ISSN 0869-5938, Stratigraphy and Geological Correlation, 2006, Vol. 14, No. 6, pp. 655–667. © MAIK "Nauka/Interperiodica" (Russia), 2006.
Original Russian Text © E.A. Vangengeim, A.N. Lungu, A.S. Tesakov, 2006, published in Stratigrafiya. Geologicheskaya Korrelyatsiya, 2006, Vol. 14, No. 6, pp. 81–93.

Age of the Vallesian Lower Boundary (Continental Miocene of Europe)

E. A. Vangengeim[a], A. N. Lungu[b], and A. S. Tesakov[a]

[a] *Geological Institute, Russian Academy of Sciences, Moscow, Russia*
[b] *Tiraspol State Pedagogical University, Chisinau, Moldova*

Received April 17, 2006

Abstract—The Vallesian lower boundary and "*Hipparion*-datum" are estimated as ranging in age from 11.2 to 10.7 Ma in Central to Western Europe and Western Asia. Judging from complete sections of Sarmatian marine sediments in the Tamanskii Peninsula and Transcaucasia with known paleomagnetic characteristics, the above dates correspond to the lower upper Sarmatian (Khersonian) of the Eastern Paratethys, although in Moldova and Ukraine the earliest hipparion remains are associated with the middle Sarmatian (Bessarabian) sediments. The normally magnetized middle Sarmatian deposits in hipparion localities of Moldova are correlative with an upper part of Chron C5An (upper boundary 11.9 Ma old) or, less likely, with Subchron C5r2n (base 11.5 Ma old). Consequently, the first occurrence of hipparions in southeastern Europe is recorded in the Middle Miocene, i.e., 0.7 m.y. (or 0.3 m.y.) earlier than the date of 11.2 Ma formerly accepted for the Vallesian lower boundary in Europe. Possible reasons for disagreements in age determination of the Vallesian base are discussed.

DOI: 10.1134/S0869593806060050

Key words: Vallesian, Sarmatian, magnetostratigraphy, hipparions, Eastern Paratethys, Europe, Western Asia.

INTRODUCTION

In the West European continental scale, two the Vallesian and Turolian "stages" or European Land Mammal Ages (ELMA) are discriminated in the Upper Miocene. The Vallesian base is determined in the Old World by the first occurrence of a three-toed horse *Hipparion* (or *Hippotherium* in current nomenclature) that migrated from North America. Appearance of this form in Eurasia and North Africa is considered as a great event in history of land mammals, so important that 30 years ago it marked the Miocene-Pliocene boundary in some stratigraphic schemes (for instance, Sickenberg et al., 1975). Numerous papers are dedicated to age determination of the hipparion first occurrence in the Old World, of the so-called *Hipparion*-datum, and of the Vallesian lower boundary, respectively. In most of current stratigraphic schemes, the Vallesian base coincides with the lower boundary of the Upper Miocene (Steininger et al., 1996; Sen, 1996; Fejfar et al., 1998; Steininger, 1999). According to Berggren and coworkers (Berggren et al., 1995; Steininger et al., 1996), the Upper Miocene base is dated at ~11.2 Ma, thus being in the upper portion of Subchron C5r2r. In the Geologic Time Scale (Gradstein et al., 2004), the astrochronological age of 11.608 Ma is adopted for this boundary and it is correlated with Subchron C5r2n (according to Berggren et al., 1995, the subchron is dated within 11.476–11.531 Ma), though the boundary stratotype in Monte dei Corvi, Italy is lacking reliable paleomagnetic data on this part of the section.

At present, there is no agreement among researchers as to dating the *Hipparion*-datum, and even there is no consensus on the issue within the same regions (Woodburne et al., 1996; Sen, 1997; Agusti et al., 2001; Koufos, 2003).

The aim of this paper is to report available materials on the appearance time of hipparions in the Eastern Paratethys, which have not been considered by foreign authors as a rule. In Moldova, southern Ukraine, and Georgia, numerous localities of hipparion fauna are associated with middle and upper Sarmatian marine sediments with known paleomagnetic characteristics. Most of these sections are not thick and paleomagnetic records are often fragmentary. However they can be quite reliably correlated with the magnetochronological scale as there are several thick continuous magnetostratigraphic sections of the marine Sarmatian.

CURRENT KNOWLEDGE OF THE *HIPPARION*-DATUM

The appearance time of hipparions is commonly estimated using mammal localities with magnetostratigraphic characteristics. Radiometric ages are known for a very few of them.

The most archaic among known European hipparions was found in the Gaiselberg locality, Austria, in the

Viennese basin of the Central Paratethys. The enclosing sediments are referred to the Zone C of the Pannonian. The lower boundary of the Pannonian is dated at about 11.5 Ma. According to Rögl and Daxner-Höck (1996), hipparions appeared during the Sarmatian (s. str.) in the Eastern Paratethys and later, during the Pannonian, in the Central Paratethys. It is possible though that "…this apparent asynchroneity was based on the misinterpretation of the Sarmatian's chronological limits" (Rögl and Daxner-Höck, 1996, p. 48). Age of the Gaiselberg hipparion is estimated to be 11.2 Ma (Steininger et al., 1996). In the Hovorany locality, the northern Viennese basin, hipparion remains are also known from sediments of the older Zone B of the Pannonian (Woodburn et al., 1996).

In the Siwalik locality of the Potwar Plateau, Pakistan, hipparion remains occur in the normal-polarity interval correlated with the lower part of Chron C5n dated at about 10.7 Ma (Pilbeam et al., 1996).

In the Sinap Tepe locality, central Turkey, first hipparion was found in the lower portion of normally magnetized deposits of the Sinap Formation. Based on paleomagnetic data and estimated sedimentation rate, Kappelman et al. (1996) determined age of the finding at 10.46 or 10.64 Ma. Comparing their data with those of Pilbeam et al. (1996), the mentioned authors inferred that hipparion appeared in the Old World between the base of the middle interval and the middle of Chron C5n. The *Hipparion*-datum of 10.7 Ma was accepted later (Lunkka et al., 1999; Kappelman et al., 2003).

In western Anatolia, the K–Ar age of 11.6 ± 0.25 Ma was obtained for the latest pre-Vallesian Yailacilar locality. The date was obtained for sediments immediately underlying the bone bed. In the Yeni Eskihisar 2 locality, southwestern Turkey, sediments overlying bone beds are dated at 11.1 ± 0.2 Ma. Judging from evolutionary level of the fauna, it is younger than the latest Astaracian La Grive L3 locality in France. Hipparion remains have not been encountered in this locality, where machairodus was found however (Sickenberg et al., 1975; Becker-Platen et al., 1977). As is inferred, hipparion is missing here because of taphonomic or ecological reasons (Agusti et al., 1997).

Agusti et al. (2001) defined the *Hipparion*-datum at 11.1 Ma in Spain and placed it at the base of Chron C5r1r based on paleomagnetic characteristics of the Montagut composite section in the Vallés-Penedés basin (Can Guitart locality—CCN-20 and 22, Fig. 1, **I**). In this locality, beds bearing the Astaracian fauna are missing. Sen (1997) who studied the Torremormojon section in the Duero basin correlated the first occurrence of hipparion (locality TM4) with the lower portion of thick normal-polarity interval that he referred to Chron C5n. He dated the first appearance datum (FAD) of *Hipparion* at 10.8 Ma. Krijgsman et al. (1996) placed the Vallesian lower boundary in the same section within Subchron C5r1n at the level of 11.1 Ma. Their inference is based on the typical Vallesian fauna of rodents found below the level with hipparion remains.

It is believed that in the 120-m-thick Nombrevilla section, Zaragoza, Spain, there is recorded transition from the Astaracian (the Aragonian in Spain) to Vallesian (Garcés et al., 2003). The section is composed of alternating alluvial and lacustrine deposits. Describing the section, Alvarez Sierra et al. (2003) reported on numerous levels of subaerial exposition indicating breaks of sedimentation.

In lower alluvial red argillites of the section, there are three bone beds (localities NOM 2, 3, and 4) with the typical Astaracian (Aragonian) fauna of the Zone G after Daams and Freudenthal (Fig. 1, **II**). Sediments enclosing bones belong to the reversed-polarity zone. The overlying sequence corresponds to carbonate lacustrine deposits with basal conglomerates. The 7-m-thick zone of normal polarity N2 is established in the lowermost part of the sequence. The bone bed NOM9 with diverse fauna of small mammals typical of the early Vallesian (Zone H *Hispanomys-Megacricetodon ibericus*) is detected 35 m above in the magnetic polarity zone R3 that is about 25 m thick. In the middle of the section, 15 m higher, hipparion remains have been found (NOM1). They occur in the lower third of a thick zone of normal polarity N3.

