, mud, hydro);
- health-improving resources of active recreation (rivers and reservoirs, beaches, forested areas);
- tourist-excursion resources (natural, cultural, historical, and architectural landmarks);
- tourist and recreational infrastructure.

In reality, the recreational resources exist as functional combinations of the components of natural and cultural landscapes that allow developing certain types of recreational activities. This, in turn, helps to create various subtypes of recreational facilities within the same territory.

Table 1. The list factors of the recreational of Crimea

	Factors
1	scenic value of the landscape (alternating open and closed spaces, presence of scenic views, etc.)
2	diversity and alternation of relief forms (depth and density of differentiation, steepness of slopes)
3	diversity of flora and fauna (number of species)
4	presence, size and quality of water bodies (sea, rivers, lakes, and ponds)
5	presence and characteristics of beaches пляжей (see Table 2)
6	presence of unique species, natural features (parks, waterfalls, etc.), monuments of history, culture and art
7	availability of balneological resources (phytoplankton, mineral water, mud, brine, etc.)
8	characteristics of microclimate

The result of recreational use of natural resources is the health effect expressed in increased efficiency, reduced morbidity and mortality, and other social indexes. This social effect always transitions into the economic effect manifested in enhanced productivity, reduced sick leave, and lower health care costs.

In general, all the components of the potential can be expressed as shown in Table 1.

It is quite clear that beaches are the most crucial part of the recreational potential. That is why in the summer, millions of people rush to the sea. Thus, the development of the cadastre of the recreational resources of Crimea should start from the cadastral assessment of its beaches.

ASSESSMENT METHOD

The most important component of the recreational resources, beaches, should be assessed in much detail. In addition to a standard set of geomorphologic research methods, it is necessary to examine and

Table 2. Main characteristics of beaches

1	Geomorphologic characteristics
1.1	dimensions (length on the ground and average width)
1.2	type (full or partial profile)
1.3	length of coastline
1.4	curvature (tortuosity) of coastline
1.5	average gradient of the coastal and underwater areas of the beach
1.6	elevation gradient of the coastal beach zone
1.7	direction of exposure
1.8	height and average slope cliff of the beach with incomplete
1.9	composition and size of bearing beach material
1.10	area of the beach, its coastal zone and waters
1.11	area of safe children and adult swimming
1.12	zoning and partitioning
1.13	length and slope of the path to the beach
1.14	share of green area in the beach zone
1.15	presence of individual features (rivers' mouths, gullies, etc.)
2	economic characteristics
2.1	ownership (health-improving and municipal organizations and recreational centers)
2.2	beach accessibility (private, commercial, public)
2.3	presence, length and average width of pedestrian zone (lane)
2.4	infrastructure facilities in the beach zone
2.5	distance from the beaches to build-up and buildable zone and industrial facilities
2.6	distance from the beaches to dormitories (only for therapeutic beaches)
2.7	approximate number of vacationers during the swimming season
3	social characteristics
3.1	accessibility and cost of admittance
3.2	distance from the city or town center
3.3	availability of public transportation
3.4	availability of guarded parking
3.5	number of gear rental centers
3.6	availability, number and the area of tent sites
3.7	number of water and shore amusement rides
3.8	presence of archeological, historical, architectural and art landmarks
3.9	presence of unique plant species
3.10	presence of unique nature landmarks
3.11	availability of balneological resources (mud, mineral waters, etc.)
4	environmental characteristic
4.1	distance form water and air pollution sources
4.2	distance from the main traffic arteries
4.3	availability and number of garbage containers
4.4	frequency of clean-up work in the beach zone
5	climatic characteristics
5.1	number of days in children and adult swimming season
5.2	average water and air temperature during swimming season
5.3	number of sunny, rainy, and stormy days during swimming season
5.4	number of days in upwelling

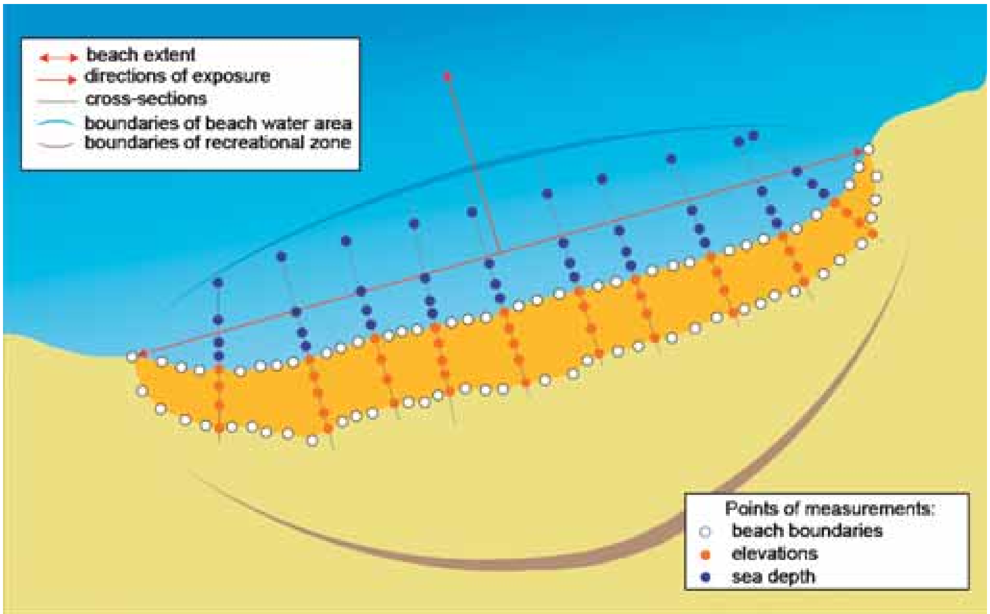

Figure 1. Schematic representation of the assessment procedure

evaluate the individual characteristics of recreational areas surrounding beaches, including their infrastructure (Table 2).

Composition of beach forming material. Global positioning devices are nowadays used to obtain the exact locations of points on the terrain and their elevations. In our studies, we used "Trimble-4600LS" with a few centimeters horizontal and vertical measurement accuracy. Thickness and volume of beach forming material were obtained by ground-penetrating radar "AB-400". The measurements were performed on a series of cross-sectional lines perpendicular to the water's edge; the length of the beach and its heterogeneity determined their number. The individual characteristics of the beaches, including ravines, cliffs, estuaries, etc, were also determined.

The depth of the swimming zone, slope, and bedrock material were identified in the aquatic zones of the beaches, "TM-2A" portable turbidity meter allowed measuring vertical profiles of water transparency with a seven cm resolution. The work procedure is schematically presented in Fig. 1.

The recreational areas bound by the state roads or residential development were also carefully examined. Within these boundaries, all infrastructure elements, green space and its appearance, landfills, waste sites, latrines, sources of fresh water, etc. were described. Potentially dangerous sources of air and water pollution located nearby were also recorded. The implementation of these activities was the first and most time-consuming step.

In the second phase, the obtained data were fed into the GIS as separate map layers. The identification of objects can be facilitated by the use of georeferenced high-resolution satellite maps, including maps obtained from Google Maps. Fig. 2 presents an example of the measurement results for one of Sevastopol beaches (the beach of the village Lyubimovka). Further data processing included calculation of necessary design parameters. Two types of data, specifically, information and control parameters, were calculated and evaluated. The first group was used in the analysis of the state of the recreational areas and included derived values; these parameters were the curvature of beach coastline, area to perimeter ratio, differences in elevation, slopes, etc.

In contrast, the control characteristics, in addition to their information load, also determined the compliance with selected indicators of the regulatory standards for the recreational areas. For this purpose, the cadastral GIS included a set of effectual regulatory standards tables. If necessary, it may be possible to conduct a testing procedure with the results compiled into a table of deviations of actual characteristics of the recreation areas from the regulatory standards (capacity, number of eateries, toilets, garbage containers, tent shelters, cabins for changing clothes, etc.). This undoubtedly contributes to rapid decision-making, quality, and conditions of use of the recreational potential.

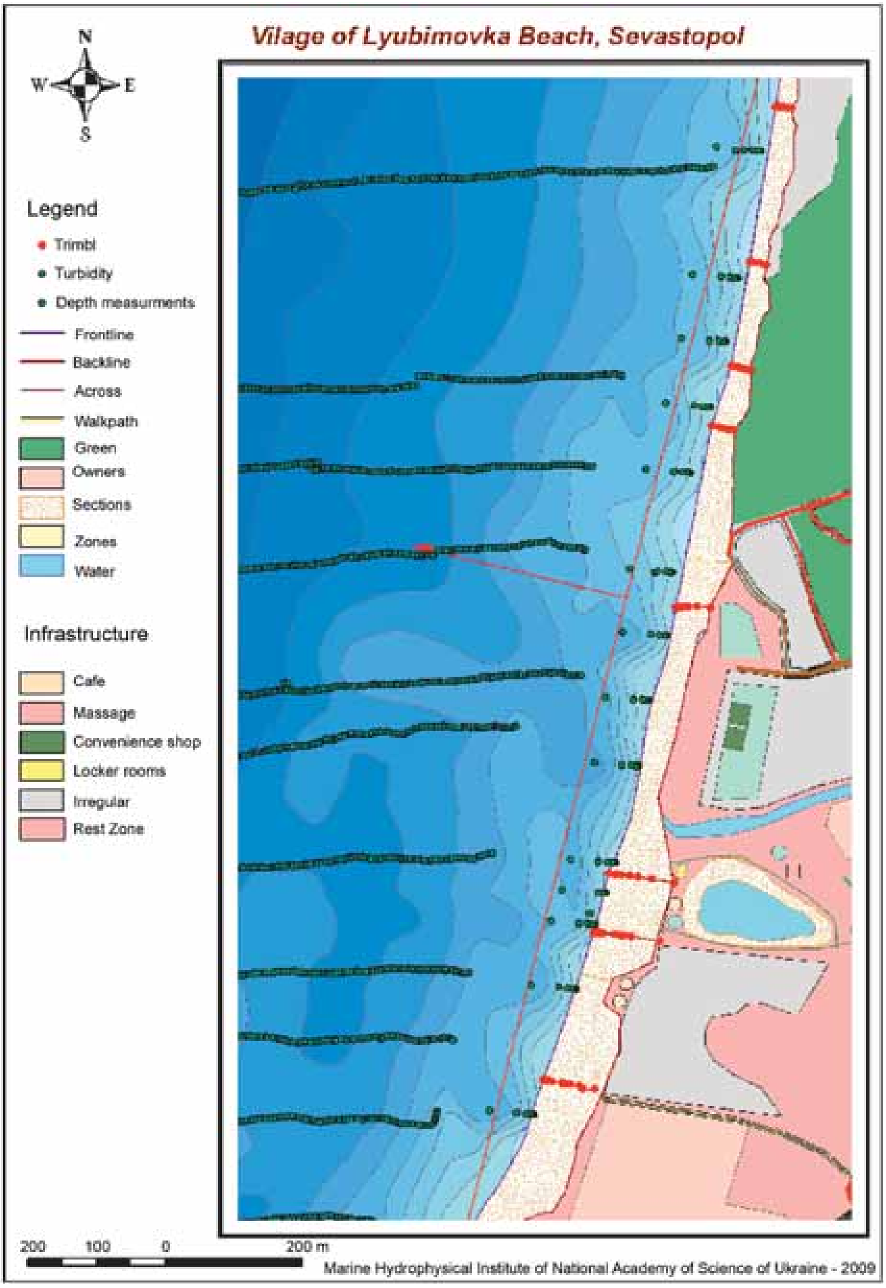

Figure 2. Schematic representation of the assessment procedure at the village Luybimovka beach

BASIC REQUIREMENTS FOR THE INFORMATION SYSTEM

Like any other inventory, the cadastre of the recreational resources must be as complete and detailed set of field data and derivatives of calculated values as possible. As shown above, the total number of parameters is quite considerable, so the assessment of the individual components and recreational resources in general for a given region was performed using evaluation and presentation algorithms that are commonly used in GIS.

