FOSSIL MAMMALS OF ASIA

NEOGENE BIOSTRATIGRAPHY AND CHRONOLOGY

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Chapter 23

Late Miocene Mammal Localities of Eastern Europe and Western Asia

Toward Biostratigraphic Synthesis

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Numerous localities of the "fauna of Hipparion" are known in the Northern Black Sea region (Ukraine, Moldova, Russia) and in the Transcaucasus (Georgia). They are associated with shallow marine deposits of the Eastern Paratethys spanning the middle Sarmatian through Pontian regional stages, and with synchronous terrestrial formations. Many of these sites have a paleomagnetic record and can be correlated with the magnetochronological time scale based on relatively complete marine sections of the Eastern Paratethys.

The mammal-based biochronological zonation of Pierre Mein (1975, 1989) originally established for the continental Neogene of western and central Europe (MN zones) is widely used in different regions of the Palearctic—in particular, in the south of east Europe and in Transcaucasus.

In the last decade, magnetostratigraphic data have been obtained for many mammal localities in central and southwestern Europe (Bernor et al. 1996b; Krijgsman et al. 1996; Agustí et al. 1997; Garcés, Krijgsman, and Agustí 1998; Agustí, Cabera, and Garcés 2001; Daxner-Höck 2001; and other works). These studies resulted in age estimates for the boundaries of MN zones (figure 23.1).

In this chapter, we give a synthesis of magnetostratigraphy-based correlations of large mammal localities from southern east Europe and the Transcaucasus with MN zones of central and western Europe (Vangengeim, Lungu, and Tesakov 2006; Vangengeim and Tesakov 2008a, 2008b) (figures 23.2 and 23.3). In addition, data on most important small mammal sites and biochronological markers were used, as well. In this study, we attempted to reconsider traditional concepts on faunal correlations between west and east Europe and define biochronological boundaries in southern east Europe in accordance with the known ages of MN zones' boundaries.

The study of the paleogeographic setting for middle to upper Sarmatian and paleomagnetic data has shown a possibility of a somewhat different chronological sequence of localities in this geological interval as compared to views of other authors (figure 23.4). The sequence of localities in the Maeotian-Pontian interval is agreed upon by the majority of Ukrainian and Russian authors (Korotkevich 1988; Pevzner and Vangengeim 1993; Pevzner et al. 2003; Vangengeim, Lungu, and Tesakov 2006; Vangengeim and Tesakov 2008a, 2008b).

In this chapter, the taxonomic nomenclature for hipparions is after Bernor, Koufos, et al. (1996b), and for carnivorans, ungulates, and elephants it is after Gabunia (1986), Godina (1979), Korotkevich (1988), Krakhmalnaya (1996a, 2008), Krokos (1939), Lungu (1990), Lungu and Delinschi (2008), Markov (2008), Pevzner et al. (1987), Semenov (1989, 2001a, 2001b, 2008), Sotnikova (2005), Vangengeim (1993), Werdelin and Solounias (1991), Wolsan and Semenov (1996). Many mammalian groups and faunal lists need revision.

Eleonora Vangengeim is deceased.