The zone N3 is correlated with Chron C5n. The section lower part that is predominantly of reversed polarity corresponds to a part of Chron C5r. It is difficult to correlate the normal-polarity zones in this section interval because their number in Chron C5r is presently not exactly determined. The cited authors suggest two variants of correlation with the CK95 scale: either (1) zone N2 is correlative with Subchron C5r2n and the pre-Vallesian locality NOM2 is about 11.6 Ma old, or (2) this zone corresponds to the new Subchron C5r1r-n and NOM2 is 11.3 Ma old. In any case, the base of the Zone H is older than the Astaracian–Vallesian boundary as it is adopted by the Spanish researchers. The first occurrence hipparion in the section is dated at 10.7–10.8 Ma (Garcés et al., 2003).

According to degree of evolutionary development, hipparion from the Nombrevilla locality is intermediate between forms from the Eppelsheim (type species *H. primigenium*, more advanced than *H. primigenium* from the Gaiselberg) and Höwenegg localities. Age of the latter is estimated to be about 10.3 Ma (Woodburne et al., 1996; Bernor et al., 1996).

In the Saint Fons locality of southern France, Rhone basin, the early Vallesian hipparion fauna was encountered in the Serravallian marine sediments, i.e., in the uppermost Middle Miocene (Mein, 1999). Hipparion remains found in deposits older than the Tortonian was reported from the Vaison-La-Romaine basin of southeastern France (Guerin et al., 1972).

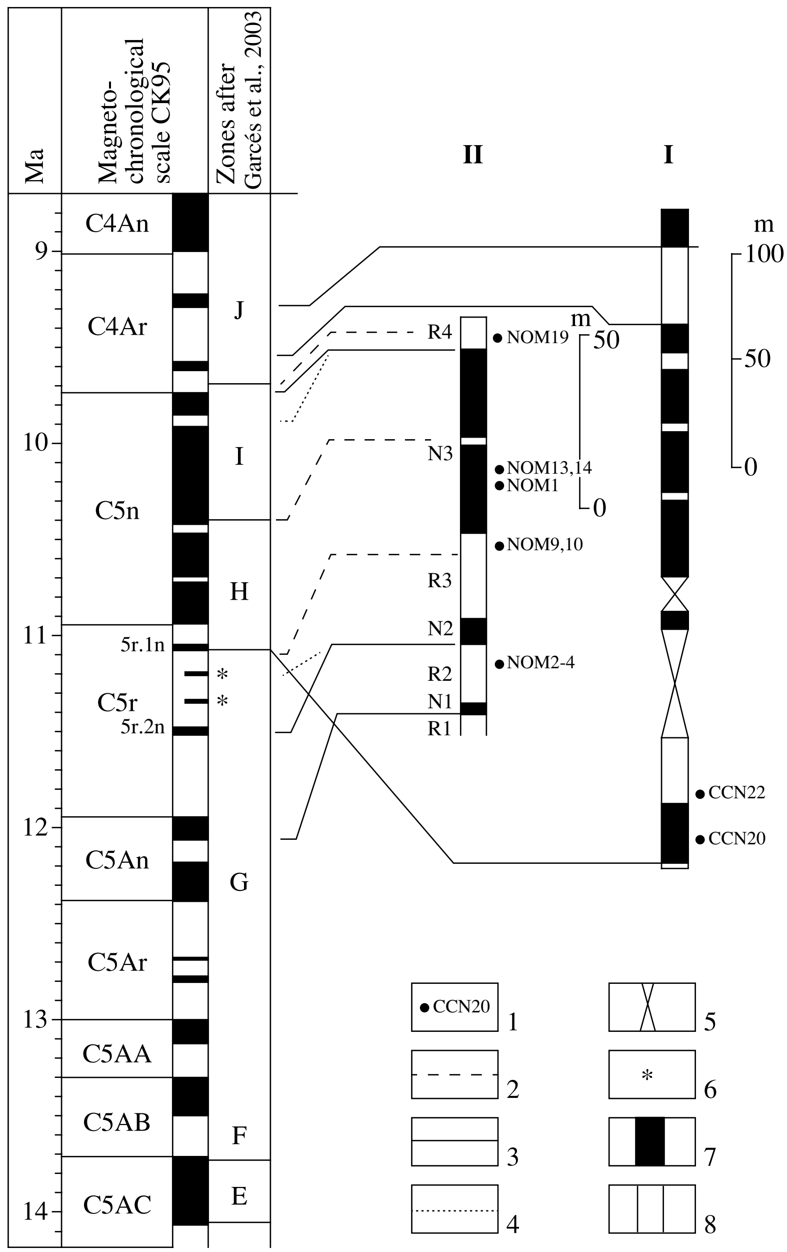

Fig. 1. Correlation of the Montagut (**I**) and Nombrevilla (**II**) sections with the magnetochronological scale (after Agusti et al., 1997, and Garcés et al., 2003): (1) mammal localities; (2) biostratigraphic correlation; (3) magnetostratigraphic correlation; (4) alternative magnetostratigraphic correlation; (5) missing records; (6) potential position of new subchrons in Chron C5r (Garcés et al., 2003); (7) normal and (8) reversed polarity.

At the Congress "BiochroM'97," the *Hipparion*-datum and Vallesian lower boundary are defined at the level of 11.2 Ma (*Actes du Congrés*…, 1997).

Thus, according to available data, the appearance time of hipparion (*Hipparion*-datum) and age of the Vallesian base in Central to Western Europe and Western Asia ranges, as estimated, from 11.2 to 10.7 Ma. Taking into consideration the data on the Yailacilar and Yeni Eskihisar localities in Turkey, the Vallesian lower boundary should be between dates characterizing these sites, i.e., older than 11.2 Ma.

MAGNETOSTRATIGRAPHIC SECTIONS OF THE MIDDLE AND UPPER SARMATIAN MARINE SEDIMENTS IN THE EASTERN PARATETHYS

Southwestern Tamanskii Peninsula

An almost complete uninterrupted section of Sarmatian sediments is exposed in the anticline western flank east of the Panagiya Cape (Fig. 2, **I**). Only the lowermost Sarmatian interval is hidden here under landslides. The total section is over 400 m thick with

