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Last-interglacial records from central Asia to the northern Black Sea shoreline: stratigraphy and correlation

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Abstract

The records of the last interglacial in several palaeogeographical zones and various sedimentary environments from Central Asia to the Black Sea shoreline are presented. The last interglacial is characterized in the study areas by a two- or three-unit stratigraphical complex with both terrestrial and marine formations. Finds of significant small mammalian remains, together with a characteristic mollusc fauna in the Karangatian marine sediments, provide key levels for biostratigraphical correlation between the marine and continental deposits. New U/Th dates allow the correlation of the Karangatian transgression with $\delta^{18}O$ substage 5e.

Keywords: last interglacial, loess, marine transgression, mollusc fauna, palaeosol, stratigraphy

Introduction

The last interglacial is of special importance in the research on Quaternary and global change. As the youngest interglacial, it has been used as a model for the discussion of the present-day and future climate (Velichko, 1993; Kukla et al., 1997). Many details of the chronology and regional variation of the last interglacial in different climatic zones and various sedimentary environments are still not well understood, however. The present contribution deals with the Pleistocene records from South Tadjikistan, South Russia, Ukraine and Moldova (Fig. 1). These areas belong to different palaeoclimatic zones ranging from arid in central Asia to the temperate periglacial zone of the Eastern European Plain. The former is known as a classic loess region and includes a complete loess/palaeosol succession. The latter, along the Black and Azov Seas, includes well-developed marine and lagoonal sediments containing mollusc and micromammalian faunas. The loess/palaeosol succession in the region bordering the northern Black Sea serves as an important tool for correlating the glacial and marine sediments.

The authors adopted a multidisciplinary approach for the present study, involving palaeontological, lithological, palaeopedological, palaeomagnetic and oxygen-isotope analyses, as well as ^{14}C and U/Th dating. The stratigraphically significant remains of small mammals and the corresponding characteristic mollusc fauna serve as a basis for biostratigraphical correlation between the marine and continental deposits. The comparative analysis of mollusc faunas allows the interpretation of various palaeoenvironmental sit-