The design of the cadastral structure took into account the following considerations:

- the assessment of the recreational potential should be applied to objects or parts of Crimean regions that have spatial references;
- the cadastre should support at least three languages due to ethnically diverse population of Ukraine and Crimea;
- the cadastre should not be based on regulatory data, which may affect the estimates and vary over time;
- it is necessary to maximally automate processing of the field data and limit pre-processing;
- it is necessary to provide a multi-level selection of studied recreational facilities for the analysis according to various criteria;
- it is necessary to support the cadastre through periodic repeated surveys with varying intervals of measurements for different objects.

The last point suggests that available cadastral data should be divided into the "background" or relatively stable over time, and the "results of individual surveys". The former may include such survey items, as roads, riverbeds, construction, onshore facilities, etc. Furthermore, it is obvious that some measurable parameters, such as parameters of water and air quality, may not have spatial referencing, which involves the creation of a number of additional specialized tables. This in turn, requires insuring linkages between the tables and, consequently, developing a georelational database as the basis for the cadastral GIS.

ESRI ArcGIS is widely used for data processing and the implementation of non-standard analytical operations since this system is extremely popular worldwide and provides the maximum support in Ukraine. The cartographic and tabular data formats were designed considering the requirements of this system. Thus, the cadastre represents a georelational database, consisting on layers of cartographic data in ESRI SHAPE format, i.e., point, polyline and polygonal, including Z-parameters; the associated attribute tables were compiled in DBF format. The cadastre also included additional tables of codes and names of the studied objects, measured parameters, linguistic analogues of rows, regulatory values, and some other entities.

The electronic shell of the cadastre should facilitate a quick input and analyses of available information. This shell can be written in ArcGIS environment or developed for separate modules using modern programming languages. When choosing the implementation of the GIS analytical module, the authors took into account the following:

- ESRI ArcGIS is a multi-purpose system capable of creating, processing, and analyzing spatially distributed objects; the cadastral GIS is unlikely to use a significant portion of its capabilities because, practically, it does not fully utilize its potential to create objects downloaded in the form of ready-made data derived from the measuring devices;
- the cadastral GIS will be provided to many municipal organizations of the coastal cities;
- the ESRI data are open source formats;
- there should be standard cadastral data processing methods capable of generating pre-defined reports;
- given a relatively small size of the studied objects, there is no need to use different projections and re-projection;
- it is desirable to maximally automate loading and processing of data in accordance with the developed procedures.

Undoubtedly, the requirements of ESRI ArcGIS packages to computer's capacity and their considerable cost should also be taken into account. Thus, the authors developed their own access drivers for cartographic and tabular ArcGIS objects using programming environment "Borland Delphi_7". The resulting program represents a universal GIS with a special cadastral toolbar, including the following:

- download of GPS data collected using such devices as "Trimble-4600LS" and "Garmin eTrex" with automatic detection of file structures and formation of a minimal set of map data necessary for carrying out cadastral valuation of beaches;
- creation of the list of beaches monitored by districts or regions, taking into account the structure of beach material and ownership;
- automatic calculation of cadastral characteristics of selected beaches;
- preparation of various types of illustrative materials based on the results of calculations;
- generation of documents for certification of beaches in accordance with approved formats;
- generation of tables of deviations from the regulatory standards for beaches.

The prospects for the analysis and assessment of the recreational potential are constantly improving. It is also possible to develop appropriate tools exclusively in ArcGIS environment.

ASSESSMENT OF CONDITIONS OF RECREATIONAL AREAS

The assessment of conditions and natural features of the recreational areas is a major task. We have already noted that the composition of the recreational potential is diverse, but its impact (mostly positive) on the human body has been insufficiently explored. The assessment is also complicated by the fact that the recreational areas as well as the beaches themselves, belong to organizations of various ownership. In accordance with the certification requirements [Concerning the approval ..., 2002], beaches are classified into three groups: beaches of health care organizations, hotels and resorts, and open public access beaches. Many of the regulatory requirements applied to different categories vary considerably. The recommended assessments of the recreational potential factors also differ significantly. In addition, the regulatory documents assign categories to beaches based on the assessment of their current performance individually for each group.

The author of one of the few research works devoted to the assessment of the impact of Crimean individual recreational factors on the human body [Efremov, 2003] suggests dividing beaches into three classes: beaches of subtropical zone, subtropical zone periphery, and southern steppe zone. For each class, the author proposes to introduce the concept of a "perfect beach", i.e. the beach with the best characteristics. He also presents a list of characteristics for each class of the "ideal beaches" (Table 3); the assessment of the actual beach conditions is done in points and in comparison to the "ideal beach" in each class. The values are derived by Crimean balneology physicians based on the impact of environmental factors on the human organism.

Table 4 presents the list of natural health-improving factors developed by this author. Thus, already at this stage, it is clear that it is possible to evaluate the recreational potential of Crimea using various systems of assessment reflecting different types of classifications, including, those that are based on the evaluation of environmental conditions of recreational objects. Recreation objects and especially their water component are subject to constant environmental analyses during the recreational period. The number of regulated analyzed environmental compounds reaches several hundreds.

In reality, only about 20 water-polluting compounds are most often determined on a five-point scale (Table 5).

Table 3. List of natural features that define the "ideal beach"

№	Categories that define the beach's category		1 category		2 category		3 category	
			value	point	value	point	value	point
1	Average air temperature during swimming season (t, °C)		20–21	3.5	19–20	3.4	18–19	3.2
2	Average water temperature during swimming season (t, °C)		21–22	3.5	20–21	3.3	19–20	3.1
3	Number of sunny days during swimming season (%)		75–80	3.5	70–75	3.3	65–70	2.1
4	Cliff characteristics	availability of vegetation	–	4.0	–	3.7	–	3.0
		absence of vegetation	–	2.0	–	0.8	–	0.6
		rock	–	1.5	–	0.4	–	0
5	Structure of beach-forming material	sand	–	3.0	–	2.3	–	2.0
		fine gravel	–	3.0	–	2.3	–	2.0
		large gravel	–	1.0	–	0.9	–	0.7
6	Bench structure	sand	–	2.5	–	1.3	–	1.1
		fine gravel	–	2.5	–	1.7	–	1.5
		large gravel	–	1.5	–	0.3	–	0.2
		silt or clay	–	0.3	–	0.2	–	0.1
7	Beach sun baths	sand	–	2.0	–	1.8	–	1.7
		fine gravel	–	2.0	–	1.3	–	1.1
		large gravel	–	1.6	–	0.5	–	0.3
8	Bench slope (%)		2	2.0	–	–	–	–
			1	1.8	–	–	–	–
			0.5	1.6	–	–	–	–
	Maximum number of points			24.0		20.0		17.0

Table 4. Physicians-balneologists' expert assessment of the influence of the recreational factors on health-improving processes

	Recreational factors	Score
1	sea bathing	12
2	sunbathing on beach	3
3	sea air	1
4	emotional impact of the sea	1
5	emotional impact of subtropical flora	3
6	mountain forest air	2
7	emotional impact of mountains	2
8	sunbathing in the woods and fields	1

Table 5. Point-value assessment of the quality of the water body

Characteristics	Value
clean	1,5
relatively clean	1,2
low-polluted	0,9
medium polluted	0,7
highly polluted	0,5

Table 6. Classification objects based on recreational uniqueness

Characteristics	Value
Coefficient of environmental value (environmental importance) of water body	
a) unique water bodies	2,0
б) environmentally especially important objects	1,5
в) environmentally important objects	1,2

Table 7. Classification of recreational objects based on their natural value

Parameter	Value
Coefficient of objects with health-improving and recreational:	
Autonomic Republic of Crimea, including	3,6
South coast	7,6
South-eastern coast	4,5
West coast	5,4

There are also classifications based on the uniqueness (Table 6) and value of natural environment of health-improving and recreational facilities (Table 7).

Specially developed computer programs would facilitate handling such diverse classification systems and large number of assessment parameters.

VERSIONS OF CADASTRAL ASSESSMENTS

The cadastral valuation of the recreational resources aids in assessment of the current state and dynamics of recreation objects. A comparative assessment of the studied objects would help to develop measures addressing shortcomings in the organization of consumer services sector supported by these recreational objects.

The most feasible method is the analysis of different types of recreational potential for each object of recreation. In this case, the results can relate to either individual objects, their majority (see Fig. 5 further down), or even the entire group (Fig. 3).

In the latter case, it is feasible to use the method of conditional formatting, which assigns different colors to cells with substantially high or, conversely, low levels of certain types of resources. This table would be would clearly indicate what indicators and objects need improvement; grouping the same color cells would highlight a particular level of development of the whole region (assuming the distribution of objects in the table corresponds to their location on the ground). This method of analysis can be extremely effective in making decisions about the development of recreational areas in individual regions.