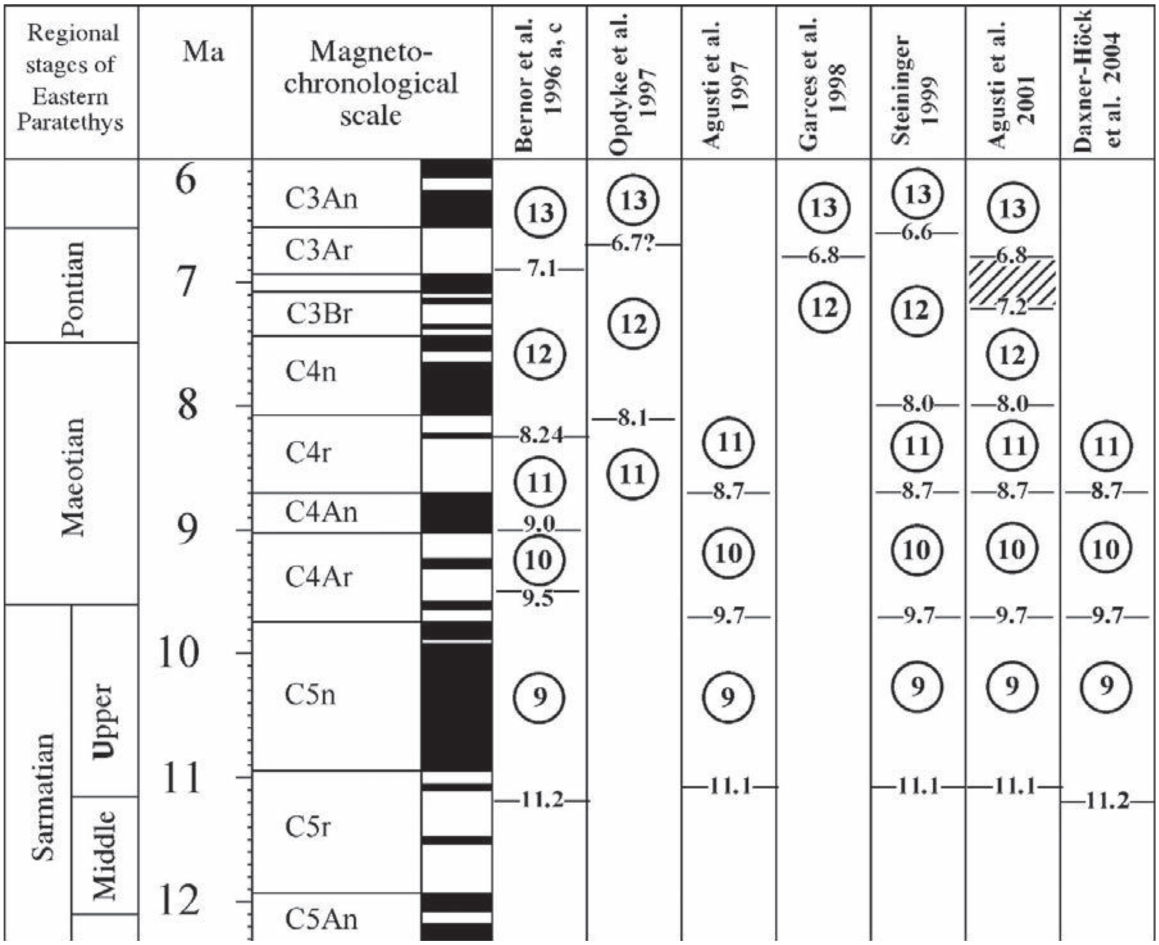

Figure 23.1 Ages of MN zone boundaries in western Europe according by different authors. Zone numbers are in circles. After Vangengeim and Tesakov (2008b).

Ages of magnetochronological boundaries are according to the geomagnetic polarity timescale (GPTS) CK95 following Berggren et al. (1995). The updated scale ATNTS2004 (Lourens et al. 2004) was used for comparisons with most recent data. Deposits of Eastern Paratethys are correlated to the magnetochronological scale based on data of Pevzner (1986; Pevzner, Semenenko, and Vangengeim 2003).

Locations of most important localities are given in figure 23.5 and table 23.1.

PALEOMAGNETIC CHARACTERISTICS FOR MIDDLE SARMATIAN-KIMMERIAN DEPOSITS OF EASTERN PARATETHYS

The representative sections of the marine middle and upper Sarmatian, characterized by malacofauna and studied paleomagnetically, are known on the Taman Peninsula, and at the Eldari section in eastern Georgia (Pevzner 1986; Vangengeim et al. 1989; Pevzner and Vangengeim, 1993; Pevzner, Semenenko, and Vangengeim 2003; Vangengeim, Lungu, and Tesakov 2006; see figure 23.2).

The lower normally magnetized part of the middle Sarmatian is correlated with the upper part of chron C5An. The middle Sarmatian is 135 m thick in the section east of the cape Panagia on the Taman Peninsula, and about 360 m thick in the Eldari section. This interval is capped by reversely magnetized deposits correlative with larger part of chron C5r. On the Taman Peninsula, the upper Sarmatian deposits have a thickness about 150 m; in Eldari, they are 980 m thick. The boundary between the upper and middle Sarmatian is situated slightly below a normal polarity zone that we correlate with subchron C5r.1n. Its age, estimated near 11.2 Ma, is controlled by the fission-track date 11.19 ± 0.74 Ma