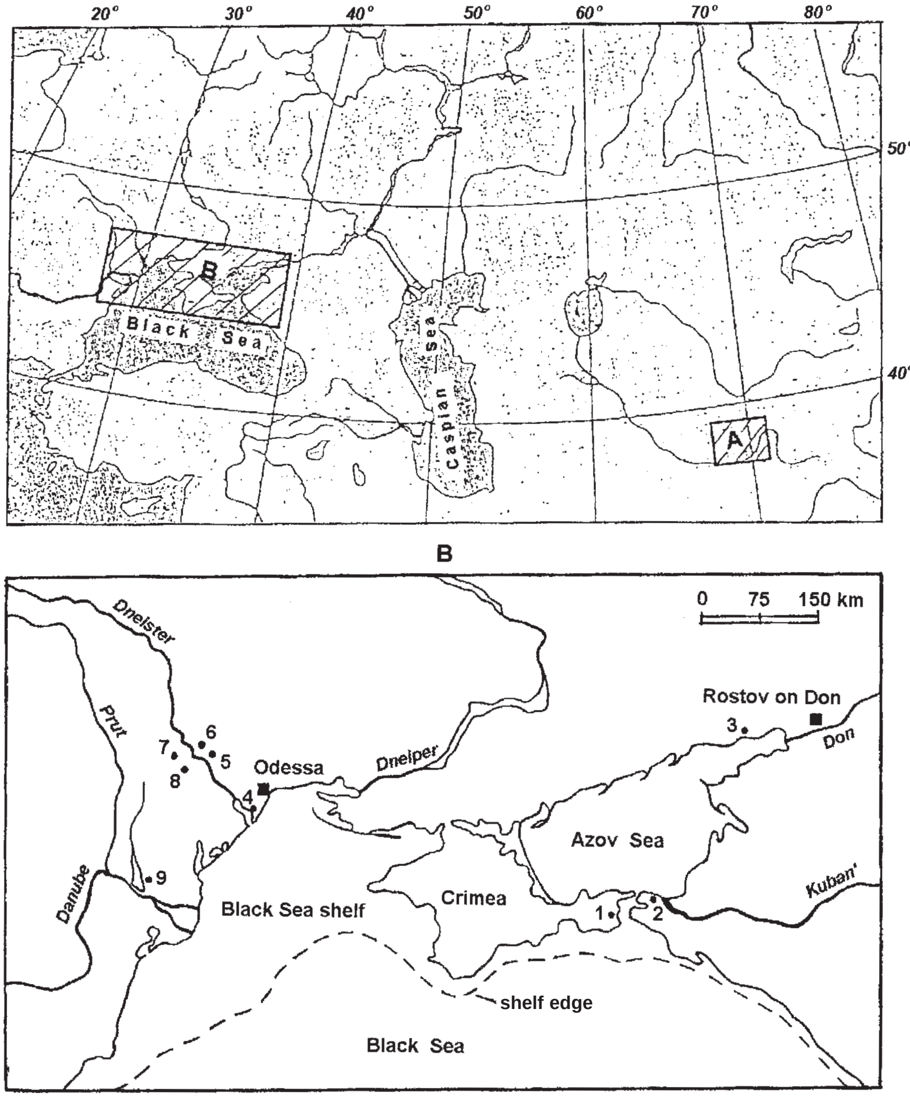

Fig. 1. Location of the study areas: A = South Tadjikistan, central Asia. B = Northern Black Sea shore.
Studied sections: 1 = Eltigen; 2 = Pekla; 3 = Priazovskoe; 4 = Nikoni/Roksolany; 5 = Tiraspol/Kolkotova Balka; 6 = Komarova Balka; 7 = Varnitsa; 8 = Khadzhimus; 9 = Novonekrasovka.

uations and sedimentary cycles related to sea-level changes. Bio- and climatostratigraphical correlations are supported by absolute dates.

The last interglacial in loess/palaeosol sequences

South Tadjikistan, Central Asia

Palaeosols in loesses are widespread in the piedmont of the Tian Shan Mountains and the Western Pamirs. The thickness of the loess cover varies in these regions from a few metres to 200 m (Dodonov, 1991; Dodonov & Baiguzina, 1995). Three stratigraphical subdivisions – the Lower, Middle and Upper Pleistocene – are established in the loess/palaeosol sequences. Palaeontological and palaeomagnetic investigations provide general geochronological controls at the level between the Lower and Middle Pleistocene. The Matuyama-Brunhes magnetic reversal (780 ka) has been indicated at the base of or immediately below the 9th pedocomplex (PC9) in many sections. Just below this boundary, a well-studied mammalian faunal assemblage occurs in the Lakhuti locality (bone horizon Lakhuti-2). It corresponds to the transitional-type fauna ranging from the Taman to the Tiraspol Complex. The latter is correlated with the Cromerian assemblage of Western Europe (Sotnikova et al., 1997).

For a long time, there was major confusion with respect to the stratigraphical position of the last-interglacial palaeosols in the central Asian loess. Recent luminescence dating of Pleistocene loess in Uzbekistan (Zhou et al., 1995) discussed the severe age under-estimations in the previous loess chronology, which had been based on TL measurements made in 1970s by the TL laboratory in Kiev. Similar work was carried out in southern Tadjikistan (Frechen & Dodonov, 1998). Although the new luminescence dates also show age under-estimates, it is clear that the loess above the first pedocomplex (PC1) represents the last glaciation (Valdaian) and that PC1 most likely dates from the last interglacial, equivalent to the entire Marine Isotope Stage 5 (MIS 5), as suggested by Forster & Heller (1994) and Shackleton et al. (1995).

PC1 consists of three units. The lower palaeosol, $PC1_3$, is a typical cinnamon soil, the middle one, $PC1_2$, is calcareous cinnamon, and the upper one, $PC1_1$, is similar to serozem. The triple structure of the PC1 can be recognized in the calcium-carbonate curve of the Darai Kalon loess section in Tadjikistan (Fig. 2). The detailed magnetic susceptibility measurements for the same section show a great contrast between loess and palaeosols; the latter have susceptibility values 3-6 times higher than the loess units. Because the magnetic variations reflect changes in the past pedoenvironment (e.g., Zhou et al., 1990), which was controlled by climatic conditions, susceptibility can be used as a climatic proxy. PC1 has three peaks in magnetic susceptibility, which may be seen as manifestations of the triple structure of this pedocomplex.