The recommendations of the World Bank [Integrated ..., 1993; Koptyug, 1992] indicate that it is quite difficult to operate with a list of dozens or hundreds of parameters in the decision-making process. For timely decision-making, the number of indicators should be limited to a dozen. Therefore, we suggest using the minimal number of integral indicators, calculated from the full list. In this case, and in accordance with the fundamentals of recreational geography [Kuskov, 2004], three major components of a recreational facility or region deserve special attention: natural, economic, and social (culturological). The natural component describes dynamic changes caused by natural or anthropogenic impacts. The

Codes \ Beaches	Andreevka	Kacha	Orlovka	Lyubimovka	Odissei	Mokrousova	Uchkuevka	Toistyi Mys	Konstsntinovskyi	Staroseverny	Karantinnaya	Khersones	Solnechnyi	Pesochnyi	Park Pobedy	Omega	B. Abramovka	Golubasya Bukhta	Karavella	Tsarskyi	Yashmovyi	Vasili	Serebryanyi	Zolotoi	BO ChF	Batiliman	Laspi
RSDST	1.15	1.15	1.39	1.15	1.15	1.15	1.15	1.06	1.15	1.06	1.09	1.15	1.04	1.06	1.15	1.04	1.09	1.15	1.48	1.50	1.45	1.30	1.24	1.35	1.24	1.24	1.24
WALK	1.61	1.67	1.72	1.78	1.67	1.94	1.78	1.61	1.89	1.89	1.78	1.44	1.89	1.94	2.00	2.00	1.89	1.60	1.56	1.56	1.56	1.56	1.61	1.17	1.89	1.88	1.88
WIDTH	1.10	1.21	1.35	1.41	1.26	1.15	1.20	1.15	1.12	1.08	1.13	1.10	1.25	1.47	1.12	1.10	1.18	1.15	1.07	1.14	1.31	1.28	1.23	1.25	1.20	1.41	1.18
W_QUAL	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.20	0.90	1.50	1.20	1.20	1.50	0.90	1.50	1.20	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
KE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.00	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.50	1.50	1.50	2.00	2.00	2.00
AREA	2.16	2.45	2.36	2.62	2.02	1.97	2.28	1.77	1.74	1.36	1.50	1.43	1.67	1.92	1.81	2.08	1.84	1.64	1.48	1.82	2.10	2.27	1.94	2.14	1.45	1.85	1.85
PLANT	1.05	1.03	1.03	1.02	1.50	1.30	1.70	1.10	1.00	1.00	1.00	1.00	1.20	1.30	1.50	1.10	1.10	1.00	1.10	1.10	1.05	1.05	1.10	1.15	1.09	1.90	1.90
SPORT	1.00	1.00	1.00	1.00	1.00	1.05	1.01	1.00	1.00	1.00	1.00	1.00	1.18	1.00	1.00	1.03	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.01	1.00	1.08
GAMES	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.02	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
WC	1.00	1.00	1.00	1.00	1.00	1.04	1.04	1.02	1.00	1.00	1.00	1.00	1.15	1.05	1.15	1.05	1.07	1.08	1.00	1.00	1.00	1.00	1.00	1.00	1.20	1.06	1.12
CAFE	1.00	1.00	1.00	1.00	1.00	1.19	1.45	1.45	1.00	1.00	1.00	1.00	1.74	1.11	2.53	2.47	1.17	1.42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.16
WATER	1.00	1.00	1.00	1.00	1.00	1.00	1.07	1.00	1.00	1.00	1.00	1.00	1.37	1.11	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.16
SLOPE	1.46	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.35	1.43	1.43	1.43	1.35	1.35	1.35	1.35	1.35	1.35	1.43	1.43	1.43	1.50	1.50	1.50	1.50	1.50	1.50
STUFF	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.20	1.50	1.50	1.50	1.20	0.80	1.50	1.50	0.80	1.50	0.80	1.50	1.50	1.20	1.20	1.20	1.20	1.50	1.50	1.50
CURV	1.06	1.00	1.01	1.01	1.02	1.11	1.04	1.04	1.09	1.05	1.02	1.00	1.09	1.19	1.05	1.08	1.07	1.18	1.07	1.05	1.03	1.02	1.03	1.03	1.05	1.06	1.06
BENCH	1.47	1.20	1.20	1.20	1.20	1.10	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
CLIF_H	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.49	1.49	1.48	1.49	1.45	1.45	1.44	1.44	1.44
DISTANCE	0.77	0.83	0.85	0.87	0.94	0.96	0.97	0.98	0.98	0.99	0.98	0.97	0.97	0.96	0.94	0.93	0.92	0.88	0.88	0.87	0.87	0.85	0.84	0.82	0.75	0.74	0.74
TRANSP	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.70	0.52	0.52	0.70	0.70	0.70
ACCESS	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	0.80	1.00	1.00	1.00	1.00	0.50	1.00	0.50	0.50	0.80	0.50	1.00	1.00	0.80	0.50	0.50
ROAD	2.08	2.08	2.08	2.11	2.34	2.34	2.36	2.36	2.08	2.36	2.11	2.36	2.38	2.38	2.08	2.36	2.34	2.11	2.08	2.08	2.38	2.30	1.00	1.00	2.08	2.03	2.36
CARS	1.50	1.50	1.50	1.50	0.50	0.50	1.50	1.35	1.50	1.50	1.50	1.16	1.16	0.92	1.35	1.16	1.35	1.50	0.50	0.50	1.16	1.02	0.50	0.50	1.02	1.02	1.02
SAFETY	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
OCOAST	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.40	1.50	1.50	1.50	1.50	1.50	1.50	1.30	1.40	1.40	1.50	1.40	1.30	1.30	1.50	1.50	1.50
QWATER	1.50	1.40	1.40	1.40	1.40	1.40	1.40	1.50	1.40	1.30	1.30	1.50	1.40	1.40	1.40	1.20	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
TRASH	1.00	1.00	1.00	1.00	1.00	1.01	1.02	1.05	1.00	1.00	1.00	1.00	1.07	1.01	1.06	1.02	1.02	1.13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.08
ATTR_W	1.00	1.00	1.00	1.00	1.00	1.09	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.00	1.42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ATTR_C	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
POLL_A	1.48	1.40	1.34	1.30	1.26	1.23	1.20	1.15	1.20	1.08	1.15	1.15	1.15	1.15	1.04	1.04	1.08	1.11	1.30	1.34	1.40	1.18	1.18	1.26	1.54	1.58	1.57
POLL_W	1.04	1.02	1.06	1.34	1.34	1.34	1.34	1.34	1.40	1.18	1.04	1.36	1.23	1.23	1.43	1.63	1.40	1.63	1.04	1.23	1.91	1.51	1.41	1.64	1.60	1.41	1.07
LEASE	1.00	1.00	1.00	1.00	1.00	1.09	1.02	1.23	1.00	1.00	1.00	1.00	1.37	1.11	1.19	1.06	1.00	1.42	1.00	1.00	1.05	1.00	1.00	1.00	1.00	1.16	1.00
TENT	1.00	1.00	1.00	1.00	1.00	1.79	1.78	1.78	1.00	1.00	1.00	1.00	1.78	1.78	1.00	1.78	1.78	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.04	1.78	1.78

Figure 3. The resultant table of characteristic parameters of Sevastopol beaches in Crimea

economic component includes multiple financial relationships among holidaymakers and the administration, infrastructure entities of objects, and the objects themselves.

This group can also include cost indicators of the recreational resources that, as it will be shown below, are the well-founded parameters. The social component reflects the level of accessibility of the recreational potential and, to some extent, characterizes the prestige and attractiveness of a recreational facility. In the authors' opinion, the integral indicators listed above do not necessarily have to share the same data sources.

It is logical to compute the following three main integral indicators of the recreational objects: **coefficient of natural dynamics** (**CND**), **factor of recreational impact** (**FRI**) and **generalized measure of prestige** (**GMP**). However, this list does not fully reflect the economic component. In this regard and given a relatively certain, for a given time interval, land value in any region of Crimea, additional equally important economic components of the recreational potential should be calculated: **cost of parcel of land** occupied by recreational facilities (**CPL**), total **value of the recreational facility** including FRI (**VRF**), and **cost of recreational resources** (**CRR**) defined as savings in the average wages in the country multiplied by FRI and the duration of the recreational period.

Furthermore, GMP can be subdivided into its individual components: **indicator of natural attractiveness** (**INA**), **climatic prestige index** (**CPI**), and **service comfort index** (**SCI**). Finally, for a complete description of a facility or region, the list may be supplemented by two more parameters; these parameters are not integral, but play an important role in choosing recreational objects: **index of natural hazards** (**INH**) and **level of crime and political tensions in the society** (LCPT).

All these indexes represent a general list of parameters for calculations; it is possible that only some parameters are used in the analysis.

The implementation of the computational algorithmic system may involve different methods. Some of the indicators listed above can be easily calculated. Thus, CND can be calculated from a number of different geomorphologic indicators. The history of the analyses of the dynamics of actual beaches suggests that the main contribution to the index value is determined by the ratio of current to former areas of beaches and their perimeter to area ratio. Our calculations also took into account changes in the shoreline curvature and slopes in the beach zone.

CPL is determined by the regulatory documents considering its use for agricultural purposes; similarly, VRF can be calculated as the product of multiplication of CPL by FRI [Efremov, 2003]. CPI, in turn, is calculated from the amount of positive and negative climate indicators characterizing each object, and SCI – from the number and capacity of infrastructure facilities, taking into account the regulatory requirements for facilities of various ownership. RNA represents the summary assessment of specific components that contribute to natural

Table 8. Point-value assessment of recreational zones of Crimea [Main …, 2004]

Recreational zone	Zone name	Distance to sea, km	Points
№ 1	Subtropicalя	0–5	14–16
№ 2	Near sea	0–0,5	11–13
№ 3	First zone	0,5–5	7–12
№ 4	Second zone	5–25	4–6
№ 5	Central	More than 25	1–2
№ 6	Mountain-forest	–	5

Table 9. Point-based assessment of beaches under different ownership

Beach ownership	Beaches of health-improving and resort institutions				Beaches of recreational and retreat facilities, hotels, camps, etc.				Municipal, town, public, etc. beaches			
Beach category	I	II	III	IV	I	II	III	IV	I	II	III	IV
Point values	3,0	2,8	2,6	2,4	2,4	2,2	2,0	1,8	1,8	1,6	1,4	1,2

attractiveness, including all kinds of individual regional characteristics. The parameter "market value" frequently applied to coastal areas of Crimea therefore corresponds to VRF as it implicitly takes into account FRI.

INH and LCPT are assessed on a ten-point scale.

FRI represents the most complex calculated parameter and may be determined from the multiplication of the individual parameters for separate components that characterize the natural recreational potential, and points assigned based on the "ideal factor" (Table 3), locations (Tables 7 and 8) and the category (Table 9). The categories of the beaches were defined from their correspondence to the regulatory standards [Standards..., 2003] (Table 10).