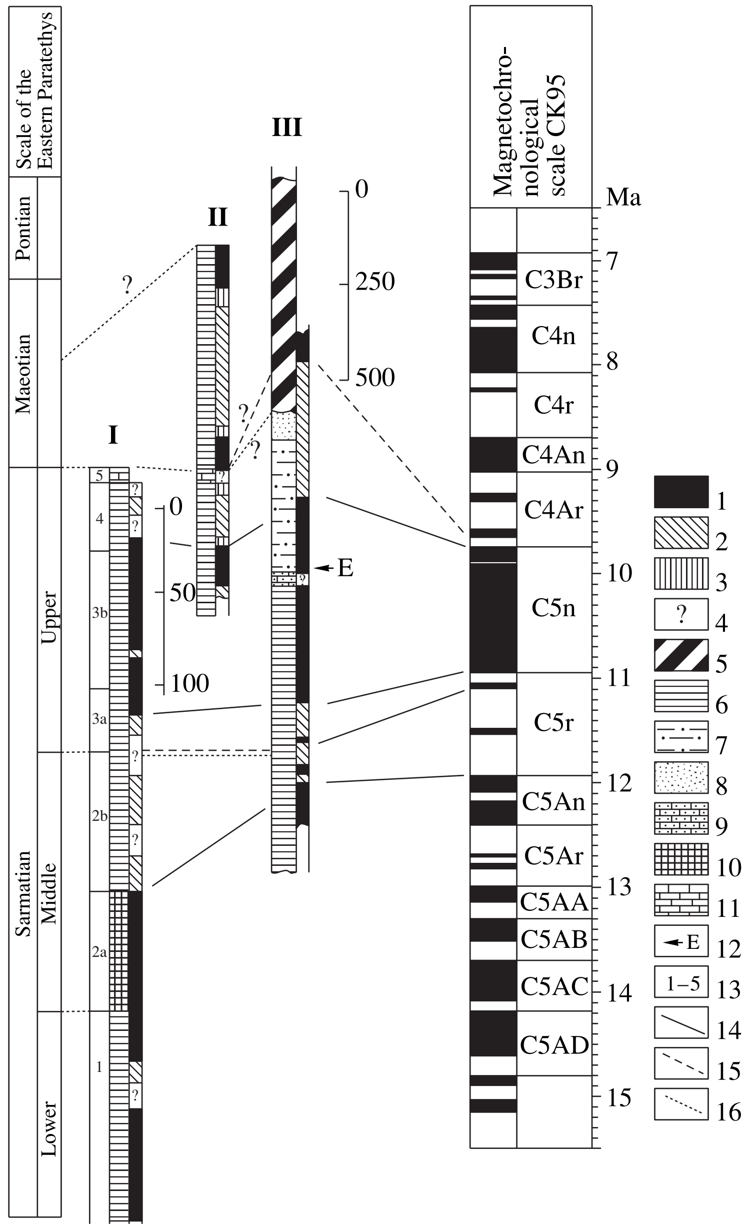

Fig. 2. Magnetostratigraphic sections of the Sarmatian sediments in the Eastern Paratethys: (**I**) Tamanskii Peninsula, western flank of the anticline east of the Panagiya Cape; (**II**) Tamanskii Peninsula, eastern flank of the anticline west of the Panagiya Cape; (**III**) eastern Georgia, the El'dari section; (1) normal, (2) reversed and (3) variable polarity; (4) missing records; (5) gray sand and clay of the continental Shiraki Formation and variegated sand and clay of the continental El'dari Formation; (6) clay; (7) sandy clay; (8) sand; (9) sandstone; (10) marl; (11) limestone; (12) El'dari bone bed; (13) numbers of lithologic members in the Tamanskii Peninsula section; (14) magnetostratigraphic correlation; (15) presumable magnetostratigraphic correlation; (16) biostratigraphic correlation.

132 to 137 m referred to the middle Sarmatian and about 150 m to the upper Sarmatian (Pevzner, 1986). The section description after M.A. Pevzner is presented below.

Lower Sarmatian

Member 1. Dark gray to grayish brown clay with rare marl layers bearing *Abra reflexa* Eichw., *Mactra andrusovi* Koles., and others. Thickness is 115 m.

Middle Sarmatian

Member 2a. Light gray to bluish compact marl with interbeds of gray and greenish clay bearing *Cryptomactra pesanseris* Andrus. Thickness is 65–70 m.

Member 2b. Bluish gray clay with marl interbeds. Thickness is 67 m.

Upper Sarmatian

Member 3a. Greenish gray clay with rare thin marl interlayers bearing *Mactra caspia* Eichw. Thickness is 34 m.

Member 3b. Greenish gray leafy clay bearing *Mactra caspia* Eichw. Thickness is 77 m.

Member 4. Dark gray thin-bedded clay with jarosite. Thickness is 37 m.

Member 5. Membranipora limestone 5–10 m thick.

The section was sampled for paleomagnetic analysis with sampling intervals of 2.5 m. The lower normal-polarity zone (60 m thick) of lower Sarmatian sediments is overlain by the 17-m-thick member, where sediments are remagnetized, and the member is overlain, in turn, by deposits 11 m thick, having reversed polarity. The upper lower (upper 30 m of Member 1) and lower middle (65 to 70 m of Member 2a) Sarmatian sediments correspond to normal-polarity zone about 100 m thick.

In the upper half of the middle Sarmatian (Member 2b) and in the lowermost upper Sarmatian (lower portion of Member 3a) sediments are weakly magnetized. It is impossible to judge confidently about magnetic polarity of deposits in this part of the section. However, three R-zones separated by intervals of unclear polarity can be recognized here.

Higher in the section, there is the 100-m-thick zone of normal polarity (uppermost Member 3a and lowermost Member 4 of the upper Sarmatian) with the 5-m-thick interval of reversed polarity (in the lower portion of Member 3b). The 6- to 7-m-thick interval of reversed polarity is distinguished in weakly magnetized sediments of Member 4. The Sarmatian–Maeotian boundary is at the top of the Membranipora limestone that is lacking paleomagnetic characterization.

In the section of the anticline eastern flank, 2 km west of the Panagiya Cape (Fig. 2, **II**), the Membranipora limestones are overlain by the 82-m-thick Maeotian sequence of alternated dark to light gray compact thin-bedded clay and greenish gray sandy clay bearing *Venerupis abichi* Andrus., *Abra tellinoides* (Sinz.), *Ervilia minuta* Sinz., and others. In this sequence, the normal polarity is definitely established for the lower 18-m-thick interval, and the overlying 80-m-thick zone is of the reversed polarity (Pevzner, 1986).

Eastern Georgia

One of the most complete and thick upper Sarmatian (Khersonian) sections with studied paleomagnetic characteristics is known in eastern Georgia near the boundary with Azerbaijan: the right bank of the Iori River in the western Eilyar-Ougi Range. The section is widely known since 1913 owing to discovery of the El'dari fauna of diverse late Sarmatian mammals that is named after the eponymous steppe extending southward of the range (Gabuniya, 1959; Tsiskarishvili, 1987). The sequence of middle and upper Sarmatian marine sediments is 1340 m thick here (Fig. 2, **III**).

In the lowermost 360-m-thick part of the sequence exposed north of the fault zone is composed of light gray clay with marl and rare thin sandstone interlayers. Based on benthic foraminifers, L.S. Maisuradze attributed these rocks to the middle Sarmatian (inference of 1987).

The indicated rocks are overlain by two sequences of upper Sarmatian sediments 980 m thick in total. The lower 460-m-thick interval is composed of light gray clay intercalated with rare sandstone layers and bearing scarce small and thin shells of *Mactra caspia* Eichw. and *Solen subfragilis* M. Hörn. (identified by L.V. Muskhelishvili). The upper interval beginning from the level of 830 m above the section base is represented by alternating sandy clay, sand, and sandstone with coquina lentils bearing *Mactra bulgarica* Toula, *M. crassicollis* Sinz., and *M. caspia* Eichw. Reddish beds of clayey sand and sandstone appear in the uppermost part of the section. The boundary between two upper Sarmatian sequences is defined at the base of a 30-m-thick petroliferous sandstone bed traceable for a distance of several kilometers as a reliable marker horizon. The bone bed of the El'dari locality is situated 70 m above the base of the petroliferous sandstone (Gabuniya, 1959; Vangengeim et al., 1988, 1989).

Judging from lithology and dwarfed molluscan fauna, the lower, mainly clayey part of the upper Sarmatian section accumulated in a relatively deep-water setting, whereas the upper sequence of more coarse-grained sediments containing abundant large molluscan shells was deposited in shallower environments, near the shore at times. This section interval likely corresponds to a regressive stage in development of the Khersonian sea.

The upper Sarmatian marine sediments are unconformably overlain by the sequence of variegated (200 m) and gray (450 m) continental clay and sandstone of the El'dari and Shiraki formations. The continental deposits are of the Maeotian–Pontian age, but the lowermost part of the El'dari Formation probably belongs to the upper Sarmatian (*Stratigraphy* …, 1986).

Samples for paleomagnetic analysis were collected with intervals of 5 to 20 m. Paleomagnetic characteristics are unknown for the greater part of the 30-m-thick sandstone bed of the mid-upper Sarmatian. The uppermost middle Sarmatian sediments correspond to the reversed-polarity. A thin (about 23 m) zone of the normal polarity is distinguished in the lowermost upper Sarmatian deposits. The overlying sediments 100 m thick show the reversed polarity. Higher in the section, there is a 607- to 608-m-thick zone of the normal polarity intervened by interval about 30 m thick, corresponding to petroliferous sandstone. The upper 250 m of the marine Sarmatian and 80 m of the continental sequence correspond to the reversed-polarity zone. The section under consideration is crowned by a 20-m-thick member of normally magnetized sediments.

CORRELATION OF MIDDLE–UPPER SARMATIAN SEDIMENTS WITH MAGNETOCHRONOLOGICAL SCALE

The El'dari section, where 608 m of uninterrupted 980-m-thick sequence of upper Sarmatian marine sediments correspond to the normal polarity zone, is especially important for correlation of the Sarmatian deposits with the magnetochronological scale. Since the lower 460 m of the upper Sarmatian section are composed of clayey, relatively deep-water deposits, it is evident that the sequence accumulated during a considerable period of time. In the Miocene part of the scale CK95, the only normal-polarity zone that is so lengthy corresponds to Chron C5n that is correlative therefore with the greater part of the upper Sarmatian. This correlation appears to correct for the Tamanskii Peninsula section, where 100 of 150 m of the upper Sarmatian again correspond to the normal-polarity zone.