Palynological analyses from the Darai Kalon section have been carried out for the upper 100-m interval including the 6^{th}, 5^{th}, 4^{th}, 3^{rd}, 2^{nd} and 1^{st} pedocomplexes. The pollen contents vary from a few to 300 grains. For example, the pollen content in PC1 varies from 30 to 100 grains. The first loess horizon, L1, contains highly variable quantities of pollen, from very rare to 280 grains. The lower palaeosol, $PC1_3$, is characterized by a high percentage of arboreal pollen (up to 80-90%), while herbs are less important at 30-50% (Fig. 2). Pollen of broad-leaved species, such as *Carpinus, Fraxinus* and *Quercus*, have been found. *Picea* and a rather high content of *Pinus* pollen (60%) were recognized in the middle part of the soil profile. In general, the presence of trees during the formation of the $PC1_3$ reflects a relatively moist climate. It should be noted that the pollen spectra from $PC1_3$ contain such forms as *Celtis, Pistacea, Juglans* and *Myrica*, which indicate favorable conditions for the growth of broad-leaved forests. Similarly, arboreal pollen dominate (up to 80-90%) in $PC1_2$. In the upper part of $PC1_2$, steppe-meadow taxa increase (up to 50%), whereas arboreal pollen decrease. The predominance of herbs and shrubs in $PC1_1$ is remarkable, since it provides evidence for increasing aridity and perhaps cooling of the climate in comparison to the situation during $PC1_3$ and $PC1_2$.

Pollen that contain dominant herbaceous and shrub pollen, as well as very rare arboreal forms, characterize L1. The arboreal pollen disappear in the upper part of L1, which is additional evidence of high aridity in the final phase of loess formation. It should be noted that the thickness of L1 is 20 m in Darai Kalon, indicating a high sedimentation rate of dust during the last glaciation.

South Russia, Ukraine and Moldova

Loess with palaeosols is widespread in the regions north of the Black and Azov Seas. Its thickness reaches 30-50 m. Seven palaeosols (or pedocomplexes) have been distinguished in the Brunhes chron in these areas. For example, the palaeosol horizons (from top downwards) Bryansk, Mezin, Romny, Kamenka, Inzhava, Vorona and Kolkotova are recognized in sections at Tiraspol/Kolkotova Balka, Varnitsa and Khadzhimus (Fig. 1). The stratigraphic scheme of Velichko et al. (1992) was used here. According to the scheme of Veklich (1982), which is widely accepted in Ukraine, the Late Pleistocene Dofinov and Priluki palaeosols are correlated with the interstadial Bryansk soil and the last-interglacial Mezin pedocomplex, respectively.

Late Pleistocene subaerial deposits of the northern Black Sea shore region are relatively thin (3-5 m) in comparison to those of the northern periglacial zone in the Eastern European plain. Recent soil often overlies the Bryansk palaeosol, partly cutting it. The Mezin pedocomplex, placed at the base of the Upper Pleistocene, is usually subdivided into two parts: the Salyn and Krutitsa palaeosols (Velichko et al., 1992). The Salyn palaeosol is described in most areas of the Russian Plain as a forest soil, although it is represented in the south as a meadow-chernozem or chernozem. The Krutitsa soil is considered as a chernozem-like soil. Along the northern Black Sea shoreline, the Mezin soil complex consists of two or three palaeosols. This triple structure of the Mezin complex is well expressed in the sections at Komarova Balka and Pekla. The lower soil is a chernozem-like soil, with features of degradation under the influence of soil development in overlying deposits. The absence of primary carbonate in the lower soil suggests that it is a variant of a leached chernozem formed under conditions typical of a forest-steppe. Small (up to 10 cm wide) cryogenic wedges filled with loess were noticed in the upper soil horizon of the Mezin pedocomplex in the Nikoni/Roksolany section. Usually, the cryogenic horizon is found in the northern part of the Eastern European plain between the Salyn and Krutitsa stages.

Subdivision of the Late Pleistocene terrestrial sequences on the northern Black Sea shore region is mainly based on palaeopedological analysis and regional stratigraphical correlation. The earlier TL dates of the upper part of the loess/palaeosol succession in the region are now in doubt (Zhou et al., 1995). The ^{14}C dates for the Bryansk palaeosol are therefore now of great importance. A ^{14}C date (IGAN-768) of 29,240 ± 2,260 year BP on humus from the Bryansk

