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Position of the Pontian of the Eastern Paratethys in the Magnetochronological Scale

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Abstract—A comprehensive analysis of paleomagnetic records, nannofossils, mammal fauna, and fission-track dating results was conducted for the Upper Miocene sediments of the Eastern Paratethys. The age of Pontian boundaries in the Eastern Paratethys (Euxinian basin) is determined. The stage base is at 7.5 Ma, the top at 6.7–6.6 Ma, and the lower-upper Pontian boundary at 7–7.1 Ma. In the magnetochronological scale, the Pontian corresponds to the uppermost Chron 7 (C4n) coupled with a greater portion of Chron 6 (C3Br–C3Ar). The lower Pontian is correlated with the upper part of the Tortonian and with an upper part of Zone MN12. The upper boundary of the lower Pontian coincides with the Tortonian-Messinian boundary. The upper Pontian corresponds to the lower third of the Messinian and to the lower part of Zone MN13. The Euxinian upper Pontian is correlated in the Caspian basin with the lower part of the Shemakhan regional substage of the middle Pontian in Azerbaijan. The Zone NN11 corresponds to the upper Maeotian, whole Pontian, and the lowermost Azov Beds of the Kimmerian.

Key words: stratigraphy, correlation, Miocene, Pontian, Eastern Paratethys, Mediterranean, magnetochronology, nannoplankton.

INTRODUCTION

There is no agreement among the geologists who studied during several decades the Pontian of the Eastern Paratethys, regarding its duration, boundary ages, and correlation with the units of the Mediterranean zonation, as exemplified even by the latest works (Steininger, 1999; Zubakov, 2000; Popov and Nevesskaya, 2000; Chumakov, 2000; Snell *et al.*, 2000, 2001; Popov *et al.*, 2001; and others) (Fig. 1).

In this paper, we consider once again the Pontian position in the magnetochronological scale and its correlation with the Mediterranean stages. Over 20 years have passed since our publication (Semenenko and Pevzner, 1979) devoted to this problem. The formerly unknown data became available during this time. New nannofossils were found in the Maeotian, Pontian, and Kimmerian sediments (Bogdanovich and Ivanova, 1997; Lyul'eva, 1989; Semenenko *et al.*, 1999). Results of fission-track dating were obtained for the Pontian and Maeotian deposits in the Black Sea (Euxinian) and Caspian basins (Chumakov *et al.*, 1992). New localities of mammal remains in the Sarmatian, Maeotian, and Pontian deposits were discovered and the formerly known sites were revised. A series of nannofossil datums was verified. Finally, ages of boundaries between magnetochronological units are now considered to be older (Cande and Kent, 1995). The last inference substantially changes former ages of boundaries of stratigraphic units under discussion and, in particular, the Pontian-Kimmerian boundary age in the Zheleznyi Rog Cape section. Nevertheless, the previous conclusion that the Black Sea Pontian is of a "short" time span and correlative with the uppermost Chron 7 and greatest interval of Chron 6, remains unchanged despite the all new data.

Let us remind that the former inference was based on the magneto- and biostratigraphic records in the Zheleznyi Rog and the Chegerchin Trough sections recovered by three boreholes at the site located eight kilometers southeast of the Kazantip Cape, near the Azovskoe Village, Kerchenskii Peninsula (Pevzner and Chikovani, 1978; Semenenko and Pevzner, 1979; *Stratigrafiya SSSR*, 1986, p. 138). Nannofossils found in samples, which have been collected by Pevzner for the paleomagnetic analysis from borehole sections of the Chegerchin trough (Semenenko and Lyul'eva, 1978) and Zheleznyi Rog Cape (Semenenko and Lyul'eva, 1982), were of great importance for interpretation of magnetostratigraphic data. When determining at that time the Pontian position in the magnetochronological scale, we assumed that this stage is represented in its full range in the Zheleznyi Rog Cape section. Since the Pontian sediments in this section show mainly a reversed polarity, they can correspond only to a single paleomagnetic chron (or to a part of it). This implies that the Pontian time span cannot be long. For-

† Deceased.

merly, some authors estimated the Pontian range to be from 3 to 4 m.y. long and dated the base and top of the stage at 9.5–8 and 6–5.5 Ma, respectively. Within this time span, the Pontian sediments with reversed polarity could be correlated with Chron 6 or with the lowermost Gilbert Chron, if one would interpret the paleomagnetic records only.

It should be noted that many researchers correlate the Pontian with the lowermost Gilbert Chron and the Maeotian with Chron 5 and 6 (Trubikhin, 1984; Trubikhin *et al.*, 1984; Svetlitskaya, 1995; Chepalyga and Svetlitskaya, 1995; Snell *et al.*, 2000, 2001; Popov and Nevesskaya, 2000; Popov, 2001; Popov *et al.*, 2001; and others). This interpretation means a significant rejuvenation of the Maeotian and Sarmatian stages and contradicts the radiologic dates obtained by the K/Ar and fission-track methods.

Before discussing the new records, we should emphasize that the Pontian of the Eastern Paratethys is considered in this work as the Pontian of the Black Sea basin. The Pontian regional stage of the Eastern Paratethys is divided in two substages: the lower Novorossian Substage with the Evpatoriya and Odessa beds, and the upper substage with the Portaferian and Bosphorian beds (*Stratigrafiya SSSR*, 1986). After the early Pontian time, an integral former basin was separated into the Black Sea and Caspian isolated basins.