The upper and lower parts of the upper Sarmatian El'dari and Tamanskii Peninsula sections, which correspond to intervals of the reversed polarity, are correlative respectively with the lower part of Chron C4Ar and the upper part of Chron C5r. A thin zone of the normal polarity in the lowermost upper Sarmatian of the El'dari section is likely an equivalent of Subchron C5r1n ranging in age from 11.05 to 11.09 Ma (Berggren et al., 1995), and the upper Sarmatian base is slightly older here than 11.1 Ma.

The reversed-polarity interval of the upper middle Sarmatian is correlative with a greater portion of Chron C5r. The normal-polarity interval about 100 m thick in the terminal lower and basal middle Sarmatian of the Tamanskii Peninsula section probably corresponds to Subchron C5An1n. In such a case, the middle Sarmatian base should be within this subchron and dated at about 12 Ma. A possibility to correlate the normal-polarity zone of the lowermost middle–uppermost lower Sarmatian with Subchron C5r2n should be excluded most likely, because the subchron is of small duration (11.47 to 11.53 Ma) in contrast to a great thickness of the normal-polarity zone in the Tamanskii section (Pevzner, 1986).

As for the upper Sarmatian top in the El'dari section, it cannot be unambiguously defined because of the erosional hiatus between the marine Sarmatian and the overlying continental sequence. In any case, it is younger than 9.74 Ma (younger boundary of Chron C5n).

In the Tamanskii Peninsula, the normal-polarity interval at the base of the Maeotian can be interpreted as Subchron C4Ar2n with older boundary at 9.6 Ma. Correspondingly, the Sarmatian–Maeotian boundary is of the same age that is consistent with nannofossil records. The NN9/NN10 boundary is established in the lower Maeotian sediments of the Crimea (Bogdanovich and Ivanova, 1997), and age of that boundary is 9.4 Ma (Berggren et al., 1995).

RADIOMETRIC AGES OF THE SARMATIAN SEDIMENTS IN CENTRAL AND EASTERN PARATETHYS

Vass et al. (1987) reported for the Central Paratethys the following mean ages obtained by the K–Ar and fission-track methods for the Sarmatian boundaries: 13.6 ± 0.2 Ma for the Badenian–Sarmatian; 12.7 Ma for the lower–middle Sarmatian; and 11.0 ± 0.5 Ma for the Sarmatian (s.str.)–Pannonian. Several fission-track dates are known in addition for the Sarmatian of the Eastern Paratethys (Chumakov et al., 1992). The age of 12.24 ± 0.97 Ma was determined for the lower Sarmatian top in the Kerchenskii Peninsula. The lower–middle Sarmatian boundary is dated by Chumakov at 12.4 Ma. The dates of 12.32 ± 0.97, 12.39 ± 1.09, and 11.99 ± 0.74 Ma are known for sediments of the lower middle Sarmatian in Moldova. In the Tamanskii Peninsula, where the upper Sarmatian section is over 200 m thick, sediments at the level of 40 m above the base are dated at 11.19 ± 0.74 Ma, and five dates ranging from 9.45 ± 0.88 to 10.20 ± 0.78 Ma are obtained here for the section upper part. The middle–upper Sarmatian boundary is estimated to be >11.19 Ma old, and the Sarmatian top is dated at about 9.3 Ma.

With due account for a considerable experimental error (6–9%) of fission-track age determinations, the reported dates are consistent with suggested correlation of the middle–upper Sarmatian with the magnetochronological interval from the end of Chron C5An to Subchron C4Ar3r inclusive.

MIDDLE SARMATIAN MAMMAL LOCALITIES (BESSARABIYA)

The most ancient hipparion localities Kalfa, Buzhor 1, Lapushna, and Chisinau-Atavaska are known in Moldova (Lungu, 1978, 1981, 1984, 1990; Pevzner et al., 1987; Pevzner and Vangengeim, 1993), where they are associated with the lower half of the Bessarabian regional stage (Fig. 3).

The K a l f a locality is situated in the Byk River right bank northeast of the Kalfa Village, the Novoannensk region (Fig. 4, **III**). It is confined to limestone about 10 m thick, intercalated with clay interbeds and bearing shells of *Plicatiformes fittoni* (Orb.), *Mactra podolica* Eichw., *Solen subfragilis* Hoern., and others. The clay interbeds show the normal polarity.

The B u z h o r site is located in the sandy quarry of the Buzhor Village southeastern margin, the Kotovsk region (Fig. 4, **I**). The basal normal-polarity zone of the section is composed here of gray to brownish gray clay bearing fresh-water mollusks and *Congeria* shells . The zone is overlain by sandy sequence about 15 m thick, with the lower bone bed Buzhor 1 at its base. This part of the section is represented by deltaic facies. Higher in the section, there is exposed a 6-m-thick member of sandy clay. Its upper part yields mammal remains (Buzhor 2) along with shells of *Plicatiformes fittoni*

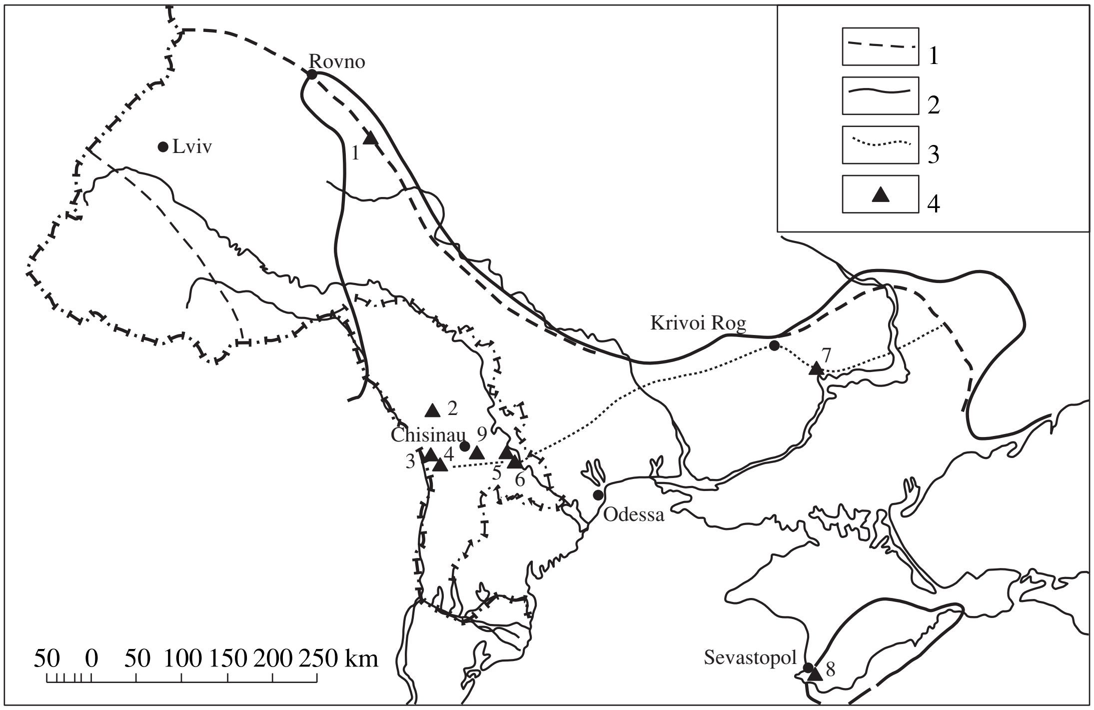

Fig. 3. Location of the middle Sarmatian mammal localities: (1–3) shorelines after Kolesnikov (1940) in (1) the early Sarmatian sea, at (2) the maximum of the middle Sarmatian transgression and in (3) the second middle Sarmatian regression; (4) mammal localities. Numbers on the map: (1) Gritsev; (2) Veveritsa; (3) Buzhor; (4) Lapushna; (5) Kalfa; (6) Varnitsa; (7) Zheltokamenka; (8) Sevastopol; (9) Chisinau-Atavaska.

(Orb.) and *Mactra fabreana* Orb. The lower part of the member shows is of normal polarity, and the upper bone bed corresponds to reversed-polarity zone. The section is crowned by the 20-m-thick sequence of sand and sandy clay of reversed polarity.

The L a p u s h n a locality in southwestern margin of the Lapushna Village is situated 10 km northeast of the Buzhor Village (Fig. 4, **II**). The section is composed of *Congeria*-bearing sandy–clayey sediments 10 m thick, which are overlain by the normal-polarity zone of sandy clay and sandstone (5 m thick) with vertebrate remains, *Mactra fabreana* Orb., *Modiolus* sp., and other shells.