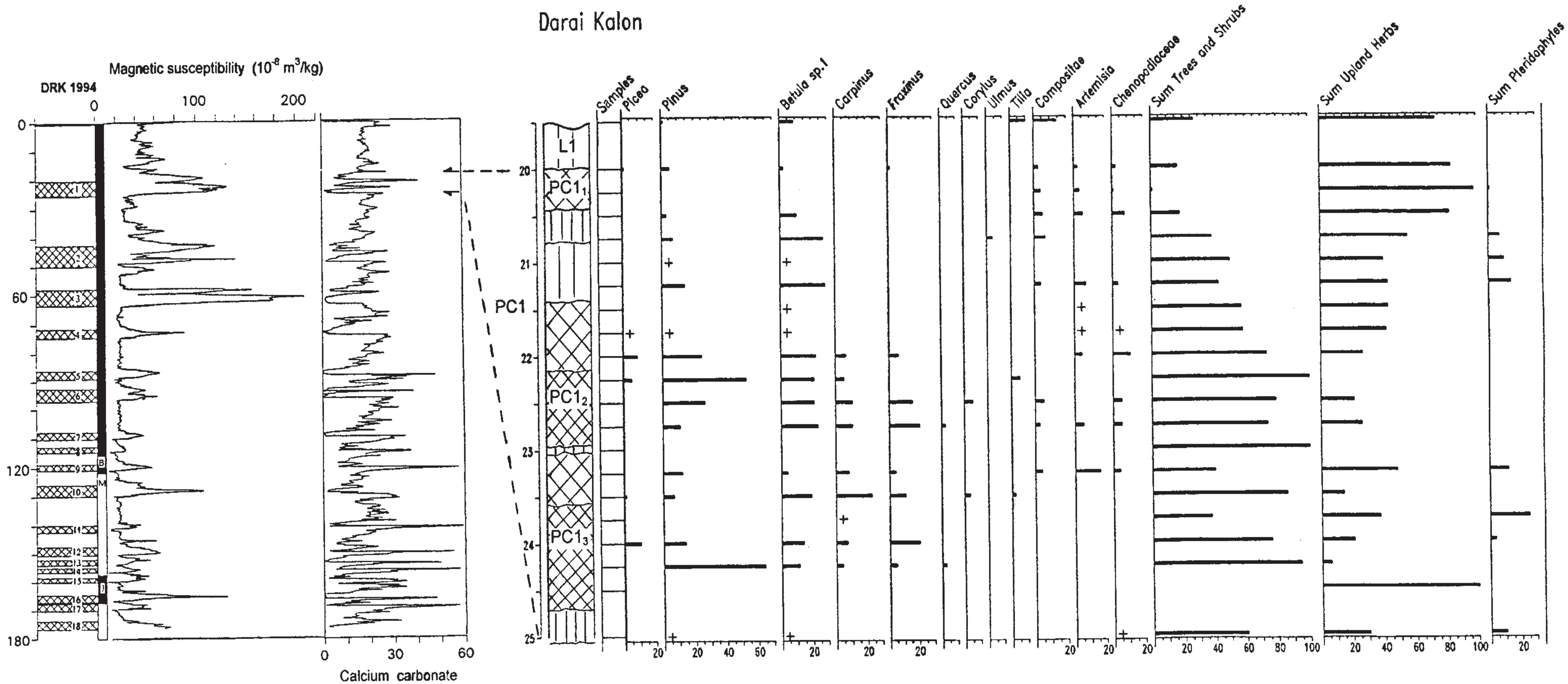

Fig. 2. The last climate cycle, and the loess/palaeosol sequence (left column: DRK 1994) at Darai Kalon in South Tadjikistan. Palynological data are represented together with the magnetic susceptibility (10^{-8} m^3/kg) and carbonate content (%) for the last interglacial pedocomplex, PC1.

palaeosol in the Kolkotova Balka section was obtained by Velichko et al. (1992). A new AMS ^{14}C date (OxA-7970) of 26,760 ± 240 year BP on humic matter from the Bryansk palaeosol was recently obtained from a sample taken from the Nikoni/Roksolany section. These dates for the Bryansk palaeosol indicate that the Mezin pedocomplex is of last-interglacial age and is therefore correlated to MIS 5.

The Late Pleistocene in the Ponto-Caspian Basin

During the last interglacial, several sedimentary basins developed in the Ponto-Caspian region: a large isolated lake in the Caspian depression, a semi-marine basin in the Azov aquatory, and a marine basin in the Black Sea depression connected to the Mediterranean Sea. These large reservoirs were linked by one-way or two-way water passages such as the Manych, Kerch and Bosphorus straits.

The Caspian Basin

The Caspian basin was flooded by brackish water during the late Khazarian transgression. The terrace at 80-85 m height on the Caucasian coast is attributed to this transgression. This terrace is characterized by a specific mollusc fauna, including the endemic Caspian species as *Didacna surachanica*, *D. nalivkini*, *D. subcrassa* and *D. pollasi*. In comparison to the Early Khazarin stage, the disappearance of the *D. trigonoides* group is noticeable. U/Th dates on mollusc shells from the Khasarian terrace deposits give an age in the range of 78-100 ka (Arslanov et al., 1988). The level of the Late Khazarian basin did not reach over +10 m asl, which is much lower than during the Early Khazarian phase when it was +50 m asl. The Late Khazarian basin was relatively warm, with a salinity close to the present value (12-13‰). The low water level of the basin did not allow it to be connected to the Black Sea through the Manych Strait.