The individual indicators were evaluated in two phases: independently and as part of the integral index. All indexes were divided into three groups. The first two groups of parameters reflected changes in a degree of influence of a specific indicator as a function of its value and depending if it varies in direct proportion or logarithmically. Percentage of vegetation in the beach zone may serve as an example of an index in the first group and the distance to the sources of pollution –

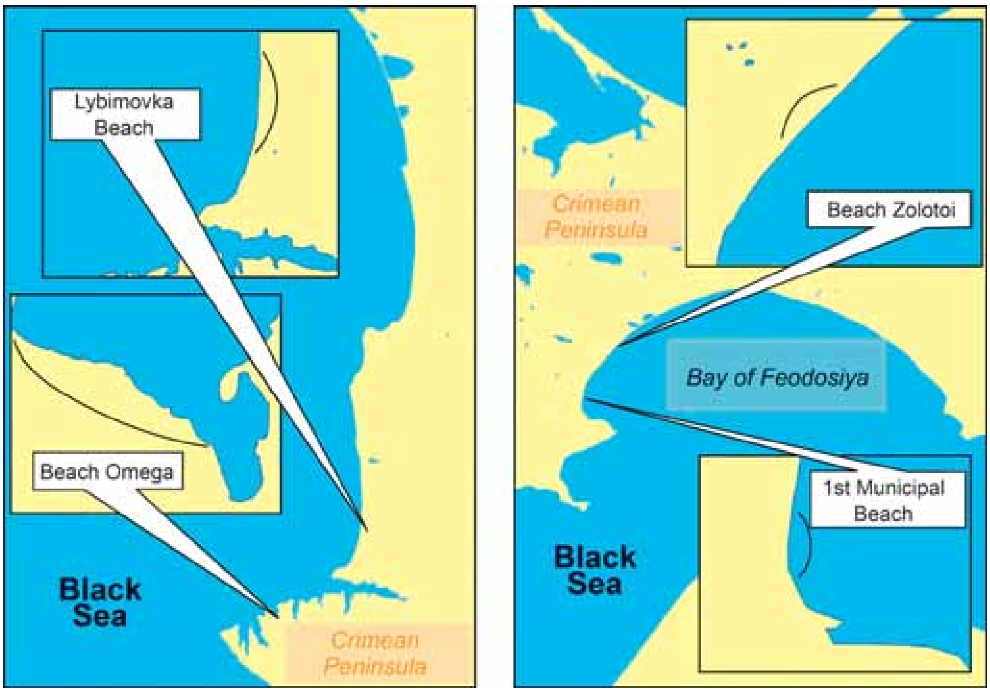

Figure 4. The studied Sevastopol (left) and Feodosiya (right) beaches

Table 10. Parameters used in the assessment of the beaches categories

N	Parameters	Beaches of health-improving and resort institutions				Beaches of recreational and retreat facilities, hotels, camps, etc.				Municipal, town, public, etc. beaches			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1.	Distance to build-up and buildable zone, main traffic areas, railroads, and industrial facilities (m))	>1000	1000-700	700-500	500-400	>500	500-300	300-100	<100	N/A			
2.	Distance from the beaches to dormitory (m)	<300	300-500	500-800	800-1200	<500	500-800	800-1200	1200-1500	N/A			
3.	Slope of the path to the beach (degrees)	3	4	5	7	7	9	12	15	N/A			
4.	Average slope value of the beach water zone in the swimming zone	0.05	0.07	0.10	0.15	0.10	0.12	0.15	0.20	0.10	0.12	0.15	0.20
5.	Mechanical composition of beach forming material (mm)												
	a) sandy beaches	0,5– 1,0	0,5-1,0	0,25-0,5	0,1-0,25	0,5–1,0	0,5-1,0	0,25-0,5	0,1-0,25	0.5–1,0	0.5-1,0	0.25–0.5	0.1–0,25
	6) gravel-pebble beaches	<20	25–50	50–100	50–100	<20	25–50	50–100	50–100	<20	25–50	50–100	50–100
6.	Beach width (m)	>35	35–30	30–25	25–20	>35	35–30	30–25	25–20	>35	35–30	30–25	25–20
7.	Water properties in the swimming zone	According to sanitary standards and regulations (SSaR) (Table 5)											

Note: the category is assigned based on specific parameters as the mean arithmetic value defined from the first six rounded parameters.

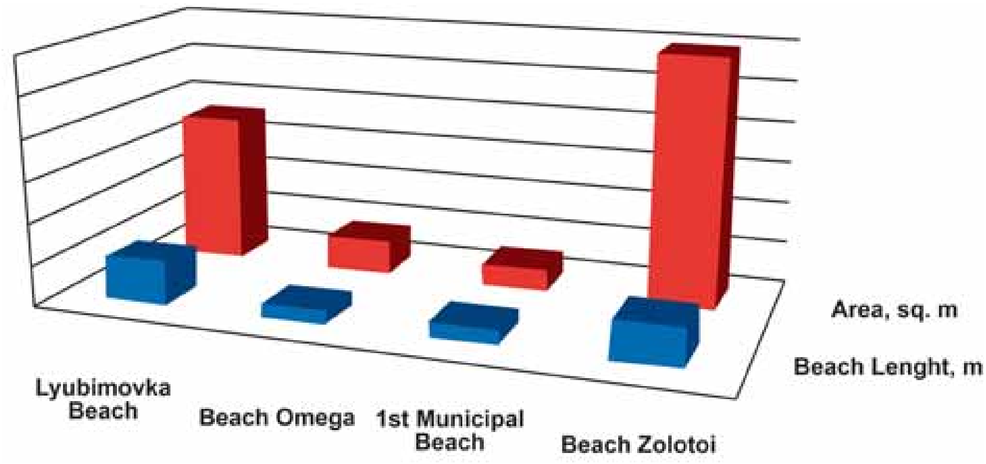

Figure 5. Comparative analysis of the beaches based on geomorphologic features

in the second. The third group combines indicators determined by the regulatory documents and calculated as the actual to regulatory performance ratio. Four Crimean beaches with maximally varying values of individual indexes were selected for the evaluation of the algorithms for computing the integral parameters. These beaches are located in sufficiently distant from each other, but similar in respect to climatic conditions Crimean regions (Feodosiya and Sevastopol). Two beaches (municipal and outside the city limits) were selected within each region (Fig. 4).

Beaches "Omega" and "Kameshki" (the 1st Municipal beach of the city of Feodosiya) are inside the city limits. The beach of the village Lyubimovka and the famous "Zolotoy" beach of the city of Feodosiya are outside the city limits (Fig. 2). These beaches are located on the open seashores, while the municipal beaches are in different size bays. A special feature of the village Lyubimovka beach is the presence of the mouth of a perennial river Belbek. The values of the basic parameters of the studied beaches are given in Table 11. The comparison of geomorphologic characteristics (Fig. 5) shows that "Zolotoy" beach has the greatest area; the village Lyubimovka beach is about 1,5 times smaller despite the fact that its perimeter and length are somewhat greater due to intense unevenness of its shoreline. The area of the 1st Municipal beach of Feodosiya ("Kameshki") is the smallest, although it is slightly greater than the extent of "Omega" beach. All studied beaches have shallow slopes, which increases the foot traffic.

Mean elevation differences within the beaches are also insignificant, but the slopes of wave-cut niches in the Lyubimovka village beach in some areas are quite noticeable, which makes it difficult getting in and out of the sea, especially for children. Beach "Omega" is the best in this respect. For the same reason, the areas of zones that are safe for children and adult swimming are minimal on the village Lyubimovka beach.

They are only approximately one-fifth and one-third, respectively, of the areas of other beaches, despite the fact that the size of two of these beaches is much smaller (Fig. 6).

The calculation of the cadastral characteristics of the beaches included measurement of a large number of additional environmental, economic, and social characteristics. The ownership, category, and category coefficient of beaches were determined from Tables 10 and 12; the coefficient reflects the level of comfort compared to public municipal beaches.

Table 11. Values of the main cadastral parameters of the beaches

№	Parameters	Units	Arenation	"Omega"	"Kameshki"	"Zolotoi"
1	Beach length in a straight line	m	2083	630	724	1860
2	Length of the coastline	m	2097	690	751	1863
3	Perimeter	m	4311	1466	1569	3872
4	Area	m^2	72854	16329	10286	118835
5	Average width	m	48	18	12	71
6	Coastline tortuosity		1,0067	1,0952	1,037	1,002
7	Average difference in elevation on shore	m	1,37	1,916	1,150	1,860
8	Average slope on shore	tg	0,029	0,106	0,096	0,026
9	Average slope of near-shore zone	tg	0,097	0,066	0	0
10	Average difference in elevation for the beach sea bottom	m	4,18	0,982	2,03	2,23
11	Average beach sea bottom slope	tg	0,084	0,0196	0,029	0,064
12	Average bench slope	tg	0,0136	0,0183	0,026	0,054
13	Average slope of wave-cut niche	tg	0,407	0,192	0,35	0,30
14	Exposure	degree	280	31	83	126
15	Area of water zone of the beach shallower than 0,5 m	m^2	14645	12070	16690	3171
16	Area of water zone of the beach shallower than 1,5 m	m^2	27898	32957	34605	7968
17	Rivers and ravines density	%	10	0	0	0
18	Cliff height	m	12*	0	–	–
19	Cliff slope	tg	0,8*	0	–	–
20	Type of beach-forming material		pebble/ sand	pebble/ sand	pebble/sand	sand
21	Size of beach grain material	cm	5/0,2	1,5/0,1	2/0,1	0,2
22	Percent of green area	%	18	7	11	4

* In the cliff zone.

In order to calculate the recreational potential of the beaches and FRI, first, the actual beneficial factors were assessed (Table 13) (all studied beaches belong to the second category).

The total FRI values correspond to a scale used by Zenkovich [1962]. The values can decrease if conditions of the beach zone do not comply with the environmental requirements and increase if there are additional positive considerations (Table 14).

Table 15 shows the adjusted results for the studied beaches. Despite the apparent

Table 12. Categories of the studied beaches

№	Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Ownership	resort	municipal	municipal	resort
2	Beach category	2	3	3	1
3	Category coefficient	2,2	1,4	1,4	2,4

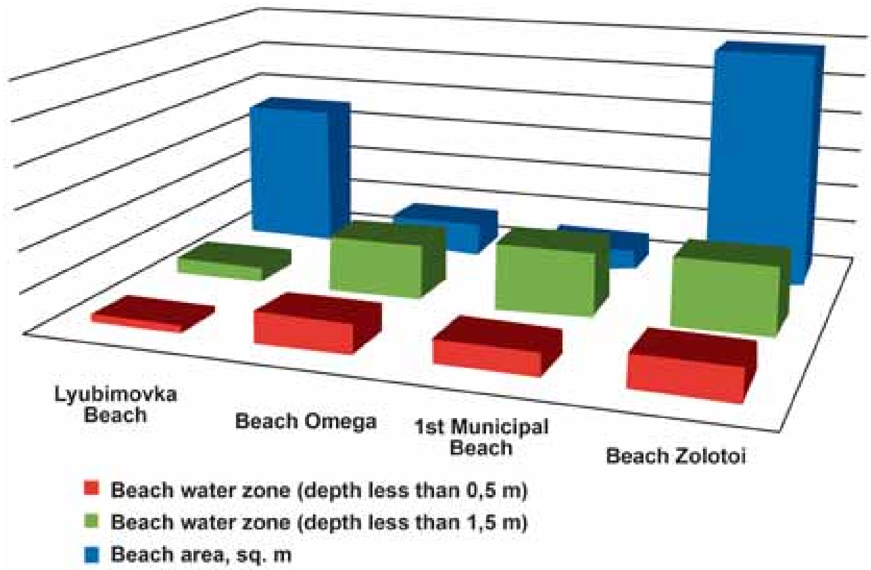

Figure 6. Analysis of zones safe for children and adult swimming and land area of the beaches

popularity of "Zolotoy" beach and high values of the corresponding recreational impact factors, its integral FRI value is lower than, for example, the same index of the Lyubimovka village beach. Relatively low FRI values of "Omega" and "Kameshki" beaches are not surprising. The cost of land allotted for a beach, is determined by the regulatory documents and a current market value. However, the latter often already includes FRI and, therefore, it is preferable to use the actual values. Thus in 2000, the value of land occupied by the studied beaches was estimated at 30–42 thousand dollars per hectare [Efremov, 2003]. Recently, the value of land has increased 100 times to about 5 thousand dollars per one hundred square meters. The cost of the same size plot in the cities centers can be an order of magnitude higher.

Without going into details of pricing and exclusively for the goals and objectives of comparing parameters of the beaches, we will accept the latest data as true. Then, the price per unit area of the beaches and sites in general is as follows (Table 16).