In the Caspian basin, the second half of the Pontian is of a different range and evolution history. In this area, the Pontian is divided into three units: the lower Novorossian, middle Shemakhan, and upper Babadzhan regional substages (*Geologiya SSSR*, 1972). Fauna of the lower substage corresponds to that of the lower Pontian in the Euxinian basin. The middle substage and the upper Pontian of the Euxinian basin bear the molluscan forms in common, while the upper substage is characterized by a very peculiar fauna and can be correlated with the lowermost Kimmerian of the Black Sea region (Andrusov, 1917).

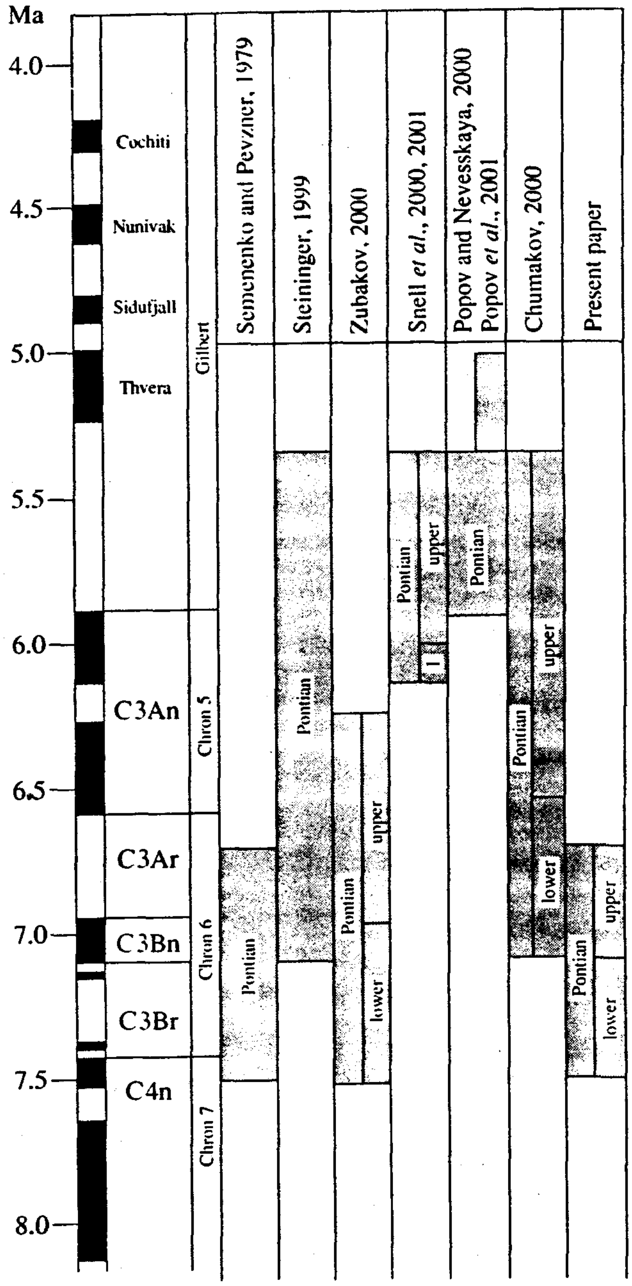

Fig. 1. Magnetochronological scale of the Eastern Paratethys and time spans of the Pontian according to various authors.

MAGNETOCHRONOLOGICAL SCALE CK95

The magnetochronological scale CK95 (Cande and Kent, 1995) used to determine ages of the unit boundaries is calibrated now based on the astrochronological records for the last 7 Ma instead of previously accepted K/Ar dates, and the Cretaceous-Paleogene boundary is dated therewith at 65 Ma instead of 66 Ma. Accordingly, boundaries between paleomagnetic units became older in the upper part of the scale and rejuvenated in the lower part, as compared to the previous magnetochronological scales.

For the last 13 million years, ages of boundaries between paleomagnetic units in the magnetochronological scale CK95 are older than the analogous boundaries in the previous scales. For the last nine million years, they are older approximately by 10%. Ages of plankton datums and stratigraphic boundaries are now determined according to the CK95 scale. To correlate sediments dated by K/Ar (or by fission-track dates calibrated against the K/Ar ages) with that scale, it is necessary to increase their ages by 10%. Without due regard for this fact, the results of correlation would be invalid.

Let us consider, as an example, the data on correlation between lower boundaries of the Pontian in the Eastern Paratethys and of the Messinian in the Mediterranean region (Steininger, 1999; Chumakov, 2000). The Messinian lower boundary (7.1 Ma) is correlative