The Late Khazarian transgression was followed by the Early Würm Atelian regression (altitude -50 m). The presence of cryogenic features in the Atelian Clays provides evidence for a cold, glacial climate. In the middle Würm, the Early Khvalynian transgression occurred, resulting in a high sea level up to + 50 m asl. At this time, a connection of the Caspian Basin through the Manych Strait to the Azov and Black Seas existed. Then, the Late Khvalynian transgression occurred about 15-20 ka BP, with a sea level of ± 0 m asl (28 m above the present Caspian level).

The Black Sea

During the last interglacial, a vast transgression originating from the Mediterranean Sea occurred in the Black Sea. Its sediments were first established in the Crimea as the Tyrrhenian by Andrusov (1904-1905). Later, in 1938, Arkhangel'sky & Strakhov (1938) proposed a new name for the last-interglacial transgression using the Cape Karangat stratotype in the Crimea, at the Kerch peninsula. The marine terraces and nearshore sediments were described from the coast of the Crimea, the Caucasus and Bulgaria, as well as from the shelf (Fedorov, 1978; Nevesskaya, 1965; Scherbakov et al., 1979; Popov, 1983). The stratigraphy of the Karangatian sediments has been studied by, among others, Nevesskaya (1965), Ostrovsky et al. (1977), Mihailescu & Markova (1992) and Tchepalyga (1997).

According to Fedorov (1988), the level of the Karangatian Basin was 6-8 m higher than the present Black Sea level. Today, Karangatian terraces are represented along the northern Black Sea shoreline only in the tectonically uplifted Kerch-Tamanian block and on the Caucasian coastline. In the western part of the northern Black Sea shore and in the Azov Sea region, the Karangatian coastline is situated below the present water level.

The most complete marine sequence of the Karangatian transgression is found in the Eltigen section on the Kerch peninsula, in a cliff 3-4 km long in the western part of the Kerch Strait. The Karangatian marine deposits, 20-25 m thick, overlie the Sarmatian Clays (N_1) and are overlain by Late Pleistocene loesses, 7-8 m thick, with one or two weakly developed palaeosols (Fig. 3). The composition of the Karangatian deposits in Eltigen shows three sedimentary cycles that correspond to sea-level oscillations.

First cycle

The lagoonal facies in the lower part of the first cycle is represented by clay deposits (layer Ia), in which smectite dominates the clay minerals. The finely dispersed smectites were formed under the influence of organic material and came to the lagoon as organic/mineral colloids. In the middle and upper part of the first cycle, the presence of authigenic glauconite characterizes the increase of the marine sedimentation. The upper part of the first cycle is represented by sorted sands with shells. The mollusc fauna from the lower part of the first cycle represents a poor complex dominated by *Cerastoderma edule*, which is an indicator of low salinity in a semi-closed lagoon. The middle and upper parts of the first cycle contain the richer stenohaline mollusc fauna with *Paphia senescens,*