Table 13. Values of recreational factors' impact

№ п/п	Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Sea swimming	8	3	3	10
2	Sunbathing on shore	2,5	1,5	1,0	2,5
3	Sea air	0,9	0,7	0,5	0,9
4	Emotional impact of the sea	0,8	0,4	0,6	0,8
5	Arenation	0	0	0	2
6	Stone therapy	2	0	0	0
7	Acupuncture	1	2	2	0,5
	Total	15,2	7,6	7,1	16,7

Table 14. Environmental parameters of the beaches

№ п/п	Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Value coefficient	5,4	5,4	4,5	4,5
2	Coefficient of status of the regions	1,5	1,5	1,5	1,5
3	Coefficient of water quality	1,5	0,7	0,7	1,5
4	Coefficient of environmental value	1,2	1,0	1,0	1,2
5	Index of cleanness of the coastal zone*	1,2	0,8	0,8	1,5
6	Environmental status	1,0	0,8	0,8	1,0
7	Reduced coefficient of green area	0,77	0,605	0,665	0,56
	Result of multiplication of parameters	13,5	2,2	2,0	10,2
*Assessment criteria: 0,8 – dirty beach (grass on shore); 1,2– clean beach, presence of garbage containers; 1,5– clean beach (daily clean-up even during winter).					

Table 15. The resultant factor of recreational impact considering the environmental situation in the beach zone

Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
FRI	205	17	14	170

Table 16. Cost of land designated for beaches (in thousands of dollars)

Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
Cost of 1 ha of beach	500	5000	5000	500
Total cost of beach	3642	8165	5143	5942

Table 17. Cost of the recreational resources of the beaches (in thousands of dollars)

Parameter	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
Cost of the beach as an object of recreation	746610	138805	72002	1010140

Table 18. The cost of recreational resources of the beaches

№	Parameter	Units	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Duration of swimming season	Days	150	150	146	146
2	Cost of recreational resources	Thous. dollars	7779	645	531	6452

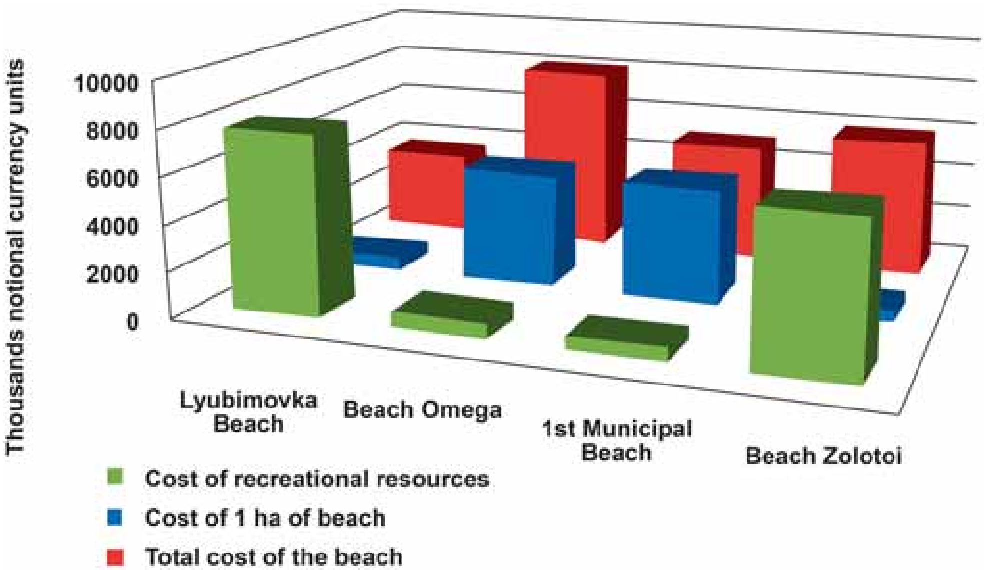

Figure 7. Comparative analysis of cost indicators of the beaches

It is then possible to estimate the cost of the beach in terms of its recreational value by multiplying the cost of land by FRI. The results are presented in Table. 17.

To calculate the value of the recreational resources of the beaches (CRI), it is necessary to have data on the duration of the swimming season for different beaches and the average wage during the calculation period. The duration of the swimming season for adults according to climatic data [Company..., 2008] is given in Table. 18. The average wage in Ukraine was 253 dollars per month in 2007 (i.e., 1265 hryvnas) [Kinakh, 2007]. The summary and comparative description of the cost values is shown in Fig. 7.

The index of natural attractiveness characterizes the effects of a beneficial externality of the beaches. One of the ways to determine this indicator is through the results of sociological surveys of people that use the beach. This is a subjective evaluation method. The objective method involves a calculation of scores for each factor affecting the result. In the absence of sociological surveys, this study used the second method.

Several available indicators of the natural attractiveness are summarized in Table 19. The

Table 19. Parameters of natural attractiveness of the beaches

№	Parameter	Village Lyubimovka	“Omega”	“Kameshki”	“Zolotoi”
1	Individual natural features	River Belbek mouth	–	–	Unique attractive properties of sand
2	Unique plant species	–	-	-	–
3	Historical landmarks	–	Zone of excavation of ancient settlement	–	–
4	Other attractiveness factors	–	–	–	–
	Total score	1	1	0	1

Table 20. Climatic parameters of the beaches

№	Parameter	Units	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Duration of the swimming season for adults	days	150	150	146	146
2	Duration of the swimming season for children	days	102	102	74	74
3	Number of sunny days in the swimming season	days	100	100	50	50
4	Number of rainy days in the swimming season	days	10	10	20	20
5	Number of stormy days in the swimming season	days	6	6	15	15
6	Number of upwelling days	days	2	2	34	34
	CPI		1,23	1,23	0,47	0,47

Table 21. Parameters of infrastructure development of the beaches

№	Parameters	Units	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Beach capacity	persons	12142	2114	1714	19806
2	Beach accessibility	score	1	1	1	0,75
3	Distance to the city center	km	5,4	0	0	4,7
4	Transfers	number	2	0	0	1
5	Access roads	number	3	5	5	5
6	Open parking	number	100	10	0	20
7	Guarded parking	number	0	30	0	0
8	Distance from the beach to public transport stops	m	360	100	200	150
9	Cafés and restaurants	number	0	20	2	7
10	Other service sites	number	0	0	0	2
11	Cabins for changing	number	3	5	7	12
12	Play grounds	number	0	2	2	1
13	Rental centers	number	0	2	0	1
14	Toilets	number	0	2	1	6
15	Garbage containers	number	10	3	5	10
16	Площадь тентовых площадок	m^2/%	1625/2	490/3	1280/12	480/1
17	Water amusement rides	number	2	2	1	2
18	Amusement rides on shore	number	0	1	1	1
	SCI		0,48	6,1	5,7	0,62

Table 22. Integral parameters of the beaches' conditions for 2007

№	Parameters	Village Lyubimovka	"Omega"	"Kameshki"	"Zolotoi"
1	Cost of parcel of land under the beach (thous. dollars)	3642	8165	5143	5942
2	Factor of recreational impact, score	205	17	14	170
3	Cost of the beach as an object for recreation (thous. dollars)	746610	138805	72002	1010140
4	Cost of recreational resources (thous. dollars)	7779	645	531	6452
5	Indicator of natural attractiveness	1	1	0	1
6	Climatic prestige index	1,23	1,23	0,47	0,47
7	Service comfort index	0,48	6,1	5,7	0,62
8	Index of natural hazard	0	0	0	0
9	Level of crime and political tensions in the society	0	0	0	0

studied beaches do not differ significantly by the attractiveness factor. This statement does not apply to other Crimean beaches, many of which, on contrary, have the extraordinary richness and variety of factors of the natural attractiveness.

CPI was calculated from the relevant climatic parameters (Table 20). The values of individual parameters were taken from Podgorodetsky [1988]. As expected, the integrated CPI for the studied beaches was not very informative, since each pair of beaches had the same values of the individual parameters. However, this conclusion should not be extended to all cases of the assessment of the beaches because the climate of Crimean regions is very diverse.

SCI is largely defined by the presence and a number of infrastructure objects on the beach and their locations and accessibility (Table 21).

The computation of the resultant integral index was performed using specially developed algorithms and the regulatory requirements. Analysis of the table shows that the beaches located near the city limits have the most developed infrastructure. The low value of SCI of the Lyubimovka village beach, in comparison with "Zolotoi" beach of Feodosiya may be specifically explained by its location that involves at least two transfers.

The calculation of this parameter was made only for the purpose of a demonstration and does not pretend to absolute accuracy of the estimates, since the survey of the beaches was carried out in different seasons and much of the infrastructure, operating in the summer, could be closed for the winter. Also, when evaluating areas of the awnings of the tent sites, only structures that are required to have awnings in the summer were taken into account, whereas in reality, additional awnings can be installed at the beaches. In order to provide a comprehensive cadastral assessment of the individual SCI factors, it is necessary to survey beaches during their mass use.

The SCI values given in the last table were calculated using a simplified procedure. For example, only the count of catering sites, toilets, and cabins for changing clothes was used in the calculations, although the method allows to also handling the capacity of these facilities. Furthermore, this study does not include the assessment of natural and technogenic hazards (INH) and the level of political tension and crime in the region (UPR), as these indicators are not calculated, but determined by the experts individually for each beach and the region. For the studied beaches, these indexes have zero values, i.e., the situation is completely safe in terms of potential hazards and crime.

The combined effect of the cadastral assessment of the studied beaches is a large set of parameters, as well as a set of generalized summary characteristics (Table 22).

CONCLUSIONS

This study is the result of a three-year research and development work by the authors in the field of cadastral assessment of the recreational resources, specifically, the beaches of Crimea. The main goal of the paper is to summarize and systematize these research activities as well as to describe in detail the main assumptions of the proposed method.

The scope of the cadastral development of Crimean recreational resources was demonstrated using the four studied beaches as an example. Undoubtedly, in Crimea, where recreational facilities are a development priority, the recreational resource potential needs not just one-time, but constant monitoring and assessment.