In the C h i s i n a u – A t a v a s k a locality of the quarry in southeastern margin of Chisinau, the 70-m-thick sequence of clay, sand, and sandy clay is exposed. *Mactra fabreana* Orb. and *Plicatiformis fittoni* (Orb.) occur throughout the sequence, and bone bed is confined to its middle part corresponding to normal-polarity interval.

All the localities contain remains of *"Hipparion" sarmaticum* Lungu that is the most similar to *H. primigenium* (Meyer) according to its dimensions and teeth structure (Lungu, 1984). A. Forsten (1978, pp. 305–306) classed the remains with *H. primigenium* but noted that in hipparion remains from the Kalfa has "protocone of uppers is significantly shorter than in any of the Rhine valley samples."

It is remarkable that in the Buzhor 1 locality remains of *Progonomys cathalai* Schaub (Lungu, 1981, 1990; = *Parapodemus* sp. after Martin Suarez and Mein, 1998) were found together with hipparion bones. This is the oldest Muridae finding in Europe.

Bone beds in all the localities, except for the upper one at the Buzhor site, are in the normal-polarity zone correlative with the upper part of Chron C5An, and their age is close to 11.9 Ma (the younger chron boundary). The alternative correlation with Subchron C5r2n (11.47–11.53 Ma) is unlikely. It can hardly been conceived that such a short-term interval of normal polarity was recorded in four sections.

The Z h e l t o k a m e n k a locality in the Dnepropetrovsk region, Ukraine, is likely similar in age to that group of bone beds. In addition to rounded bones of marine mammals, the middle Sarmatian limestone yields here scarce remains of *Machairodus* sp., two mastodont forms, *Aceratherium*, giraffes of unclear species affinities, and an *Anchitherium* phalanx. Hipparion remains have not been listed (Pidoplichko, 1956; Korotkevich, 1988). Paleomagnetic characterization of the site is unknown (normal polarity of sediments was mistakenly mentioned by Sen, 1997; presence of hipparion by Woodburne et al., 1996). Age of the *Zheltokamenka* locality was presumably estimated based on the site position relative to shoreline of the basin in the mid-Bessarabian (Pevzner and Vangengeim, 1993).

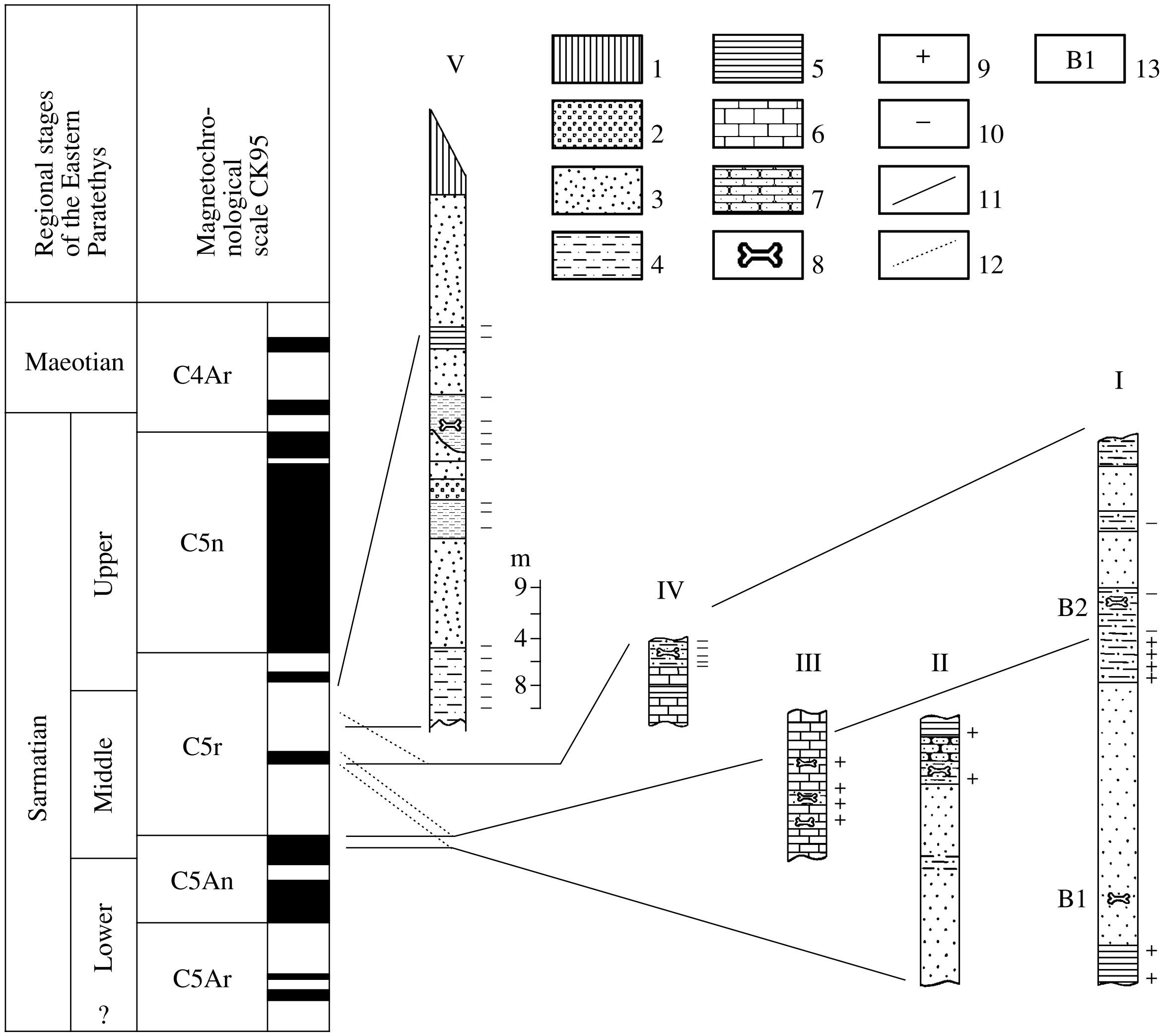

Fig. 4. Correlation of the middle Sarmatian localities with the magnetochronological scale: (**I**) Buzhor; (**II**) Lapushna; (**III**) Kalfa; (**IV**) Varnitsa; (**V**) Veveritsa; (1) covering loam; (2) gravel; (3) sand; (4) sandy clay; (5) clay; (6) limestone; (7) sandstone; (8) bone beds; (9) normal and (10) reversed polarity; (11) magnetostratigraphic correlation; (12) alternative magnetostratigraphic correlation; (13) bone beds in the Buzhor locality.

Younger bone beds are represented in the B u z h o r 2 (see above) and V a r n i t s a localities. The latter is situated in the northern margin of the Varnitsa Village, the Dniester River right bank in Novoannensk region (Fig. 4, **IV**). The section lower part corresponds here to a thick sequence of middle Sarmatian limestone. It is overlain by the bone-bearing sequence composed at the base of greenish gray sandy clay with *Plicatiformes fittoni* (Orb.), interval 1–1.7 m, that grades upward into sandy gravel 5 to 6 m thick. Hipparion from the Varnitsa is represented by a form classed with *Hipparion* cf. *verae* Gabuniya by Lungu; in the Buzhor 2 site, it is determined as *H. sarmaticum* (Lungu, 1990). The bone beds Buzhor 2 and Varnitsa are in the reversed-polarity zone correlated with Chron C5r (Pevzner et al., 1987).

The locality nearby northern margin of the V e v e r i t s a Village, Kalarash district, Moldova, is located at the absolute height of 340 m in the Kodru, being referred to the upper part of the Bessarabian. The middle Sarmatian marine sediments are exposed at the base of the section. The overlying 50-m-thick sequence is represented by continental facies of alternated sand, sandstone, and sandy clay of the Balta Formation. The bone bed in the middle of continental sequence contains *"Hipparion"* sp. and *Progonomys* cf. *cathalai* Schaub (Lungu and Obada, 2001). Clays in the lower and middle part of the section correspond to interval of the reversed polarity that is correlated with Subchron C5r2r (data by Pevzner).

The Sevastopol locality (Crimea) is attributed to the uppermost middle Sarmatian. The bone bed is confined to limestone bearing marine mollusks. Hipparion of this locality is classed with *H. sebastopolitanum* Boriss. (Gabuniya, 1959). Forsten (1978) considered this small hipparion as a separate local form concurrent to *H. primigenium.*

All the middle Sarmatian localities can be ranging in age from ~11.9 to ~11.2 Ma (from the upper part of Chron C5An to the upper part of Subchron C5r2r). It is noteworthy that hipparions differing from the typical *Hippotherium primigenium*, i.e., *H.* cf. *verae* from the Varnitsa and *H. sebastopolitanum* from the Sevastopol appeared in the terminal Bessarabian, because earlier faunas include one form only. Evidently, a certain differentiation of species *H. primigenium* took place by the end of the Bessarabian in southeastern Europe.