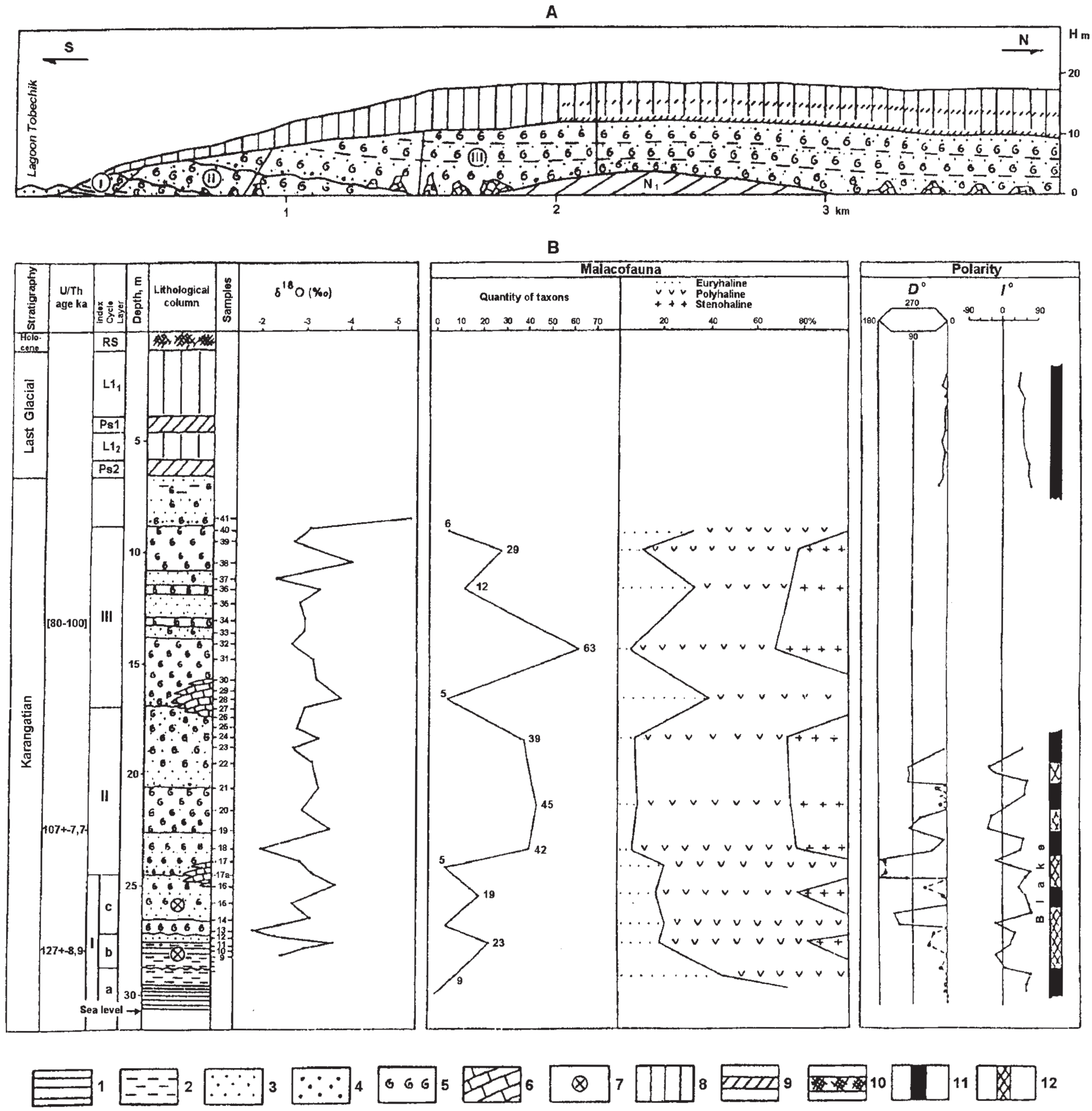

Fig. 3. The Eltigen section. A = geological section of the Eltigen cliff; B = Eltigen section and its characteristic ($\delta^{18}O$, malacofauna, polarity). Lithology: 1 = clay, 2 = silt, 3 = sand, 4 = gravel, 5 = shells, 6 = bioherm limestone, 7 = remnants of small mammals, 8 = loess (L), 9 = palaeosol (Ps), 10 = modern soil (Rs), 11= normal polarity, 12 = anomalous polarity.

Mytilus edulus, *Cerithium vulgatum* and *Acanthocardia tuberculata*. This fauna demonstrates the increase in salinity to 30‰ as well as a high sea level and wide connection to the Mediterranean Sea.

The sediments of the first cycle (beds Ib,c) contain a small-mammal fauna with *Spermophilus* sp., *Spalax* sp., *Ellobius talpinus*, *Arvicola* ex gr. *terrestris*, *Eolagurus luteus*, *Lagurus lagurus*, *Microtus (Microtus) arvalis obscurus* and *Microtus (Stenocranius) gregalis*. Steppe forms dominate this fauna: ground squirrels, mole rats, mole-voles, steppe lemmings, yellow steppe lemmings and narrow-skull voles. The meadow-steppe vole, *Microtus arvalis obscurus*, is the dominant species. The presence of remnants of *Lagurus lagurus*, with morphological features of teeth close to those of modern *L. lagurus*, and the teeth of *Arvicola* ex gr. *terrestris*, with slightly positive enamel, is peculiar to the Late Pleistocene of Eastern Europe. The micromammalian fauna from the Karangatian sediments at Eltigen corresponds to the last interglacial (Mikulian) microtheriofauna represented in many sections on the Russian plain, such as Shkurlat, Godyach, Malutino, Chernyanka and others. Thus the biostratigraphical evidence facilitates a direct correlation between marine and continental last-interglacial deposits.