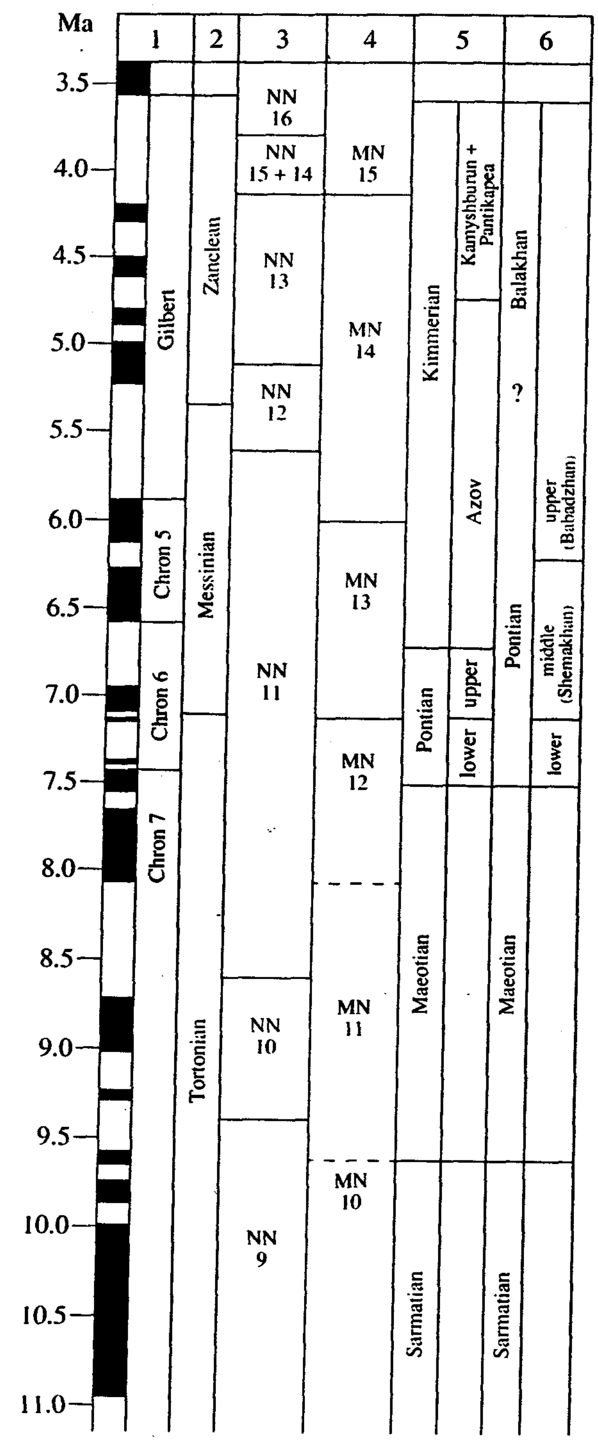

Fig. 2. Correlation of regional stages of the Eastern Paratethys with the magnetochronological scale, Mediterranean stages, nannofossil and mammal zones: (1) magnetochronological scale (CK95); (2) Mediterranean stages; (3) nannofossil zones; (4) mammal zones; (5, 6) regional stages and substages of the (5) Euxinian and (6) Caspian basins.

with the Pontian base dated by fission-track method at 7 Ma (Chumakov *et al.*, 1992). However, such a correlation is incompatible with the paleomagnetic records. In the magnetochronological scale, the base of the Messinian is placed in the middle of Chron 6, and the uppermost Tortonian sediments show a reversed polarity (Fig. 2). In the Eastern Paratethys, a thick zone of the upper Maeotian sediments with normal polarity is situated just below the Pontian deposits (Fig. 3). Regarding the Pontian base as correlative with the Messinian lower boundary, we come to an ambiguous conclusion that the upper part of the Tortonian referred to the lower half of Chron 6 is correlative with the normally magnetized sediments of the upper Maeotian. Increasing fission-track dates for the Pontian rocks by 10%, we avoid this contradiction. For instance, the fission-track date of 6.4 Ma obtained for the lower Pontian top (Chumakov *et al.*, 1992) will be equal to 7 Ma, if increased by 10%, and thus almost identical to the age of the Messinian base. The fission-track date 7 Ma estimated for the Pontian base will be as high as 7.7 Ma after the 10% increase. In this case, we also eliminate the contradiction between radiologic and paleomagnetic data, because the lower Pontian will correspond now to the lower half of Chron 6 and to the uppermost Chron 7.

FISSION-TRACK AGES OF SEDIMENTS IN THE EASTERN PARATETHYS

It should be noted that the fission-track dates obtained for the lower Pontian sediments and for the base of the Shemakhan substage (Chumakov *et al.*, 1992) confirmed not only the correctness of correlation of the Pontian with Chron 6, but also the ages of the lower Pontian boundaries established based on paleomagnetic data (Semenenko and Pevzner, 1979).

All the fission-track dates published by Chumakov were obtained using the decay constant of the ^{238}U—$\lambda_f = 7.03 \times 10^{-17}$ yrs^{-1}. As noted by Kashkarov *et al.* (1987, p. 20), "Special dating of volcanic tuff with the known K/Ar age (tuff sample from the Fish Canyon, Colorado) in many laboratories of the world indicates that the most compatible results can be obtained using the decay constant $\lambda_f = (7.03 + 0.11) \times 10^{-17}$ yrs^{-1} (Roberts *et al.*, 1968). This value was subsequently recommended for a fission-track dating (Naeser *et al.*, 1981)..."