Of special note is the G r i t s e v locality near the eponymous village in the Shepetovka district, Khmel'nitskaya oblast, Ukraine, where bone-bearing sediments fill in the karstic sinkholes in reefal limestone of the lower horizon in the middle Sarmatian that contains *Mactra vitaliana* Orb. The overlying deposits are represented by calcareous gravelstone and clay with *Mactra podolica* Eichw. (Topachevsky et al., 1996). The karstic fill and overlying sediments correspond to the reversed-polarity zone (Korotkevich et al., 1985).

Ukrainian paleontologists consider this locality as the oldest one in the early Vallesian of Europe. This inference is based on a significant proportion of characteristic Astaracian forms: *Lantanotherium, Dinosorex, Miopetaurista, Eomyops, Myoglis, Paraglirulus*, and *Miodyromys* (Nesin and Topachevsky, 1999). However, three former genera still occur in Zone MN11 of the Dorn-Dürkheim in Central Europe (Franzen and Storch, 1999), *Eomyops* existed in southern France up to the terminal Turolian (Mein, 1999), and the other forms are known from Zone MN10 (Daxner-Höck, 1996). Hipparions are represented by *Hippotherium primigenium* (Meyer) and larger *"Hipparion"* sp. (Krakhmalnaya, 1996). Petauristids and glirids are of the most diverse taxonomic composition. Insectivore remains are the most numerous in the locality. Muridae representatives are missing. Among carnivores, about ten mustelid forms were encountered (Topachevsky et al., 1996; Semenov, 2002).

The Gritsev locality is situated 300 km northward from the oldest middle Sarmatian sites in Moldova. Comparison of the Gritsev fauna with the old group of Moldavian faunas shows that the latter are lacking petauristids and dimylids, families Eomyidae and Gliridae are represented by a single species each, and mustelids are less numerous. The distinctions indicate more arid and open landscapes in Moldova than at the Gritsev site (Lungu, 1990; Pevzner and Vangengeim, 1993).

Fortelius et al. (1996) recognized two paleozoogeographic provinces in Eastern Europe: the Central European one including Germany, Switzerland, Poland, former Czechoslovakia, Hungary, and the Southeastern province embracing territory of former Yugoslavia, Greece, Turkish Thrace, Bulgaria, Romania, Moldova, and Ukraine. In the Central European province, a conservative forest environment retained up to the terminal Late Miocene. In the Southeastern province open landscapes originated earlier and climatic seasonality was more pronounced (Bernor et al., 1996; Fortelius et al., 1996). A similar paleozoogeographic division of the territory under consideration was proposed by Lungu (1990) who distinguished the Central and East European provinces.

Among 29 genera of small mammals identified in the Gritsev fauna, 17 ones and two species (*Myoglis ucrainicus* Nes., Kow. and *Paraglirulus* cf. *werenfelsi* Engesser) occur as well in Hungary at the Rudabanya locality (Nesin and Kowalski, 1997; Nesin and Nadachowski, 2001; Bernor et al., 2004). According to L. Kordos (Bernor et al., 2004), *Anomalomys* from the Gritsev site is transitional in morphology between *A. rudabanensis* Kordos (MN9) and *Allospalax petteri* Bachm. et Wils. (MN11). Both faunas are also similar in diversity of soricids and glirids among small mammals and in abundance of mustelids among carnivores that is indicative of widespread forest environments and warm subtropical climate. In the Rudabanya and Gritsev localities, there are identified two hipparion taxa: *H. intrans* Kretzoi and smaller *H.* sp. Based on their evolutionary advancement, the localities are referred to the upper part of Zone MN9. It is assumed that these forms diverged from *H. primigenium* by the end of Zone MN9 time (Bernor et al., 2004).

The above comparison shows that faunas of Moldova, on the one hand, and of the Rudabanya and Gritsev localities, on the other, originated in different paleozoogeographic provinces, the Southeastern and Central European, respectively. Joint occurrence of two hipparion forms and reversed polarity of bone-bearing deposits at the Gritsev locality suggest that it is at a younger level than that of the Kalfa, Buzhor 1, Lapushna, and Chisinau-Atavaska faunas. Consequently, the Gritsev fauna can be attributed to the mid-middle Sarmatian and considered as close in age to the Buzhor 2 and Varnitsa faunas of Moldova, thus being in Chron C5r of the magnetochronological scale. The Rudabanya locality is younger than the Gritsev fauna. According to evolutionary development of hipparions, the Rudabanya fauna is estimated to be 10 to 9.7 Ma old and correlative with the Pannonian Zone F of the Central Paratethys (Bernor et al., 2004). In the scale of the Eastern Paratethys, this fauna can be attributed to the upper Sarmatian and correlated with Chron C5n of the magnetochronological scale.

DISCUSSION AND CONCLUSIONS

As is shown above, the upper Sarmatian of the Eastern Paratethys corresponds to joint interval of Subchron C4Ar3r, Chron C5n, and upper part of Chron C5r, Subchron C5r1n included. The upper Sarmatian base is slightly older than 11.1 Ma. All the dating results obtained for the Vallesian lower boundary and *Hippotherium* FAD in Western and Central Europe, Pakistan, and Turkey enable their correlation with the *lower upper Sarmatian* of the Eastern Paratethys. In southeastern Europe (Moldova and Ukraine), the oldest hipparion remains are found in the *middle Sarmatian* deposits.

If the normal-polarity zone of the middle Sarmatian sediments in the Kalfa, Buzhor 1, and other localities corresponds to Subchron C5r2n, the *Hipparion*-datum is about 11.5 Ma old. This age is by 0.3 to 0.8 m.y. older than other European dates, being close to age values of 11.6 and 11.2 Ma estimated for the Yeni Eskihisar 2 locality in Turkey. According to more preferable correlation of deposits with the upper part of Subchron C5An1n, the Vallesian lower boundary and *Hippotherium* FAD are as old as 11.9 Ma, i.e., by 0.7 to 1.2 m.y. older than the other dates accepted in Europe.

The time difference between *Hipparion*-datums in different regions can be explained by diachronous dispersal of equids. Sen (1997, p. 191) suggested that "the Iberian peninsula, because of its geographical situation, constitutes a refuge area at the end of immigration routs… As a consequence, the first occurrence of an immigrant taxon might be diachronic in different bioprovinces of Europe, and particularly in the Iberian peninsula". An example of such diachronism can be the Muridae dispersal: they populated territory from Pakistan to during about two million years (Agusti et al., 1997).

Woodburne et al., (1996, p. 134) considered "prochoresis of Old World *Hippotherium* to have been nominally instantaneous within the span of 0.5 m.y". Under favorable conditions, dispersal of mammal could be even faster. For instance, habitat area of *Capreolus capreolus* extended in Sweden northward for 1000 km during 100 years, from mid-19th to mid-20th century (Timofeev-Resovskii et al., 1973). In the 1930s–1940s, distribution area of elks advanced southward in European Russia with the rate of 400 km per 18–20 years (Geptner et al., 1961).

Absence of hipparion remains in the European localities within the Astaracian-Vallesian transition could be likely an impact of ecological (as it is suggested for the Yeni Eskihisar locality in Turkey) or taphonomic factors, if the low density of pioneering hipparion populations migrating from the east westward is taken into account. Otherwise, remains of large mammals have not been preserved in certain boundary localities.

On the other hand, correlation of Spanish localities with the Astaracian-Vallesian boundary interval of magnetochronological scale cannot be regarded as unambiguously proved based on analysis of relevant geological and paleomagnetic records. For instance, there are many hiatuses in the Nombrevilla section (Alvarez Sierra et al., 2003), or certain intervals in lower parts of the Montagut sections that have no paleomagnetic characteristics (Agusti et al., 1997). In such a situation, we cannot rule out that omission of some magnetic polarity zones results in misleading correlation of sediments with paleomagnetic scale.