Second and third cycles

The second and the third cycles are represented mostly by shell deposits with layers of sands, shelly sands and gravels. The stenohaline mollusc fauna with typical Karangatian forms, such as *Acanthocardia tuberculata, Paphia senescens, Mactra corallina* and *Cerithium vulgatum*, occurs in both cycle II and cycle III. The number of mollusc species reaches 40-60 in the cycles II and III. At the boundary between these cycles, the decline in mollusc diversity – resulting in a complete disappearance – is remarkable. This can be taken as evidence for a drop in the sea level.

Environmental conditions

Bioherm limestones are characteristic of the boundary between the first and the second cycle, as well as at the base of the third cycle. Bioherms served as barrier reefs separating lagoons from outer sea. Oxygen-isotope analysis was performed on 32 samples from bottom to top. For these analyses, *Ostrea* shells were used because this form spread over most of marine sediments. The $\delta^{18}O$ values are in the range of -2 :-3:-3.5‰ (Fig. 3), which may be interpreted as indicating an influence of fresh water from the palaeo-Don and palaeo-Kuban rivers in the Kerch Strait.

The presence of a rich marine fauna with *Acanthocardia tuberculata* and *Paphia senescens,* which do not exist today in the Black Sea, is evidence for a relatively high water level in the Karangatian Basin, and for a connection with the Mediterranean Sea. The Karangatian Basin had an almost normal salinity, of 30‰. All substages of the Karangatian transgression arose from eustatic oscillations of the Mediterranean Sea.

Ostrovsky et al. (1977) and Arslanov et al. (1983) dated mollusc shells from the upper part of the Karangatian deposits to 80-100 ka. New U/Th dates (LU-4202) of 127±8.9 ka for cycle I and 107±7.7 ka for cycle II (LU-4203) were recently obtained by the Geochronological Laboratory of St. Petersburg University. The sediments of both cycles contain well-preserved specimens of bivalve molluscs. Shells of *Cerastoderma edule* were used for dating cycle I, and *Paphia senescens* for dating cycle II.

Palaeomagnetic measurements show a 10-m interval with an anomalous direction of the magnetic field in the lower part of the Karangatian deposits in the Eltigen section. This may be interpreted as indicating the Blake Event (Fig. 3).

The Karangatian transgression flooded the mouths of the Danube, Dneister, Dneiper and Don rivers, as well as the Kolkhidian lowland. Several types of littoral deposits, such as alluvial-deltaic, lagoonal and liman-marine sediments, were formed within the river mouths and along the coastal zone. These sediments are usually represented by clays and loamy sands that contain many fossil remains of both terrestrial and marine organisms.

The lower Danube is one of the biggest sedimentary traps in the northwestern Black Sea region. In this area, lagoonal sediments that are considered to be equivalent with the Karangatian transgression, outcrop 4-5 m above the present sea level, except in the Danube delta proper and the aquatory of limans where the top of lagoon sediments is at -3 to -8 m depth. The richest brackish mollusc fauna, with small mammal remains, was found near the village of Novonekrasovka, on the eastern scarp of the Yalpug liman. The two lagoonal sandy patches (4-5 m thick in total), each with gravels at the base, occur in the lowest part of this section. The lagoonal sediments are overlain by lacustrine clay silts (1.6 m thick) and loess (8 m) with two buried soils (the lower is a hydromorphous soil and the upper is characterized by ice-wedge pseudomorphs). The upper soil could be conventionally assigned to the interstadial Bryansk soil. The lower lagoonal accumulation contains brackish mollusc species such as *Didacna danubica* and *D. ultima.* In the upper part, a number of brackish forms, including *Didacna danubica*, *Monodacna subcolorata*, *Hypanis fragilis*, *Adacna plicata, Micromelania lincta* and *Dreissena polymorpha*, were recovered. The brackish mollusc fauna is accompanied by fresh-water thermophiles such as *Corbicula fluminalis* and *Melanopsis praerosa,* which do not exist in this area now since their northern limit is 500 km to the south (southern Bulgaria). This indicates that these lagoonal sediments are of interglacial age.

Small mammalian remains of *Arvicola* ex gr. *terrestris* and *Microtus (Microtus) arvalis* were found in both lagoonal sequences. Water-vole teeth are characterized by slightly positive enamel, which is very typical of Mikulino-age faunas on the Russian Plain (Markova & Mihailescu, 1990). The evolutionary stage of *Arvicola* permits correlation of this fauna with the Shkurlat faunal assemblage in Eastern Europe. These data are in good agreement with the biostratigraphical characteristics of the first sedimentary cycle of the Karangatian stage at Eltigen.