To avoid a revision of their standpoint, proponents of a higher Pontian position in the magnetochronological scale recalculated the fission-track dates from works by Chumakov using the decay constant $\lambda_f = (8.24) \times 10^{-17}$ yrs^{-1} (Golovina *et al.*, 1989). Their results significantly rejuvenate ages of stratigraphic boundaries in the Eastern Paratethys. For instance, the Pontian base age of 7 Ma was recalculated into 5.84 Ma, and the last value was regarded as the evidence in favor of referring the Pontian sediments with reversed polarity to the lowermost Gilbert Chron. It is obvious, however, that such a manipulation with the fission-track dates by using the different decay constant of ^{238}U is incorrect. This manipulation lacks any physical substantiation, and the

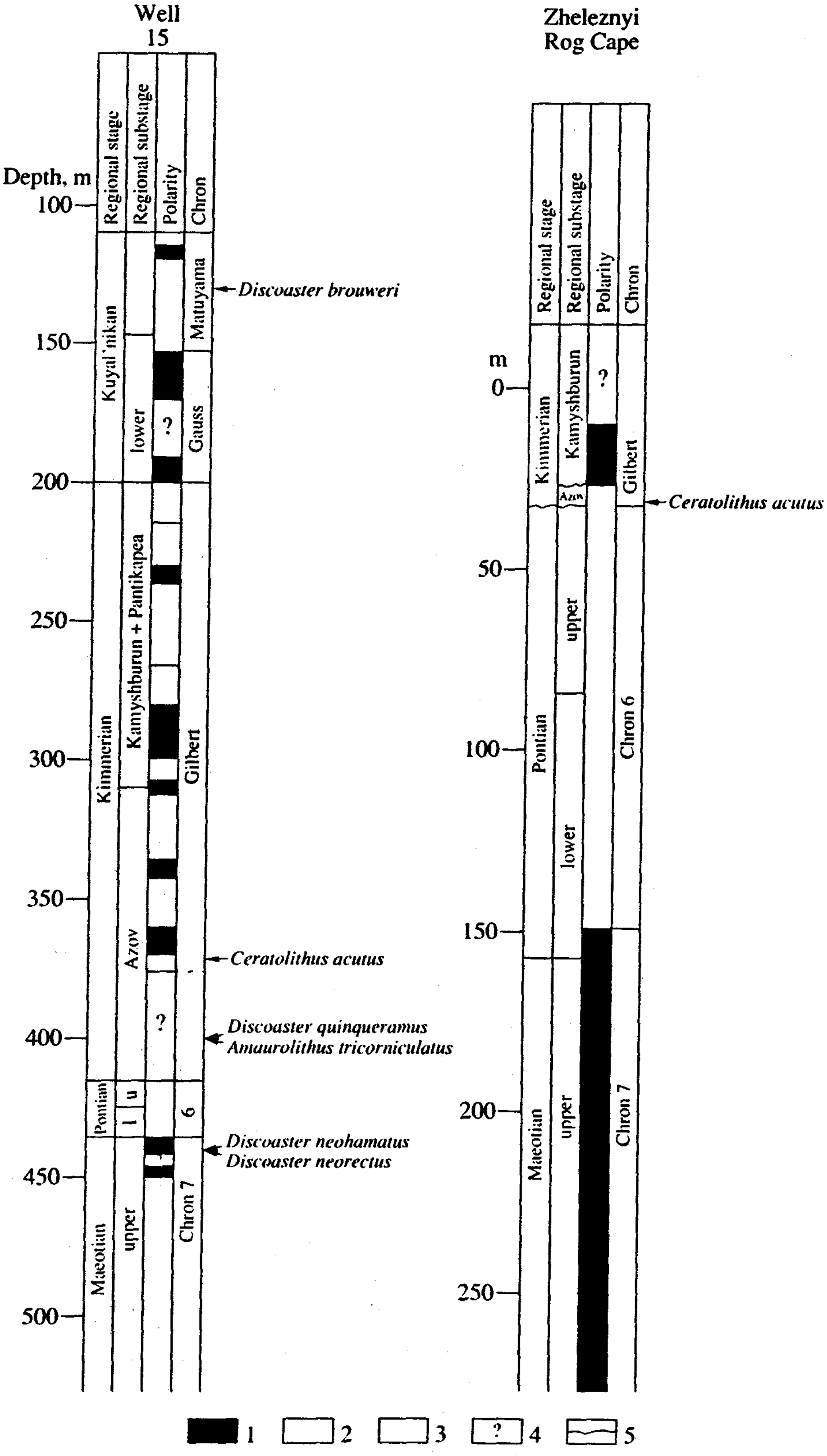

Fig. 3. Paleomagnetic characteristics of Well 15 and Zheleznyi Rog Cape sections and position of nannofossil findings: (1) normal, (2) reversed, and (3) anomalous polarity; (4) break in paleomagnetic records; (5) stratigraphic hiatus.

Age (Ma) of boundaries between stratigraphic units of the Eastern Paratethys

Regional stage	Regional substage	Nanno-fossils	Mam-mals	Fission-track dates	Paleomag-netic records
Kimmerian	upper				3.6
	middle				4.7
	lower	>5.6	>6.57		6.7
Pontian	upper		7.1	7.0	
	lower	>7.4		7.7	7.5
Maeotian		<8.7			
		>9.4		<10.2	9.6
		<10.7			

ages recalculated for Pontian sediments of the Eastern Paratethys cannot be used for stratigraphic purposes.

The dates in question (Chumakov *et al.*, 1992) were obtained for the Pontian beds of volcanic ash in the Azerbaijan sections (Caspian basin). Thus, only the age determinations for the lower boundary of the Novorossian regional Substage and for the base of the Shemakhan substage (= top of the lower Pontian) are applicable to the Pontian of the Euxinian basin. There is a number of consecutive dates for the Shemakhan regional substage. Its top is as old as 5.6 Ma, or 6.2 Ma after the increased by 10%. There was a single age measurement, 5.19 ± 0.89 Ma, obtained for the Babadzhan Substage, and it is inappropriate even for approximate evaluation of the unit age owing to a large analytical error and unclear stratigraphic position of the analyzed sample (Chumakov *et al.*, 1992, p. 51).