The assessment of the individual recreational facilities of Crimea must be accompanied by the evaluation of recreational load. Organizations that use these recreational facilities should be also characterized. Data on service capacity of health care organizations, their categories, types of services provided, and other parameters represent the important components for the assessment. ■

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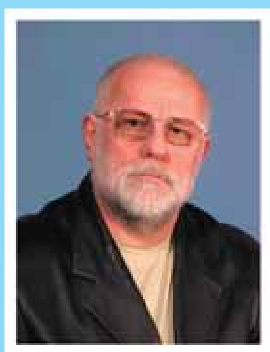


INTERCARTO CONFERENCES

Hundreds of conferences more or less closely connected with cartography and GIS are being conducted annually around the world. In Russia and the republics of the former Soviet Union, such events were rare, and international meetings had not been held at all till May 23–25, 1994, when the first international InterCarto conference took place. These conferences took place at the following locations:

InterCarto 1	Moscow (Russia), May 23–25, 1994;
InterCarto 2	Irkutsk (Russia), June 26–29, 1996;
InterCarto 3	Novosibirsk (Russia), January 27–31, 1997;
InterCarto 4	Barnaul (Russia), July 1–4, 1998;
InterCarto 5	Yakutsk (Russia), June 17–19, 1999;
InterCarto 6	Apatity, Murmansk Province (Russia), August 22–24, 2000;
InterCarto 7	Petropavlovsk-Kamchatsky (Russia), July 30–August 1, 2001;
InterCarto 8	Helsinki (Finland), St.-Petersburg (Russia), May 28–June 1, 2002;
InterCarto 9	Novorossijsk (Russia), Sevastopol (Ukraine), June 25–29, 2003;
InterCarto/InterGIS 10	Vladivostok (Russia), Changchun (China), July 12–19, 2004;
InterCarto/InterGIS 11	Stavropol-Dombai (Russia), Budapest (Hungary), September 25–October 3, 2005;
InterCarto/InterGIS 12	Kaliningrad (Russia), Berlin (Germany), August 25–31, 2006;
InterCarto/InterGIS 13	Khanty-Mansiysk (Russia), Yellowknife (Canada), August 12–24, 2007;
InterCarto/InterGIS 14	Saratov (Russia), Urumqi (China), June 24–July 1, 2008;
InterCarto/InterGIS 15	Perm (Russia), Ghent (Belgium), June 26–July 6, 2009;
InterCarto/InterGIS 16	Rostov-on-Don (Russia), Salzburg (Austria), July 3–8, 2010.

The InterCarto conferences are thematically organized to target one of the most pressing problems of modern geography – creation and use of geographical information systems (GISs) as effective tools for achieving sustainable development of territories. Wide use of information technologies by all countries has been encouraged in the *Agenda for the XXI Century (Agenda 21)* adopted by the UN Conference on Environment and Development in Rio-de-Janeiro (Brazil, 1992) and reinforced at the UN World Summit on Sustainable Development in Johannesburg, 2002. In the *Russian National Report* and the materials of the conference in Rio 10 *Information Supplement*, development of GISs has been declared one of the most relevant directions of work. The InterCarto program is supported by the International Cartographic Association (ICA) that encompasses 83 countries. The InterCarto conferences invite presentations from the most known participants – scientists and experts in the field of geo-informatics and sustainable development. Committee sessions of a number of international organizations, exhibitions, and seminars are conducted within the framework of the conferences.

Over the years, from 1994 to 2009, 1872 participants from 51 countries[1] and 156 cities, who made 1494 reports, attended the conferences. There were 1508 participants from 49 regions of Russia making 1340 presentations. The conferences hosted 31 different sections, most popular of which were *Environmental GIS-Projects: Development and Experience* (386 attendees, 204 presentations), *Sustainable Development and Innovative Projects* (349 attendees, 210 presentations), *GIS: the Theory and Methodology* (312 attendees, 217 presentations), *Projects for Russia and Regions* (185 attendees, 90 presentations),

[1] Including Australia, Austria, Belarus, Belgium, Bulgaria, Canada, China, Croatia, Czech Republic, Egypt, Estonia, Fiji, Finland, France, Ghana, Georgia, Germany, Great Britain, Hungary, Iceland, India, Indonesia, Ireland, Israel, Japan, Kazakhstan, Kyrgystan, Lithuania, Malaysia, Moldova, Mongolia, Montenegro, the Netherlands, New Zealand, Nigeria, Norway, Poland, Romania, Russia, Serbia, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Ukraine, the USA, Uzbekistan, Vietnam, and Zaire.

and *GIS-Technologies and Digital Mapping* (99 attendees, 51 presentations).

In this paper, I would like to share the highlights of the InterCarto conferences. The theme of the first conference, which was held under the auspices of the ICA and the International Geographical Union's Commission on GIS and organized by the Faculty of Geography of the Moscow State University in collaboration with GIS World Inc., was *GIS for Environmental Studies and Mapping*. More than 100 participants from ten countries including two former republics of the USSR (Georgia and Estonia) took part in the event. The most representative delegations were from Russia and the USA. *GIS World Inc.* published the first proceedings of the conference[2]. English has been the working language of the conference.

The former ICA President Joel L. Morrison (USA) greeted the meeting on behalf of the ICA. The meeting was also addressed by Nikolay D. Zhdanov, Head of the Federal Geodesy and Cartography Survey (Russia), and Nikolay S. Kasimov, Dean of the Faculty of Geography, Moscow State University (Russia). The conference had seven sessions: *GIS Theory and Methodology*, *GIS Projects for Russia*, *Technological Aspects*, *GIS and Remote Sensing, GIS: Regional Aspects, Cartographic Education and Training, and GIS Applications*.

The conference discussed theoretical and methodological problems facing the field. In addition, a great deal of attention was given to both planned GIS projects (e.g., *Development of Fiber Loop Communication System in Russia* [Robert F. Austin, USA] and *Russia's Integration into GRID-UNEP System* [Nikolay G. Rybalskij and Olga A. Novoselova, Russia]) and completed projects (e.g., the Russian-French project implemented jointly *Russia and its Nears: The Russian-French Atlas of Problems and Risks in the Former USSR* [Vladimir A. Kolossov, Roger Brunet, and Denis Eckert]). Foreign participants were particularly interested in reports on Russian software, development and implementation of remote sensing methods in environmental studies and mapping, and individual efforts that target ecosystems pollution, especially the consequences of the Chernobyl disaster.

Numerous representatives of various organizations and firms (e.g., AM/FM International, Huber, Andrew Corporation, Leica, Spans, Ilwis, Trimble Navigation, and others) attended the conference. They participated in conference activities and took part in discussions of plans and conference subjects, but there were no exhibitions that are usually arranged at such conferences. Overall, review of the conference marked the high technical level of the presentations, up-to-date GIS technology, and diversity of its applications.

The InterCarto 3 conference emphasized sustainable development – one of the most critical challenges for the world. It was held in Novosibirsk on January 27–31, 1997. The conference attracted more than 200 participants including Michael Wood (UK), President of the ICA; Milan Konecny (Czech Republic), Vice-President of the ICA; Ferjan Ormeling (The Netherlands), Chairman of CET Commission of the ICA; and Walter H. Mayer (Austria), President of PROGIS. The technical program included many national and international presentations on a wide range of GIS fields. Indeed, my appreciation of the magnitude of GIS-related activities in Novosibirsk and the eastern part of Russia in general has increased considerably during that time. Many participants enjoyed this winter event in Siberia, which was expressed in the speech by the ICA President Michael Wood at the closing ceremony, "It has been a very special pleasure for me to attend this meeting of InterCarto 3, the very first of its kind in Novosibirsk, and in my opinion it has, overall, been a great success. I believe that people will look back on that meeting as an important landmark in the journey to a future of greater cooperation

[2] InterCarto: GIS for Environmental Studies and Mapping Conference Proceedings, 23–25 May 1994, Moscow, Russia, 1994, 144 p.

and involvement between Russia, Europe, and other regions of the World". After the conference, he shared these positive impressions with his ICA colleagues and published a report on that meeting in the issue of the ICA Newsletter that followed. He also complemented all persons who made the conference possible referring to the directors, receptionists, interpreters, and caterers of the fine foods offered during the breaks and after the presentations. His final words to the participants and organizers were, "Congratulations, Novosibirsk, job well done"!

The technical tours were completed and positively received, judging by the enthusiasm of both demonstrators and the excursions participants. These tours were a revelation for the overseas delegates, in particular, when they saw some of the excellent research and production work conducted there. The exhibition and the tours were the highlights of the conference. The tours have convinced the participants of the vitality of GIS research and its application in Russia and especially in the Novosibirsk region, of which many in the West were totally unaware. Not only evidence of catching up with new technologies has been demonstrated, but also the enormous potential to take a lead in some fields has been shown. For example, the *Electronic Ecological Atlas of Kemerovo Oblast*, presented at the Institute of Computational Technologies, offered concepts and structures that could be adopted in other regions. We also saw the demonstration of competent programming implemented in locally produced software of exceptionally high standards.

However, there were two aspects of concern. The first was associated with the lack of papers on organizational aspects of GIS. In the West, major reasons for a complete or partial failure of GIS projects (e.g., when they have to be expanded and integrated into activities of local authorities) are often not of a technical or academic nature, but usually of an organizational origin. The InterCarto 4 helped us to find out if these matters were properly addressed. The second concern was related to a poor attendance by overseas delegates who missed so much by not being there. The conference was exceptionally well organized. The participants were able to enjoy Novosibirsk and its vicinities despite a totally unexpected heat wave that deprived them of a true Siberian adventure. The presentations were highly informative and followed by lively exchanges of views so typical to Russian scientific disputes. The environment (and especially in winter) was remarkably different and the contacts were much friendlier than many of the participants had experienced in their own, often stressed-out, societies. The participants were truly pleased to see that technological advances in Siberia were still accompanied by the old virtues of kindness and generosity.

The third event I would like to cover in this presentation is the conference held in Perm (Russian component) and Gent (Belgium component). The Russian part of the conference took place from June 26 through July 2, 2009, at the Perm State University (Perm, Russia). One hundred sixty participants attended the conference; they came from various regions of Russia and several foreign countries. The program included plenary and thematic sections, seminars, and round tables. Different problems that face modern geography were covered in the following sections: *Geo-Information Support of Sustainable Development of Territories (Theory, Geopolitical Processes, and Territorial Management)* (co-chairmen V.S. Tikunov and A.M. Korobejnikov), *Infrastructure of Spatial Data* (S.A. Miller and A.V. Koshkarev), *Remote Sensing of the Earth* (N.A. Kalinin), *Geo-Information Support for Solution of Water-Ecological, Geomorphological, Geological, and Geophysical Problems* (I.N. Rotanova and E.B. Soboleva), *Ecologic and Geo-Information Aspects in Sustainable Development* (S.A. Buzmakov), *Sustainable Development and Tourism* (A.I. Zyrjanov), and *GIS-*

FORMATION for Sustainable Development (S.V. Pjankov). Several seminars and round-table discussions were devoted to *GIS and Business* (S.A. Miller), *Infrastructure of the Spatial Data in Hydrological Researches* (A.V. Koshkarev and I.N. Rotanova), and *Historical Geo-Informatics* (V.N. Vladimirov and S.I. Kornienko). There were also presentations on mobile GIS, remote sensing techniques for analyzing land use, vegetation, and sustainable development, GIS-education for sustainable development, etc.

Printed proceedings (three-volumes) of the conference were available to the conference participants at the beginning of the event. The attendees were also able to obtain a DVD with a unique collection of Russian materials presented at all previous InterCarto conferences since 1994. At the plenary session, the participants were welcomed by I.N. Shubin, Head of the city of Perm, M.N. Shejfel, Adviser of the Chairman of the Perm Kray Government, and Professor V.V. Malanin, President of the Perm State University.

The materials of the conference can be found on the Perm State University website (http://www.gis.psu.ru/InterCarto/resolution).