After the last interglacial, during the Valdai stage, the Black Sea level fell over 100 m. The dried shelf, from the mouth of Dneister to the Crimean peninsula, was an area of deflation and loess sedimentation. The Azov Sea did not exist at the time. The northern coastline of the Black Sea was located at the outer margin of the shelf around 250-300 km south of the present mouths of the Dneister, Dneiper and Don rivers.

Discussion

Questions concerning the chronology of geological events and specific palaeoenvironmental changes during the Quaternary arise frequently because of dating problems, particularly for the interval prior to the last interglacial. Nevertheless, dating methods such as luminescence and U/Th can, despite their limitations, partly facilitate the comparison of the last-interglacial records in different palaeogeographical zones. The data provided in the present contribution show a good agreement between arid and periglacial zones in the loess/palaeosol succession as well as a close correlation between terrestrial and marine sediments. A similarity between the terrestrial sedimentation patterns from central Asia to the northern Black Sea shore implies that processes such as aeolian sedimentation and air-mass circulation have been subjected to a fairly uniform system. Evidently, soil formation and moisture were controlled during warm stages or substages by western transfer in the southern part of the Eastern European plain. The same air-mass system, with the same periodicity, effected the palaeoenvironmental conditions in the western part of central Asia. Along the northern Black Sea shore zone, the sea-level oscillations provided an additional mechanism, by forcing a higher humidity, for the transgression phases. In cold periods, wet oceanic depressions could not penetrate deep into the continent because they were blocked by polar anticyclones coming from the North, while the strengthening of the Siberian-Mongolian High further increased the already high aridity and cooling tendency in central Asia.

The palaeoenvironmental conditions and stratigraphical structure for the last interglacial in central Asia were very similar to those in Northern China, where three soil-forming intervals, subdivided by two phases of dust deposition, are indicated for the last interglacial soil (S1) in the Luochuan and Lanzhou loess/palaeosol sequence (Kemp et al., 1995; Xiao et al., 1995). The Chinese loess/palaeosol sequence for the last interglacial illustrates the palaeoclimatic effect of enhanced summer monsoon circulation during soil-forming substages and winter monsoon strength for dust sedimentation increase. Moreover, the geological events after the last interglacial in eastern China are similar to those found in the northern Black Sea shore area. A sharp deterioration of the palaeoclimate and a sea-level fall initiated deflation and loess sedimentation on the Bohai Sea shelf (Huang, 1984; Li & Zhou, 1993), which is comparable with the palaeoenvironmental conditions of the Black Sea shelf during the Würm.

The Eemian transgression with its high sea level and warm climatic episodes, is assumed to have occurred during MIS 5e (Zagwijn, 1983, 1989). The main climatic succession and the character of the Eemian transgression have been supported by recent studies (Cleveringa et al., 2000; Bosch et al., 2000 – both this issue). The fall of the sea level during the late Eemian is presumably a result of eustatic oscillations. In comparison to the 'classical Eemian', the marine Karangatian transgression covered a longer time interval within the last interglacial, as evidenced by geochronological and biostratigraphical data. It is proposed that this transgression in the Black Sea lasted throughout MIS 5. In this respect, only the early Karangatin phase could correspond to the Eemian transgression. In spite of a lack of the middle and late Karangatian analogous in the Eemian, the former probably corresponds to the late Tyrrhenean in the Mediterranean Sea from a biostratigraphical and geochronological point of view.

Conclusions

It has been shown that, in the studied areas of the northern Black Sea shore and central Asia, the last interglacial can be subdivided into two or three stratigraphical units. Such a stratigraphical structure is expressed in both the marine and the terrestrial successions. In the last interglacial pedocomplex, the lower soil was usually formed under conditions of a climatic optimum. The three sedimentary cycles recognized in the Eltigen section can be interpreted as evidence of sea-level oscillations probably correlatable with 'warm' substages within MIS 5. All the transgressive substages in the Karangatian Basin have arisen from eustatic oscillations of the Mediterranean Sea level. The new U/Th dates for the Karangatian deposits, and the luminescence dates for the first pedocomplex (PC1) in central Asia serve as good geochronological controls for their correlation with MIS 5.

The anomalous magnetic directions measured in the lower part of the Karangatian sequence (Eltigen) may be considered to represent the Blake Event, when the biostratigraphical and geochronological data are taken into account.

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