Thus, the fission-track ages (Chumakov *et al.*, 1992) increased by 10% lead to the following inferences: the Maeotian base is not older than 10.2 Ma, the Pontian base is as old as 7.7 Ma, and the top of the lower Pontian is 7.0 Ma old with an accuracy of ±8% (table).

NANNOFOSSILS FROM THE MAEOTIAN, PONTIAN, AND KIMMERIAN DEPOSITS OF THE EASTERN PARATETHYS

The Maeotian is subdivided in two regional substages, the lower Bagerovian and the upper Akmanaian (*Stratigrafiya SSSR*, 1986). In the Maeotian sediments of the Crimea, Well 501 on the Akmanaiskii Isthmus of the Kerchenskii Peninsula, the *D. hamatus* Zone NN9 was recognized in the lower part of the Bagerovian Substage that yields *Discoaster hamatus* Mart. et Bram. and *Catinaster calyculus* Mart. et Bram. The upper part of the Bagerovian and the lower of the Akmanaian substages are correlated with the *D. calcaris* Zone NN10 (= *Discoaster neohamatus* CN8 and the *Discoaster bellus* Subzone CN8a; Bogdanovich and Ivanova, 1997). Therefore, the boundary between zones NN9/NN10 is recorded in the lower Maeotian sediments. Its age is 9.4 Ma (Berggren *et al.*, 1995), indicating that the Maeotian base is older than this date. Species *Catinaster calyculus* Mart. et Bram. present in the lowermost Maeotian restricts the stage basal age by the appearance time of that species at 10.7 Ma (refer to the table). In Well 15 near the Kazantip Cape, Kerchenskii Peninsula (Fig. 3), the uppermost Maeotian sediments yield *Discoaster neorectus* Bukry (Semenenko and Lyul'eva, 1978; Semenenko and Pevzner, 1979). Stratigraphic ranges of *Discoaster neorectus* Bukry and *Discoaster loeblichii* Bukry completely coincide (Perch-Nielsen, 1985). The latter appeared at the level of 8.7 Ma and became extinct at 7.4 Ma (Berggren *et al.*, 1995). Thus, *Discoaster neorectus* found in the uppermost Maeotian interval of Well 15 indicates that the Maeotian-Pontian boundary is not younger than 7.4 Ma and no older than 8.7 Ma.

Nannofossils of the lower Pontian sediments are known from several sections of the Eastern Paratethys, but the zonal species are missing there. The index species of the *Discoaster quinqueramus* Gart. Zone NN11 with the LAD at 5.6 Ma (Berggren *et al.*, 1995) was encountered in the lower Azov strata of the Kimmerian, Well 15 in the Chegerchin Trough (Semenenko and Lyul'eva, 1978; Semenenko and Pevzner, 1979). This finding indicates that the Pontian top is older than 5.6 Ma. *Discoaster quinqueramus* present in the Kimmerian deposits excludes a possibility that the Bosphorian beds of the upper Pontian is correlative with the *A. tricorniculatus* Zone NN12, as was suggested by Snell *et al.*, (2000, 2001).

In Well 15, *Ceratolithus acutus* Gartner et Bukry was found in sediments with reversed polarity of the Azov regional substage of the Kimmerian immediately below the normal polarity zone that is correlated with the Thvera Subchron (Semenenko and Pevzner, 1979). Semenenko found this species in the Zheleznyi Rog Cape section also in deposits with the reversed polarity of the Azov Substage (see below). The occurrence of *Ceratolithus acutus* in the apparently lower Kimmerian sediments of the Euxinian basin indicates that their range corresponds to the upper part of the Zone NN12 (= *C. acutus* Zone CN10b).

MAMMAL FAUNA OF THE PONTIAN

Researchers who study the Pontian mammal fauna of the Eastern Paratethys have controversial opinions with respect to correlation between these faunas and MN zones. Gabuniya (1986) assigned the lower Pontian mammals to Zone MN12, Korotkevich (1988) to the upper part of Zone MN13, Krakhmalnaya (1996) and Topachevskii *et al.* (1997, 1998) to Zone MN14.

Mammal remains associated with marine sediments of the upper Pontian are not yet found on the CIS territory. The mammal fauna from the upper Pontian deposits with reversed polarity (above the beds bearing *Congeria rhomboidea* M.Hoern.) is known from the Pannonian Basin, the Hatvan locality of Hungary (Pevzner, 1986), where it is referred to the lower half of Zone MN13 (Mein, 1990).