The hipparion prochoresis from North America to Eurasia is commonly considered in terms of global sea-level lowering and emergence of the Bering Land Bridge close to the Serravallian–Tortonian boundary time (Agusti et al., 1997; etc.). However, studies of mollusks and diatoms in the Pacific and Arctic regions showed that the Bering Strait opening and first communication between North Pacific and Arctic basins took place in the Neogene epoch only about 5.5–5.4 Ma ago. The regional tectonic processes could play therewith an important role in the strait formation (Gladenkov and Gladenkov, 2004). Consequently, the hipparion prochoresis from the New World need not be associated with eustatic sea-level oscillations. The Bering Land of greater or lesser size existed most likely throughout the Neogene. In the Barstovian, proboscideans migrated from Eurasia to North America through the Beringia during a high sea-level stand in the World Ocean 16–12.5 Ma ago (Woodburne, 2004).

Summarizing the considered data, we can state the following.

1. If the ***Hipparion*-datum in the Old World corresponds to the Vallesian base, the latter should be dated as 11.9 (or 11.5) Ma old based on the middle Sarmatian localities in Moldova.**

2. **The Vallesian base is older than the middle–upper Miocene boundary dated at 11.1 Ma by Berggren et al. (1995).** It could be close to the Middle–Upper Miocene boundary fixed by the IUGS at the level of 11.6 Ma (Gradstein et al., 2004), if the older localities in Moldova are correlative with Subchron C5r2n, or older, if these localities correspond in age to the upper part of Chron C5An.

3. In order to trace this boundary in Western Europe and the Eastern Mediterranean, **it is necessary to figure out the additional criteria indicating commencement of the Vallesian** (apart from the *Hippotherium* FAD), studying preferably the localities of small mammals, which are much more frequent than those of large mammals.

In Western Europe, the boundary event is likely recorded at the base of Zone H (*Hispanomys–Megacricetodon ibericus*) in the scale by Daams and Freudenthal, as in certain Spanish sections they established distinct replacement of one ecologic grouping of small mammals by the other one (Daams et al., 1988). However, this boundary event have not been reliably dated yet because of the reasons mentioned above.

4. **Differentiation of the *Hippotherium primigenium* lineage commenced in southeastern Europe** as early as in the middle Sarmatian beginning from the upper part of Chron C5r, i.e., **earlier than it is suggested for the other European regions** (from mid-Chron C5n). This is evident from appearance of forms differing from the typical *H. primigenium* in the middle Sarmatian localities of Moldova (*H.* cf. *verae* in the Buzhor 2) and Ukraine (*H.* sp. in the Gritsev and *H. sebastopolitanum* in the Sevastopol localities).

The final age determination for the Vallesian lower boundary should be based on additional paleontological and magnetostratigraphic research.

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research, project no. 06-05-64049-a.

Reviewer I.A. Vislobokova

REFERENCES

1. "Actes du Congres BiochroM'97," Mem. Trav. E.P.H.E. Inst. Montpellier, No. 21, 69–805 (1997).
2. J. Agusti, L. Cabrera, M. Garcés and J. M. Parés, "The Vallesian Mammal Succession in the Valles–Penedes Basin (Northeast Spain): Paleomagnetic Calibration and Correlation with Global Events," Palaeogeogr., Palaeoclimatol., Palaeoecol. **133** (3–4), 149–180 (1997).
3. J. Agusti, L. Cabrera, M. Garcés, et al., "A Calibrated Mammal Scale for the Neogene of Western Europe. State of the Art," Earth Sci. Rev., No. 52, 247–260 (2001).
4. M. A. Alvarez Sierra, J. P. Calvo, J. Morales, et al., "El Transito Aragoniense-Vallesiense en el Area de Daroca–Nombrevilla (Zaragoza, España)," Coloquios de Paleontologia *Ext. 1*, 25–33 (2003).
5. J. D. Becker-Platen, L. Benda, and P. Steffens, "Litho- und biostratigraphic Deutung radiometrischer Altersbestimmungen aus der Jungtertiar der Turkei," Geol. Jahrb. **B** (25), 139–167 (1977).
6. W. A. Berggren, D. V. Kent, C. C. Swisher, and M. P. Aubry, "A Revised Cenozoic Geochronology Time Scales and Global Stratigraphic Correlation," SEPM Spec. Publ., No. 54, 129–212 (1995).
7. R. L. Bernor, L. Kordos, L. Rook, et al., "Recent Advances on Multidisciplinary Research at Rudabanya, Late Miocene (MN9), Hungary: a Compendium," Palaeontogr. Italica **89**, 3–36 (2004).
8. R. L. Bernor, G. D. Koufos, M. O. Woodburne, and M. Fortelius, "The Evolutionary History and Biochronology of European and Southwest Asian Late Miocene and Pliocene Hipparionine Horses," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, N. Y., 1996), pp. 307–338.
9. E. M. Bogdanovich and T. A. Ivanova, "On New Finding of Planktonic Organisms in the Maeotian of the Crimea," Dok. Nat. Akad. Nauk Ukrainy, No. 6, 127–129 (1997).
10. I. S. Chumakov, S. L. Byzova, and S. S. Ganzei, *Late Cenozoic Geochronology and Correlation in the Paratethys* (Nauka, Moscow, 1992) [in Russian].
11. R. Daams, M. Freudenthal, and A. J. van der Meulen, "Ecostratigraphy of Micromammal Faunas from the Neogene of Spain," Scripta Geol. Spec. Issue, No. 1, 287–302 (1988).
12. G. Daxner-Höck, "Middle and Late Miocene Gliridae of Western, Central and Southern Europe," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 261–263.
13. O. Fejfar, W.-D. Heinrich, and E. H. Lindsay, "Updating the Neogene Rodent Biochronology in Europe," Mededel. Nederl. Inst. Toegep. Geowetensch. TNO, No. 60, 533–554 (1998).
14. A. Forsten, "*Hipparion primigenium* (v. Meyer, 1829), an Early Three-Toed Horse," Ann. Zool. Fennici, No. 15, 298–313 (1978).
15. M. Fortelius, J. van der Made, and R. L. Bernor, "Middle and Late Miocene Suoidea of Central Europe and the Eastern Mediterranean: Evolution, Biogeography, and Paleoecology," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 348–375.
16. J. L. Franzen and G. Storch, "Late Miocene Mammals from Central Europe," in *The Evolution of Neogene Terrestrial Ecosystems in Europe*, Ed. by J. Agusti, L. Rook, and P. Andrews (Cambridge University Press, Cambridge, 1999), pp. 165–190.
17. L. K. Gabuniya, *On the History of Hipparions* (Akad. Nauk SSSR, Moscow, 1959) [in Russian].
18. M. Garcés, W. Krijgsman, P. Peláes-Campomanes, et al., "Hipparion Dispersal in Europe: Magnetostratigraphic Constraints from the Daroca Area (Spain)," Coloq. Paleontol. **1**, 171–178 (2003).
19. V. G. Geptner, A. A. Nasimovich, and A. G. Bannikov, *Mammals of the USSR. Vol. 1* (Vysshaya Shkola, Moscow, 1961) [in Russian].
20. A. Yu. Gladenkov and Yu. B. Gladenkov, "Onset of Connections between the Pacific and Arctic Oceans through the Bering Strait in the Neogene," Stratigr. Geol. Korrelyatsiya **12** (2), 72–89 (2004) [Stratigr. Geol. Correlation **12**, (2), 175–187 (2004)].
21. F. M. Gradstein, J. G. Ogg, A. G. Smith, et al., "A New Geologic Time Scale, with Special Reference to Precambrian and Neogene," Episodes **27** (2), 93–100 (2004).
22. C. Guérin, P. Mein, M. Philippe, and G. Truc, "Découverte d'Hipparions Ante-Tortoniens dans le Bassin de Vaison-la-Romaine (Vaucluse, Sud-Est de la France)," C. R. Acad. Sci., Paris, No. 274, 1276–1279 (1972).
23. J. Kappelman, A. Duncan, M. A. Feseha, et al., "Chronology of the Sinap Formation," in *Geology and Paleontology of the Miocene Sinap Formation, Turkey*, Ed. by M. Fortelius, J. Kappelman, et al. (Columbia Univ. Press, New York, 2003), pp. 41–68.
24. J. Kappelman, S. Sen, M. Fortelius, et al., "Chronology and Biostratigraphy of the Miocene Sinap Formation of Central Turkey," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 78–95.
25. V. P. Kolesnikov, "Upper Miocene," in *Stratigraphy of the USSR. Vol. XII: Neogene of the USSR*, Ed. by A. D. Arkhangel'skii (Akad. Nauk SSSR, Moscow, 1940), pp. 229–373 [in Russian].
26. E. L. Korotkevich, *History of the Hipparion Fauna Origin in Eastern Europe* (Naukova Dumka, Kiev, 1988) [in Russian].
27. E. L. Korotkevich, V. N. Kushniruk, Yu. A. Semenov, and A. L. Chepalyga, "New Locality of the Middle Sarma-

tian Vertebrates in Ukraine," Vestn. Zool., No. 3, 81–82 (1985).