The Belgian component of the conference took place on July 3–6, 2009. Fifty participants, many of whom travelled from Russia, attended the meeting. The sections covered GIS applications in different fields, such as environmental protection and ecological studies, road system economics and navigation, space monitoring and mapping, dynamics of land use, prevention of consequences of natural catastrophes, demography, remote training, and development of spatial data infrastructure and its components. Twenty five presentations were delivered during seven conference sections that have illustrated the process of fundamental changes in methods and tools of modern cartography, for example, the process of continuous migration of geo-informatics from GIS paradigm to SDI environment.

After the opening speech by F. De Mayer, the main organizer of the conference in Ghent, two plenary presentations were made: the first one dealt with the use of geo-information technologies in studies of global demographic processes (V.S. Tikunov) and the second was on the history of "neocartography", entitled "From Maps of Ortelij to Service Openstreetmap.org" (F. Ormeling). The presentation by V.S. Tikunov emphasized the importance of maps, mathematical-cartographical modeling, and GIS tools for studying demographic processes. The presentation was illustrated with a series of animated anamorphose maps of global basic changes of the demographic situation in the world. The speaker also talked about essential changes in the epoch of modern cartography that have occurred recently. F. Ormeling discussed theoretic works in the field of cartographic communications and works by A. Kolachny who contributed much to the filed. A. Kolachny had anticipated use of information technologies in cartography. He had foreseen the first computer maps, geo-information technologies, modern cartographic web applications, LBS-services in smart phones and communicators, and cartographic devices in automobile navigators, i. e. geo-information management processes that were so uncontrollable in the age of ancient science.

The most recent InterCarto-InterGIS 16 conference was held in Rostov-on-Don (Russia) on July 3–4, 2010, and in Salzburg (Austria) on July 6–8, 2010. The thematic sections of the conference included: *GIS Support of Sustainable Development of Territories (Theory, Geopolitical Processes, and Territorial Management)*, *Remote Sensing and Sustainable Development of Territories*, *Mobile GIS*, *GIS and Business, Sustainable Development and Tourism (Problems and Perspectives)*, *Spatial Data*

Infrastructure, and *GIS-Education for Sustainable Development*.

The conference presentations covered theoretical and methodological problems of cartography and temporal-spatial geo-information modeling. Conference topics also included geo-information support for promoting sustainable development of Russian and other territories, experiences of GIS use in addressing ecological problems, and infrastructure of spatial data. Several presentations addressed methods of cartographic and geo-informational modeling, problems and prospects of sustainable tourism development, and medical-geographical aspects of sustainable development. Participants also discussed outcomes of research on near-border cooperation, education in general, and education that specifically targets sustainable development. The conference participants stressed the fact that the development and use of GIS technologies, GIS-based projects, and cartographic forecast modeling are being increasingly incorporated in land use planning and management, environmental management, and education. They further stressed that these projects are of high scientific and practical significance.

The next annual InterCarto-InterGIS conference will take place in December 2011. The Russian component of the conference will be held in the Altay Kray followed by another meeting on Bali, Indonesia (Website – http://intercarto17.net/)

Vladimir S. Tikunov

"THE CASPIAN REGION: ENVIRONMENTAL CONSEQUENCES OF THE CLIMATE CHANGE"

THE INTERNATIONAL CONFERENCE

October 14–16, Moscow State University, Russia

The Caspian region has unique natural environments. Abrupt sea-level change is characteristic for this region. The observed sea-level drop that reached its lowest level of –29,01 m in 1977 was followed by the sea-level rise of up to –26,66 m in 1995. Geomorphologic, archaeological, cartographic and other evidence throughout historical times, as well as the results of paleogeographical studies covering tens of thousands of years, indicate that periodical variations in sea-level are a normal phenomenon of the unstable state of the enclosed body of water with changing conditions at its outer boundaries, with the climate change being the most important of these conditions.

Revealing the linkage between climate change, the Caspian sea-level change and development of the natural environments of the region is the defining condition for building a strategy for sustainable development of the region. Scientists from the Moscow State University's Faculty of Geography have devoted multiannual studies to solving this problem. Within the last two decades the interest of the international scientific community to the evolution of the Caspian and its coastal areas under conditions of high sea-level rise as a model of possible consequences of global climate warming has risen significantly. A number of scientific projects were carried out in cooperation with scientists from the Netherlands, Great Britain, Belgium, Iran, Canada, Azerbaijan, Kazakhstan and Ukraine.

To discuss the obtained results, the Faculty of Geography organized the International Conference on "The Caspian Region: Environmental Consequences of the Climate Change". Academician N.S. Kasimov – Dean of the faculty, became the leader of the Organizing Committee. As a scientific time frame, the conference focused on the final stage of Caspian development – the Holocene. This time interval in the history of the region is critical for it includes climatic events of different scale and opposite trends, and allows for understanding the response of the natural basin environments and coastal area to these climatic events.

The objectives of the conference drew a lot of interest from the scientific community. Scientists from all countries of the Caspian region – Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan, along with Great Britain, Canada, the Netherlands and Ukraine, participated. Scientific presentations showed the complexity of the study case. Specialists on different areas of expertise – climatologists, hydrologists, oceanographers, marine geologists, geomorphologists, cartographers, paleogeographers, geochemists, biologists and others – addressed fundamental and

Holocene were presented by S.B. Kroonenberg (the Netherlands), A. Kakroodi and colleagues (Iran), E. Konikov, G. Pedan (Ukraine), V. Putans (Institute of Oceanology), A. Chepalyga (Institute of Geography). The report on evaluating the runoff of the Caspian basin rivers in the same time interval was presented by A. Panin, A. Sidorchuk (MSU) and O. Borisova (Institute of Geography). Geochemical changes in the near-shore zone, caused by sea-level

applied questions associated with sustainable development of the Caspian region.

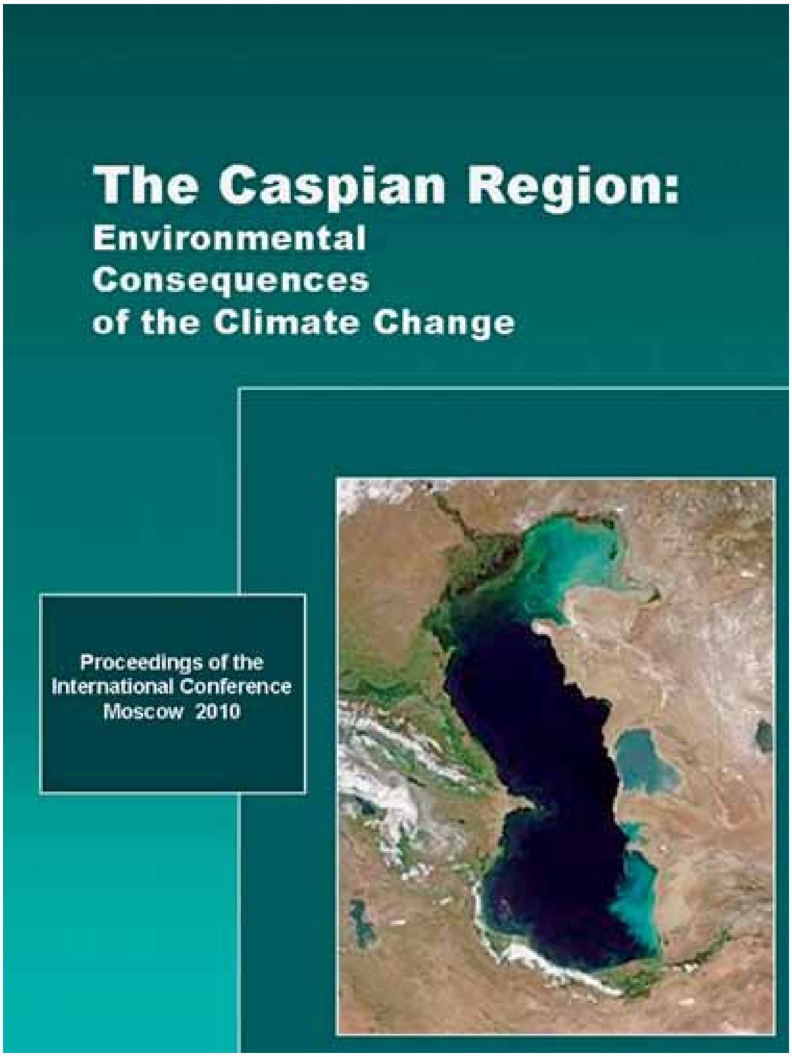
The plenary session took place on October 14th. The session was opened by the Chairman of the Organizing Committee and Dean of the Faculty of Geography of the Moscow State University, Academician N.S. Kasimov, and by the Chairman of the Scientific Committee – Professor S.B. Kroonenberg from the Delft Technological University (the Netherlands). The following leading scientists in the Caspian region research presented plenary lectures: from Russia (S. Kislov, N. Kasimov, M. Lychagin, A. Svitoch, N. Alekseevskyi), Azerbaijan (E. Alieva, R. Mamedov), the Netherlands (S. Kroonenberg, R. Hoogendoorn), Great Britain (S. Leroy) and Canada (V. Yanko-Hombach). They summarized the results of the multiannual research in the Caspian region and presented the data from the international projects IGCP, INTAS and RFBR-NWO.

On October 15th six sessions were open. The session "Palaeoclimatic and palaeoenvironmental changes in the Caspian Sea region" presented the reports on different aspects of this theme, which is fundamental for understanding the patterns of the evolution of the Caspian and its natural environments under conditions of climatic changes of variable scale and for forecasting their future development. Reports on the reconstruction of the Caspian sea-level change in the Late Pleistocene and

change were discussed in presentations by M. Kasatenkova, N. Kasimov, A. Gennadiev, M. Lychagin (MSU). An overview on the vegetation and climate evolution of the Lower Volga region was presented by N. Bolikhovskaya and N. Kasimov (MSU); on the Volga Delta by K. Richards (Great Britain) and N. Bolikhovskaya (MSU). R. Gallagher (Great Britain) presented a highly debatable view of the extraordinary Caspian sea-level rise in the Late Pleistocene that reached 155 m and reconstructed the landscape development of the Azerbaijanian coast of the Caspian and pointed to the possible link between prehistoric cultures of Egypt and Azerbaijan, referring to paleogeographic and archaeological evidence. A complex of geological, geomorphological and geophysical data was used as a basis for reconstructing the development of the Turali coast of Dagestan undertaken by E. Badukova and A. Kalashnikov (MSU). Evolution of the Iranian coastal zone under conditions of sea-level variations was presented by Iranian researchers H. Khoshravan and M. Ownegh.

The session "Evolution of the coastal zone" included reports on coastal processes, patterns of changes of the coastal landscapes, their geochemical evolution under the influence of climate change and the Caspian Sea level. In the XX century the Caspian sea-level underwent a full cycle of changes with a range of 3 m that is why researchers consider it a natural laboratory for studying fast sea-level changes and their consequences for the near-shore zone. In the presentations the development of the coasts of Kalmykia (V. Kravtsova, S. Luk'yanova, MSU), Dagestan (S. Luk'yanova, G. Solov'eva, MSU; G. Abdurakhmanov, Makhachkala), Kazakhstan (F. Akiyanova, Kazakhstan), Iran (A. Kakroodi, Iran; S. Kroonenberg, Netherlands) was described. Comparative study of the coasts of the northern Caspian and Black seas was presented by G. Pedan and colleagues (Ukraine).