The lower Pontian sediments of Odessa (station 16 of Bol'shoi Fontan) and Vinogradovka localities yield remains of *Schizogalerix* and *Spermophilinus* (Topachevskii *et al.*, 1997, 1998), which indicate that the localities are not younger than Zone MN13, since the LAD of both genera is within this zone (Mein, 1999). *Prolagus crusafonti* Lopez is present in both localities. In the middle of Zone MN13, this species is replaced by *P. michauxi* Lopez (Lopez Martinez, 1977). Thus, the fauna from these localities cannot be referred to the upper half of Zone MN13 and especially to Zone MN14. *Tetralophodon longirostris* (Kaup) found in the lower Pontian limestones near Odessa indicates, in opinion of Gabuniya (1986), that the lower Pontian mammal fauna is correlative with Zone MN12, as extinction of this genus is recorded in the uppermost part of the latter (de Bruijn *et al.*, 1992). The composition of small mammal fauna from the lower Pontian deposits of Odessa and Vinogradovka sites does not contradict this conclusion. Thus, the lower Pontian mammal fauna is referred to Zone MN12 and that of the upper Pontian to the lower half of Zone MN13 (Fig. 2).

The upper boundary of Zone MN13 is dated at about 6 Ma and corresponds to the uppermost Chron 5 (Pevzner *et al.*, 1996, 2001). The zone lower boundary is ca. 7.1 Ma old and is correlated with the base of the Messinian and with the beginning of the global C-isotope excursion (Bernor *et al.*, 1996; Steininger *et al.*, 1996).

As it follows from data considered above, the Pontian upper boundary is apparently older than 6 Ma. Taking into account that sediments with reversed polarity correspond to Chron 6 at the Hatvan locality, one can suggest that this boundary is older than the upper limit of Chron 6 dated at 6.57 Ma. The lower-upper Pontian boundary is close in age to the base of Zone MN13 that is 7.1 Ma old (table).

INTERPRETATION OF PALEOMAGNETIC RECORDS IN THE ZHELEZNYI ROG CAPE SECTION

The upper Maeotian, Pontian, and Kimmerian sediments are exposed in the Zheleznyi Rog Cape section of the Tamanskii Peninsula. The Maeotian sequence over 200 m thick is represented here by light gray thin-bedded clays in the lower and upper parts of the section, and by dark gray, commonly bituminous clays in the middle part. The deposits are almost barren of molluscan fauna. Only in a single interval, 150 m below the base of the Pontian, Semenenko identified *Abra tellinoides* Sinz., *Congeria panticapaea* Andrus., *Paphia abichi* (R. Hoern.), and *Hydrobia* sp., which confirm the Maeotian age of the studied sequence. The Maeotian-Pontian boundary is rather confidently placed at the contact between the lower 3-m-thick member of light gray, almost white clay and the overlying member of dark gray bituminous clays. Small flattened thin-walled and thin-ribbed cardiid shells were found at the base of the latter, whereas *Paradacna abichi* (R. Hoern.) typical of the Pontian was found 2.5 m above.

The Pontian deposits are represented by a 123-m-thick sequence of light gray to bluish thin-bedded clays intercalated with rare beds of darker, locally bituminous clay. *Dreissena rostriformis* Desh., *D. anisoconcha* Andrus., *Paradacna abichi* (R.Hoern.), *Didacna planicostata* (Desh.), *D. paucicostata* Desh., *D. incerta* Desh., *Plagiodacna carinata* (Desh.), *Valenciennesia* sp., and others (identified by Chikovani) are molluscan species common of the Pontian sediments. *Congeria subrhomboidea* Andrus. that marks the boundary between the lower and upper Pontian, was encountered at the level of 73 m above the Maeotian-Pontian contact. The Pontian deposits are overlain by a 3-m-thick member of dark gray, slightly brownish clays with gypsum, which was previously considered to represent the Pontian-Kimmerian transitional beds (Pevzner and Chikovani, 1978). Above the clays there are a thin (0.2 m) layer of dense, highly ferruginate marl that has been considered by Chumakov (2000) as a fossil soil and a 0.5-m-thick bed of dark gray clay overlain by a 3.5-m-thick limonite layer. Upsection, the overlying Kimmerian sediments are represented by a sequence of dark gray clays sandy in their upper part. The studied part of the sequence is 34-m thick. The lower 9 m of the Pontian deposits show normal polarity, while in the overlying 114-m-thick interval their polarity is reversed (Fig. 3).

Taking the units ages defined in the magnetochronological scale CK95 and increasing by 10% the fission-track date for the top of the lower Pontian, we can calculate now the Pontian time span and ages of its boundaries in the Zheleznyi Rog Cape section. Since the section is composed of uniform facies, we admit a constant sedimentation rate. The boundary between Pontian deposits with normal and reversed polarities is correlated with the basal limit of Chron 6 (C3Br) that is 7.43 Ma old according to the CK95 scale. The fission-track date of 7.0 Ma is selected for the upper boundary of the lower Pontian (for base of the *Congeria subrhomboidea* Beds). Hence, the lower Pontian deposits with reversed polarity, which are 64 m thick, accumulated during 0.39 m.y. If the sedimentation rate was constant, we may calculate that the 9-m-thick interval, the lower Pontian deposits have normal polarity, accumulated during 0.06 m.y., and the upper Pontian sediments, which are 50 m thick and show reversed polarity, were deposited during 0.30 m.y. The calculations suggest also that the Pontian base and top are 7.49 and

6.74 Ma old, respectively, in the Zheleznyi Rog Cape section. Thus, in this section, the Pontian base corresponds in age to 7.5 Ma, the upper Pontian base to 7.0–7.1 Ma, and the Pontian top is ca. 6.7 Ma old. According to mammalian fauna, the latter is estimated to be older than 6.57 Ma. It should be noted, however, that the fission-track date, being increased by 10%, implies a slightly older age of 7.7 Ma for the Pontian lower boundary. Accordingly, the Pontian time span in the Eastern Paratethys is 0.8 to 1.0 m.y. long.