28. G. D. Koufos, "Late Miocene Mammal Events and Biostratigraphy in the Eastern Mediterranean," in *Distribution and Migration of Tertiary Mammals in Eurasia*, Ed. by J. W. E. Reumer and W. Wessels (Deinsea, Rotterdam, 2003), pp. 343–372.
29. T. Krakhmalnaya, "Hipparions of the Northern Black Sea Coast Area (Ukraine and Moldova): Species Composition and Stratigraphic Distribution," Acta Zool. Cracov. **39** (1), 261–267 (1996).
30. W. Krijgsman, M. Garcés, C. G. Langereis, et al., "A New Chronology for the Middle to Late Miocene Continental Record in Spain," Earth Planet. Sci. Lett., **142**, 367–380 (1996).
31. A. N. Lungu, *Middle Sarmatian Hipparion Fauna of Moldova (Carnivores)* (Shtiintsa, Chisinau, 1978) [in Russian].
32. A. N. Lungu, *Middle Sarmatian Hipparion Fauna of Moldova (Insectivores, Lagomorphs, and Rodents)* (Shtiintsa, Chisinau, 1981) [in Russian].
33. A. N. Lungu, *Middle Sarmatian Hipparion Fauna of Moldova (Ungulates)* (Shtiintsa, Chisinau, 1984) [in Russian].
34. A. N. Lungu, Extended Abstract of Doctoral Dissertation in Geology and Mineralogy (GIN AN GSSR, Tbilisi, 1990).
35. A. Lungu and T. Obada, "Fauna şi Flora Terestra a Podisului Codrilor (Judetul Ungheni)," PYRETUS. Anuar. Muz. de Istorie şi Etnografie din Ungheni **1** (1), 3–8 (2001).
36. J. P. Lunkka, M. Fortelius, J. Kappelmann, and S. Sen, "Chronology and Mammal Faunas of Miocene Sinap Formation," in *The Evolution of Neogene Terrestrial Ecosystems in Europe*, Ed. by J. Agusti, L. Rook, and P. Andrews (Cambridge Univ. Press, Cambridge, 1999), pp. 238–264.
37. E. Martin Suarez and P. Mein, "Revision of the Genera *Parapodemus, Apodemus* and *Rhagapodemus* (Rodentia, Mammalia)," Geobios **31** (1), 87–97 (1998).
38. P. Mein, "The Late Miocene Small Mammal Succession from France, with Emphasis on the Rhone Valley Localities," in *The Evolution of Neogene Terrestrial Ecosystems in Europe*, Ed. by J. Agusti, L. Rook, and P. Andrews (Cambridge Univ. Press, Cambridge, 1999), pp. 140–164.
39. V. A. Nesin and K. Kowalski, "Miocene Gliridae (Mammalia, Rodentia) from Grytsiv (Ukraine)," Acta zool. cracov **40** (2), 209–222 (1997).
40. V. A. Nesin and A. Nadachowski, "Late Miocene and Pliocene Small Mammal Faunas (Insectivora, Lagomorpha, Rodentia) of Southeastern Europe," Acta Zool. Cracov. **44** (2), 107–135 (2001).
41. V. A. Nesin and V. A. Topachevsky, "The Late Miocene Small Mammals in Ukraine," in *The Evolution of Neogene Terrestrial Ecosystems in Europe*, Ed. by J. Agusti, L. Rook, and P. Andrews (Cambridge Univ. Press, Cambridge, 1999), pp. 265–272.
42. M. A. Pevzner, Doctoral Dissertation in Geology and Mineralogy (GIN AN SSSR, Moscow, 1986).
43. M. A. Pevzner, A. N. Lungu, E. A. Vangengeim, and A. E. Basilyan, "Position of the Vallesian Hipparion Faunas from Moldova in the Magnetochronological Scale," Izv. AN SSSR. Ser. geol. No. 4, 50–59 (1987).
44. M. A. Pevzner and E. A. Vangengeim, "Magnetochronological Age Assignment of Middle and Late Sarmatian Localities of the Eastern Paratethys," Newsl. Stratigr. **29** (2), 63–75 (1993).
45. I .G. Pidoplichko, *Studies of Ancient Faunas in Ukraine* (Akad. Nauk USSR, Kiev, 1956) [in Ukrainian].
46. D. Pilbeam, M. Morgan, J. C. Barry, and L. Flynn, "European MN Units and Siwalik Faunal Sequence of Pakistan," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 96–105.
47. F. Rögl and G. Daxner-Höck, "Late Miocene Paratethys Correlations," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 47–55.
48. Yu. O. Semenov, "Stratigraphic Distribution of Carnivorous Mammals in the Late Miocene of Ukraine," Tr. Nats. Nauchno-Prirodov. Muzeya NAN Ukrainy, 52–66 (2002).
49. S. Sen, "Present State of Magnetostratigraphic Studies in the Continental Neogene of Europe and Anatolia," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 56–63.
50. S. Sen, "Magnetostratigraphic Calibration of the European Neogene Mammal Chronology," Palaeogeogr., Palaeoclimatol., Palaeoecol. **133** (3–4), 181–204 (1997).
51. O. Sickenberg, J. D. Becker-Platen, L. Benda, et al., "Die Gliederung des höheren Jungtertiärs und Altquartärs in der Türkei nach Vertebraten und ihre Bedeutung für die internationale Neogen-Stratigraphie," Geol. Jahrb. **B** (15) (1975).
52. F. F. Steininger, "Chronostratigraphy, Geochronology and Biochronology of the Miocene 'European Land Mammal Mega-Zones' (ELMMZ) and the Miocene 'Mammal Zones (MN-Zones)'," in *The Miocene Land Mammals of Europe*, Ed. by G. E. Rossner and K. Hessig (Verlag Dr. Friedrich Pfeil, München, 1999), pp. 9–24.
53. F. F. Steininger, W. A. Berggren, D. V. Kent, et al., "Circum-Mediterranean Neogene (Miocene and Pliocene) Marine–Continental Chronologic Correlations of European Mammal Units," in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 7–46.
54. *Stratigraphy of the USSR. Neogene System. Vol. 1* (Nedra, Moscow, 1986) [in Russian].
55. N. V. Timofeev-Resovskii, A. V. Yablokov, and N. V. Glotov, *Sketch on the Population Studies* (Nauka, Moscow, 1973) [in Russian].
56. V. A. Topachevsky, V. A. Nesin, and I. V. Topachevsky, "The Oldest Middle Sarmatian Microtheriofauna Locality (Insestivora, Lagomorpha, Rodentia) in Eastern Europe," Dop. Nats. Akad. Nauk Ukraini, No. 2, 107–110 (1996).

57. G. V. Tsiskarishvili, *Late Tertiary Rhinoceroses (Rhinocerotidae) of the Caucasus* (Metsniereba, Tbilisi, 1987) [in Russian].

58. E. A. Vangengeim, L. K. Gabuniya, M. A. Pevzner, and G. V. Tsiskarishvili, “Stratigraphic Position of the Hipparion Faunas in the Transcaucasia in the Light of Magnetostratigraphic Records,” Izv. AN SSSR. Ser. geol. No. 8, 70–77 (1989).

59. E. A. Vangengeim, L. V. Muskhelishvili, M. A. Pevzner, and G. V. Tsiskarishvili, “Position of the Vallesian Upper Boundary in Stratigraphic Scale of the Eastern Paratethys,” Izv. Akad. Nauk SSSR, Ser. Geol. No. 6, 67–74 (1988).

60. D. Vass, I. Repcok, K. Balogh, and J. Halmai, “Revised Radiometric Time-Scale for Central Paratethyan Neogene,” Ann. Inst. Geol. Hung. **70**, 423–434 (1987).

61. M. O. Woodburne, (Ed). *Late Cretaceous and Cenozoic Mammals of North America. Biostratigraphy and Chronostratigraphy* (Columbia University Press, New York, 2004).

62. M. O. Woodburne, R. L. Bernor, and C. C. Swisher III, “An Appraisal of the Stratigraphic and Phylogenetic Bases for the *‘Hipparion’* Datum in the Old World,” in *The Evolution of Western Eurasian Neogene Mammal Faunas*, Ed. by R. L. Bernor, V. Fahlbusch, and H.-W. Mittmann (Columbia Univ. Press, New York, 1996), pp. 124–136.