The session "Evolution of the Caspian rivers deltas" included reports on the influence of climate change and sea-level on present state and development of river deltas of the Caspian region, which is one of the most critical problems of the national economies. For the Russian part of the Caspian coast the most important is the Volga Delta – a unique natural system, playing very important role in the economy and ecology of the region. The majority of presentations were devoted to the problem of Volga Delta evolution and separate components of its environment (E. Baldina, I. Labutina, A. Kur'yakova, N. Kasimov, M. Lychagin, MSU; A. Barmin, M. Iolin, University of Astrakhan; A. Gorbunov, A. Gorbunova, Astrakhan Biosphere Reserve; P. Makkaveev, E. Vinogradova, P. Khlebopashev, T. Alekseeva, V. Svalnov, Institute of Oceanology, Moscow; Yu. Gorbunova, Kaliningrad).



The session "Current conditions of the Caspian Sea" was devoted to different problems of hydrometeorological changes in the region and their influence on the functioning of all the links in the sea system: reorganization of the thermohaline fields, vertical hydrological structure (A. Kosarev, V. Tuzhilkin, MSU; R. Nikonova, Institute of Oceanography; S. Lebedev, Geophysical Center RAS; V. Polonskyi, L. Ostroumova, Institute of Oceanography); geochemical evolution and development of marine biological communities (N. Solov'eva, Institute of Oceanology; V. Sapozhnikov, N. Zozulya, N. Mordasova, Institute of Fisheries and Oceanography, Moscow); patterns in distribution of marine sediments (H. Lahijani, Iran). B. Golubov (Institute of Geosphere Dynamics) assumed significant influence of underground waters on the Caspian Sea level.

The session "The Caspian Sea region: Environmental problems and management" included presentations covering a wide range of different aspects of ecological and geochemical state of natural complexes, caused by intensive exploration and mining of hydrocarbons in the coastal zone and on the shelf of the Caspian Sea, as well as characteristics of ecological management in these regions. The reports were presented by N. Kas'yanova (Oil and Gas University), S. Lebedev (Geophysical center RAS, Moscow). Suggestions to develop the information database on the Caspian region were given by I. Lurie, A. Alyautdinov, I. Kalinkin, V. Semin (MSU).

The session "Forecasts of the Caspian Sea level and environmental changes" included a small number of presentations on the forecast of climate change in the region, as well as response of the Caspian Sea and its natural systems to these changes. The most interest was drawn to the report of R. Klige (MSU) with the analysis of the Caspian sea-level change within historical time and its forecast for the 21st century and the report of N. Makarenko (Pulkovo Observatory), in which he and his colleagues from Kazakhstan presented mathematical models of sea-level change.

On October 16th the poster session (38 posters and their discussions) and the closing plenary session were held. The plenary session presented lectures on climate forecasts, the Caspian sea-level change (G.N. Panin, Institute of Water Problems) and the state of natural environments of the region (M. V. Moghaddam, Iran). G.I. Rychagov (MSU) made special emphasis on the characteristics of economic activity in the coastal zone under conditions of unstable level of the Caspian Sea.

At the end of the meeting there was a discussion on the presentations. All speakers received appraisal for the high presentations' level and the excellent overall conference organization. It was pointed out, that the potential for international cooperation in studying the influence of climatic changes on sea-level change and the evolution of natural environments of the entire Caspian region, accumulated within the recent twenty years, is high. Presentations, discussions, workshops, that took place shortly before and during the conference helped figuring out the future tasks - to continue the research in order to better understand the causes of sea-level change and their linkage to climatic changes at global and regional scales, and their influence on all natural environments of the Caspian region. Modern investigations in the Caspian region require close cooperation between scientists not only from Russia, but also from countries of the near and far abroad. At the closing ceremony of the conference S.B. Kroonenberg and N.S. Kasimov spoke.

As a whole, 102 reports were presented, with a total of ~ 180 participants. By the beginning of the conference the volume of abstracts: "The Caspian Region: Environmental Consequences of the Climate Change" was published as the Proceedings of the International Conference. Moscow: Faculty of Geography, 2010. 352 p. (http://media.geogr.msu.ru/Caspian_2010/caspian_conference_2010.pdf)

Tamara A. Yanina, the Executive Secretary of the Conference

"ECOLOGICAL CONSEQUENCES OF BIOSPHERIC PROCESSES IN ECOTONE ZONE OF SOUTHERN SIBERIA AND CENTRAL ASIA"

THE INTERNATIONAL CONFERENCE
September, 6–8, 2010, Ulaan-Baatar, Mongolia

The conference was timed to coincide with the 40-anniversary of the Joint Russian-Mongolian Complex Biological Expedition (JRMCBE) of the Russian Academy of Sciences (RAS) and the Mongolian Academy of Sciences (MAS). In his welcoming speech, the President of the MAS, Academician B. Enhtuvshin, paid tribute to the long-term efforts of the Expedition in research on the environment and biological resources of Mongolia. The co-chairmen of the Organizing Committee, First Vice-President of the MAS, academician D. Regdel, and a member of the RAS Presidium, Academician D.S. Pavlov, delivered welcoming speeches to the participants of the conference.

Key-note presentations were made by: a member of the Committee on Food, Agriculture, and Nature of the Great Hural, G. Bayarsaikhan; Head of the RAS Department of External Relations S.S. Markianov (on behalf of the RAS President, Academician Y.P. Osipov); Deputy Minister of the Department of Nature, Environment, and Tourism, C. Jargalsaikhan; Deputy Minister of the Department of Culture, Science, and Education C. Kulanda; Professor G. Bernardi (on behalf of the International Union of Biological Sciences (IUBS); and Dr. R. Yakumar (on behalf of the Eastern-Asian Network of UNESCO Biosphere Reserves).

220 scientists from Russia, Mongolia, Germany, Israel, the USA, Uzbekistan, and Kazakhstan participated in the conference. About 80 reports were made during the plenary sessions and the conference sections on six most important areas:

1. Ecological-social problems of the natural environment pollution;
2. Environmental problems of aquatic and wetland ecosystems of the Baikal Lake basin;
3. Causes and effects of centennial climate dynamics;
4. The present condition of the network of especially protected natural territories and prospects of its development;
5. Ecological risks in anthropogenic (agricultural and forest) ecosystems;
6. Floristic, faunistic, and biogeocoenological diversity in the ecotone zone of Southern Siberia and Central Asia.

In addition to oral reports, there were a number of poster presentations on various subjects followed by discussions. Future research activities under the JRMCBE Program for the period of 2011–2015 were also discussed.

The chairmen of the conference sections made summary reports at the final plenary session. The Ulaanbaatar Declaration was accepted. Before closing the conference, a member of the Parliament of Mongolia, Kh. Narankhuu, addressed the conference with a special speech. He spoke very highly of the contribution of the JRMCBE to research efforts on Mongolian ecology and, especially, to the applied research that targets assessment of pastures' condition. He also noted that both Russian and Mongolian members of the JRMCBE received 8 state, 5 governmental, and 4 academic awards as well as certificates of honor from different Mongolian ministries and the MAS.

186 conference abstracts by 365 authors from 90 academic institutes, universities, and various departmental organizations of Russia, Mongolia, Germany, Israel, and the USA had been published in two volumes prior to the conference. The materials of the conference can be found on the site of the RAS Institute of Ecology and Evolution: http://www.sevin.ru/menues1/index_rus.html.

Mass media of Mongolia widely covered all conference activities, including the transfer of more than 500 volumes of the JRMCBE transactions on various directions of its research to fifteen libraries of Mongolia.

Yuliy I. Drobyshev
The RAS Institute of Ecology and Evolution

INSTRUCTIONS FOR AUTHORS, CONTRIBUTING TO "GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY"

AIMS AND SCOPE OF THE JOURNAL

The scientific English language journal 'GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY' aims of informing and covering the results of research and global achievements in the sphere of geography, environmental conservation and sustainable development in the changing world. Publication of the journal will be aimed at foreign and Russian scientists – geographers, ecologists, specialists in environmental conservation, natural resource usage, education for sustainable development, GIS technology, cartography, social and political geography, and also – on field studies in the sphere of environmental science. Publications that are interdisciplinary, theoretical and methodological are particularly welcome.

Among the major sections of the journal will be: basics of geography and environmental science; fundamentals of sustainable development; environmental management; environment and natural resources; human (economic and social) geography; global and regional environmental and climate change; environmental regional planning; sustainable regional development; applied geographical and environmental studies; geo-informatics and environmental mapping; oil and gas exploration and environmental problems; nature conservation and biodiversity; environment and health; education for sustainable development.

I. GENERAL GUIDELINES

1. Authors are encouraged to submit high-quality, original work: scientific papers according to the scope of the Journal, reviews (only invited) and brief articles. Materials earlier published, or accepted to the publication in other editions, are accepted under the decision of the Editorial Board.

2. Papers are accepted in English. Either British or American English spelling and punctuation may be used.

3. All the **authors** of a paper should include their full names, positions, affiliations, postal addresses, telephone and fax numbers and email addresses. One author should be identified as the Corresponding Author. We encourage authors to include theirs photograph and main points of curriculum vitae.

4. The optimum volume of manuscript is 0,2–0,5 of author's sheet (or about 3 000–5 000 words). On occassion in coordination with edition can be accepted methodological, problem or reviews in volume up to 0,7–1 author's sheet.

II. MANUSCRIPT PREPARATION

1. Manuscript should be compiled in the following **order**: authors names; title; authors affiliations, Abstract; Keywords; main text; acknowledgments; appendixes (as appropriate); references; authors (brief CV and photo)

2. Authors should use word processing software for manuscript preparation.

3. **Figures** should be produced as near to the finished size as possible. Pictures can be represented in formats of programs used for their creation: CorelDraw (up to 9 versions), Adobe Photoshop (up to 6 versions), Adobe Illustrator (up to 9 versions). Raster images should be not less 300dpi in the natural size. Captions should be given as the separate list.

4. **Tables** should not be too bulky. Each table should have a short title. Tables are to be numbered separately from the illustrations. Each table should be represented as a separate file in an original format MS Word, Excel, etc.

5. **Captions** should follow the reference to figure. The same concerns to names of tables.

6. **References** should be numbered in the alphabetical order, using Arabic numerals. Whenever possible, total number of references should not exceed 10 points. References in the text should be denoted in Harvard (Author, year) system in square brackets, e.g., [Author1, Author2, 2008]. References should be complete in the following style:

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Style for books: Author(s), year in brackets, title, publisher, location, page numbers.

Style for contribution in a book: Author's last name followed by initials for each author, year in brackets, title of a contribution. In: Editor(s), title, publisher, location, inclusive page numbers.

7. Authors must adhere to SI units. Units are not italicised.

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9. For expediting of reviewing of a paper authors are encouraged to prepare also an electronic version of their manuscripts with embedded figures of "screen" quality as Adobe Acrobat pdf files.

10. As Instruction for Authors can be changed, please, see the Last "Example of manuscript style" at http://www.geogr.msu.ru/GESJournal/author.php

III. MANUSCRIPT SUBMISSION

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