Zubakov (1990) suggested that in the Zheleznyi Rog Cape section there is a hiatus in the range of Chron 5 (C3An) at the level of the *subrhomboidea* Beds. It is possible to calculate for such a case that 64 m of the lower Pontian sediments with reversed polarity accumulated during 0.86 m.y. (= duration of Chron 6), while 50 m of the upper Pontian deposits with reversed polarity were deposited (according to sedimentation rate) during 0.67 m.y. According to these calculations, the Pontian upper boundary should be 5.22 Ma old and would be falling into the lowermost Thvera Subchron. The last inference contradicts not only the paleomagnetic records, as the uppermost Pontian strata have reversed polarity, but also the data on the Kimmerian sediments between the Thvera Subchron and the Pontian top, which are 45 m thick in Well 15, and the nannofossil and mammal evidence.

After an early publication (Semenenko and Pevzner, 1979), Semenenko comprehensively studied the Zheleznyi Rog Cape section to search for nannofossils and to verify boundaries of the Kimmerian regional substages. In the lower part of the 3-m-thick member of brownish clays previously referred to the Pontian-Kimmerian transitional beds, there were found shells of *Paradacna abichi* (R. Hoern.). The overlying bed of dense ferruginate marl yielded the early Kimmerian *Paradacna deformis* Ebers. and *Dreissensia iniquivalvis* (Desh.). According to Zhabrev and Buryak (1958), clays sandwiched between the ferruginate marl and a higher limonite layer bear remains of *P. deformis* Ebers. and *Pteradacna edentula* (Desh.). Therefore, the Pontian-Kimmerian boundary is within this "transitional" member. Molluscan shells typical of the Kamyshburun beds were found in the 3.5-m-thick limonite layer. One meter below the ferruginate marl, there was encountered *Ceratolithus acutus* Gartner et Bukry (Lyul'eva, 1989). As noted above, this species was found in the Azov regional substage of Well 15 at the level of 45 m above the substage base and immediately below the Thvera Subchron. Consequently, deposits of the Azov Substage are represented in the Zheleznyi Rog Cape section by their middle part, have small thickness about two meters, and the Pontian and Kimmerian are separated here by a hiatus. The Kimmerian clays of normal polarity, which overlie the limonite bed, can be correlated with the Nunivak or Cochiti subchrons of the Gilbert Chron, because the top of the Azov Substage in Well 15 is recorded between the Sidufjall and Nunivak subchrons. Accordingly, there is a stratigraphic hiatus between the Azov and Kamyshburun beds of the Zheleznyi Rog Cape section (Fig. 3).

AGE OF THE MAEOTIAN-PONTIAN BOUNDARY IN THE EASTERN PARATETHYS

As is evident from data presented above, age estimates obtained by different methods for the Maeotian-Pontian boundary are well consistent between each other (table). According to nannofossils, the Maeotian lower boundary is older than 9.4 Ma and younger than 10.7 Ma, while the fission-track method showed that it is younger than 10.2 Ma. Paleomagnetic records imply age of 9.6 Ma for this boundary, since it is placed at the beginning of Chron C4Ar.2n (Pevzner and Vangengeim, 1993). It is the last date that we regard as the correct age estimate for the Maeotian base.

According to nannofossils, the Maeotian-Pontian boundary is older than 7.4 Ma and younger than 8.7 Ma, whereas its age is defined at 7.7 Ma by fission-track method and at 7.5 Ma by paleomagnetic data. When evaluating this boundary age, we prefer that of the paleomagnetic scale, because the fission-track date is obtained with a significant error. Mammalian fauna suggests that the lower-upper Pontian boundary age is close to 7.1 Ma, and fission-track method determines it at 7.0 Ma. From the standpoint of age determination accuracy, these dates are coincident. Unfortunately, the available data are inadequate for dating of the Pontian upper boundary and only restrict the upper limit of the stage. The limitation level is older than 5.6 Ma in terms of nannofossil chronology and older than 6 Ma according to mammal fauna. If the mammal fauna age is calibrated with reference to the paleomagnetic records at the Hatvan locality, the stage upper limit is older than 6.57 Ma, whereas interpretation of paleomagnetic characteristics of the Zheleznyi Rog Cape section suggests its position at 6.7 Ma. Since the lowermost part of the Azov regional substage is missing in the Zheleznyi Rog Cape section, it is likely that the uppermost Pontian deposits are also eroded there. Thus, the Pontian upper boundary is estimated to be 6.6–6.7 Ma old.

The estimated dates and age (6.2 Ma) of the upper boundary of the Shemakhan regional substage, the middle one in the Pontian of the Caspian basin, allow us to conclude that not only the upper Babadzhan, but also an upper half of the Shemakhan Substage of the Caspian basin corresponds to a part of the Kimmerian (Fig. 2).

The concrete inferences from the aforesaid are as follows. (1) The Pontian of the Eastern Paratethys has a "short" time span. (2) The stage corresponds to the uppermost Chron 7 coupled with a greater interval of Chron 6 of the magnetochronological scale. (3) It is impossible to correlate the Pontian with the lower part of the Gilbert Chron and upper part of Chron 5.

CORRELATION OF THE PONTIAN OF THE EASTERN PARATETHYS WITH THE MEDITERRANEAN STRATIGRAPHIC SCALE

Figure 2 shows correlation of mammal zones and regional stages of the Black Sea and Caspian basins, as we understood it based on materials discussed above, with the Mediterranean stages and nannofossil zones calibrated versus the magnetochronological scale after Berggren *et al.* (1995).

First, we should point to a close position of the Messinian base and the lower Pontian top near the time mark of 7–7.1 Ma. This level also corresponds to the beginning of the global C-isotope excursion. In the Ain El Beida section, Morocco, the latter event is recorded within the Chron 3Bn (Benson and Rakic-El Bied, 1996). It should be noted also that there was a sea-level drop by 150-200 m in the Late Miocene, between the base of Chron 3Bn and mid-Chron 3r (Harland *et al.*, 1985). The time span of this event almost coincides with the range of the Messinian. In the scale CK95, its lower and upper limits correspond in age to 7.1 and ca. 5.5 Ma, respectively. The lower one coincides with the Messinian base and the lower Pontian top in the Eastern Paratethys. It is reasonable to suggest therefore that isolated Black Sea and Caspian basins appeared instead of a single Pontian basin in response to that global sea-level drop, which also triggered the runoff of Pontian waters in the Mediterranean region. The last event is a good explanation for appearance of the Caspian-type mollusks and ostracodes in the Messinian sediments.

Rather widespread brackish-water sediments bearing the Caspian-type fauna are well known in the Mediterranean areas under names Lago-Mare, Colombacci Formation, *Congeria*, *Melanopsis*, and *Loxoconcha djaffarovi* beds. Many researchers (Popov and Nevesskaya, 2000, and references therein) who studied the mollusks and ostracodes from these deposits correlate the latter, partially or completely, with the Pontian of the Eastern Paratethys.

Even if the Lago-Mare sediments correspond indeed to a part of the Pontian in the Eastern Paratethys, it would be incorrect to evaluate the Pontian position in the magnetochronological scale based on the age of Lago-Mare subdivision, as it has been done in some works (Popov and Nevesskaya, 2000; Popov *et al.*, 2001). In our opinion, it is more correct to define the age of Lago-Mare sediments from the Pontian position in the magnetochronological scale, since the available age determinations for these sediments are not convincing. Those few dates (Krijgsman *et al.*, 1999), which we found, indicate an older age of Lago-Mare strata (5.50–5.33 Ma) than it used to be accepted.

For instance, the autochthonous brackish-water ostracodes of the Caspian-type were encountered in the Cuevas de Almanzora section of the Vera basin, Spain, in the Messinian deposits of the *D. quinqueramus* Zone NN11 (Barragan *et al.*, 1990; Benson and Rakic-El Bied, 1996). Their host deposits underlie sediments bearing an early evolutionary form *Globorotalia margaritae* Bolli et Bermudez whose FAD is recorded in the middle of Chron C3An2n at the level of about 6.35 Ma (Benson and Rakic-El Bied, 1996). Consequently, the deposits with brackish-water ostracodes are even older.

In DSDP Hole 372 drilled on the Menorca Rise, the Messinian sediments, which span the interval of Zone NN11 or of the upper *G. plesiotumida* Zone N17 (cores 4-9), unconformably overlie the Serravalian deposits and are overlain with a hiatus by the Pliocene sediments of the *Globorotalia puncticulata* Zone MPL3. *Cyprideis pannonica* (Mehes) characteristic of the Lago-Mare sediments was found here in the Core 4-2, 90–92 cm (*Initial Reports...*, 1978). If the Lago-Mare strata are within zones NN11 and N17, then they are older than 5.6 Ma (LAD of *Discoaster quinqueramus* Gartner) or than 6.35 Ma (FAD of *Globorotalia margaritae* Bolli et Bermudez).

The third section important for the age determination of the Lago-Mare sediments is located in northern Apennines. In the Monticino gypsum quarry, Brisighella, Ravenna, the 2.3-m-thick Colombacci Formation composed of sediments with reversed polarity overlies, with a stratigraphic and angular unconformity, the gypsum beds of the Gessoso-Solfifera Formation (Marabini and Vai, 1988; Vigliotti, 1988). These sediments fill in cracks in the underlying gypsum and yield the mammal fauna of Zone MN13 (Rook, 1992). Since the upper boundary of Zone MN13 is 6 Ma old, the bone beds of the Colombacci Formation are older than this date.

The dates cited above do not contradict the commonly accepted correlation of the Lago-Mare sediments and their Mediterranean analogs with the Pontian of the Eastern Paratethys. These sediment correspond only to the upper Pontian or to a part of the latter, and are not younger than 6.6–6.7 Ma (top of the Pontian in the Eastern Paratethys). When the Lago-Mare sediments are overlain by deposits of the Zanclean transgression, we should admit a stratigraphic hiatus between them that is over one million year long.

CONCLUSIONS

The discussed materials lead to the following conclusions.

(1) The Pontian of the Eastern Paratethys corresponds to the uppermost Chron 7 coupled with a greater portion of Chron 6 and ranges in age from 7.5 to 6.7–6.6 Ma.

(2) The lower Pontian is correlative with the upper part of the Tortonian, where sediments show reversed polarity.

(3) The beginning of the late Pontian coincides with the beginning of the Messinian, and the late Pontian

corresponds to the first third of the Messinian, if the latter ranges in age from 7.1 to 5.33 Ma.

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