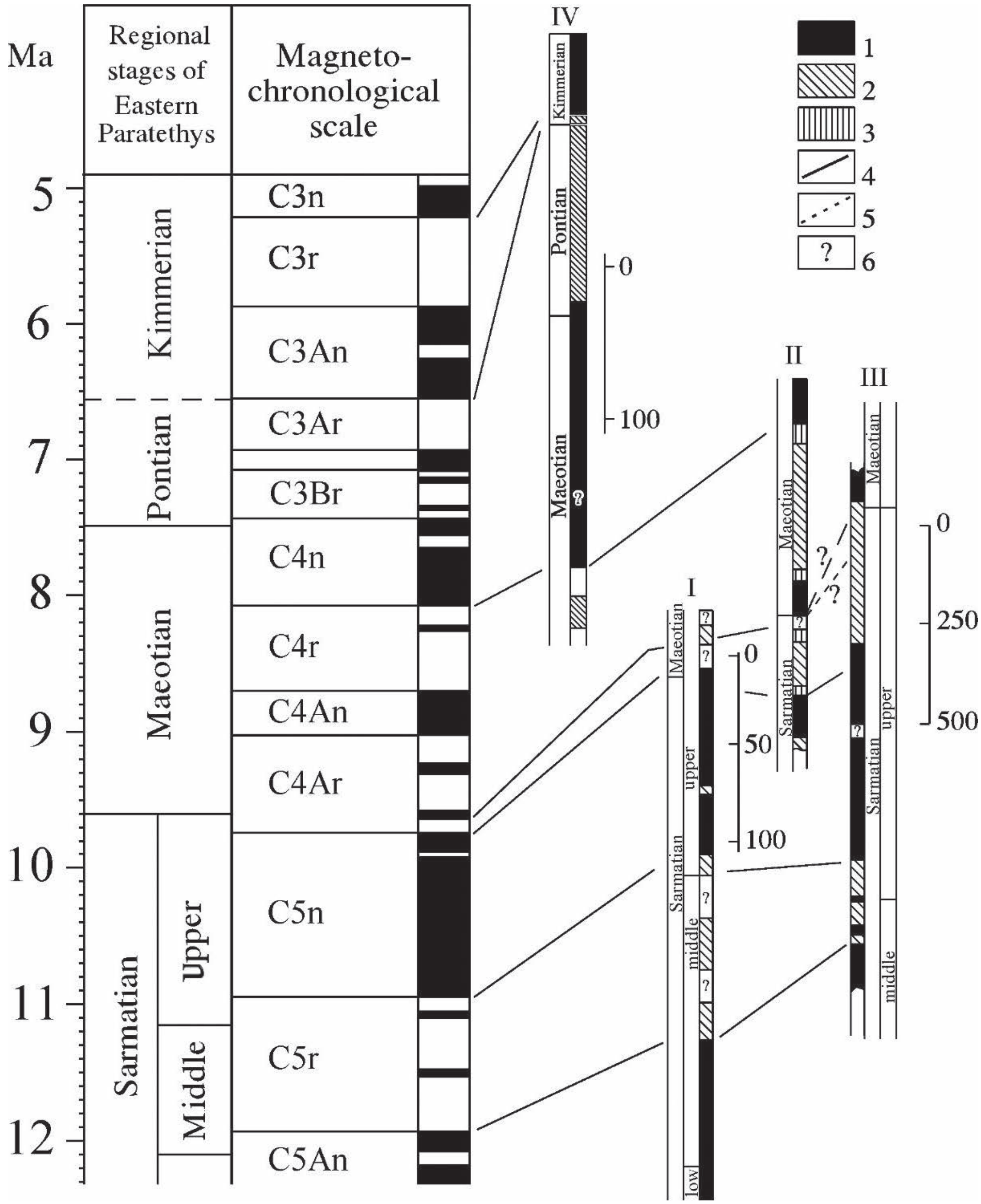

Figure 23.2 Magnetostratigraphic sections of the Sarmatian, Maeotian, and Pontian deposits of eastern Paratethys. Taman Peninsula east (*I*) and west (*II*) of the Panagia Cape; Eldari, eastern Georgia (*III*); Taman Peninsula, Zheleznyi Rog (*IV*). (*1*) normal polarity; (*2*) reversed polarity; (*3*) unstable polarity; (*4*) magnetostratigraphic correlation; (*5*) assumed magnetostratigraphic correlation; (*6*) unsampled interval. Modified after Vangengeim and Tesakov (2008a, 2008b).

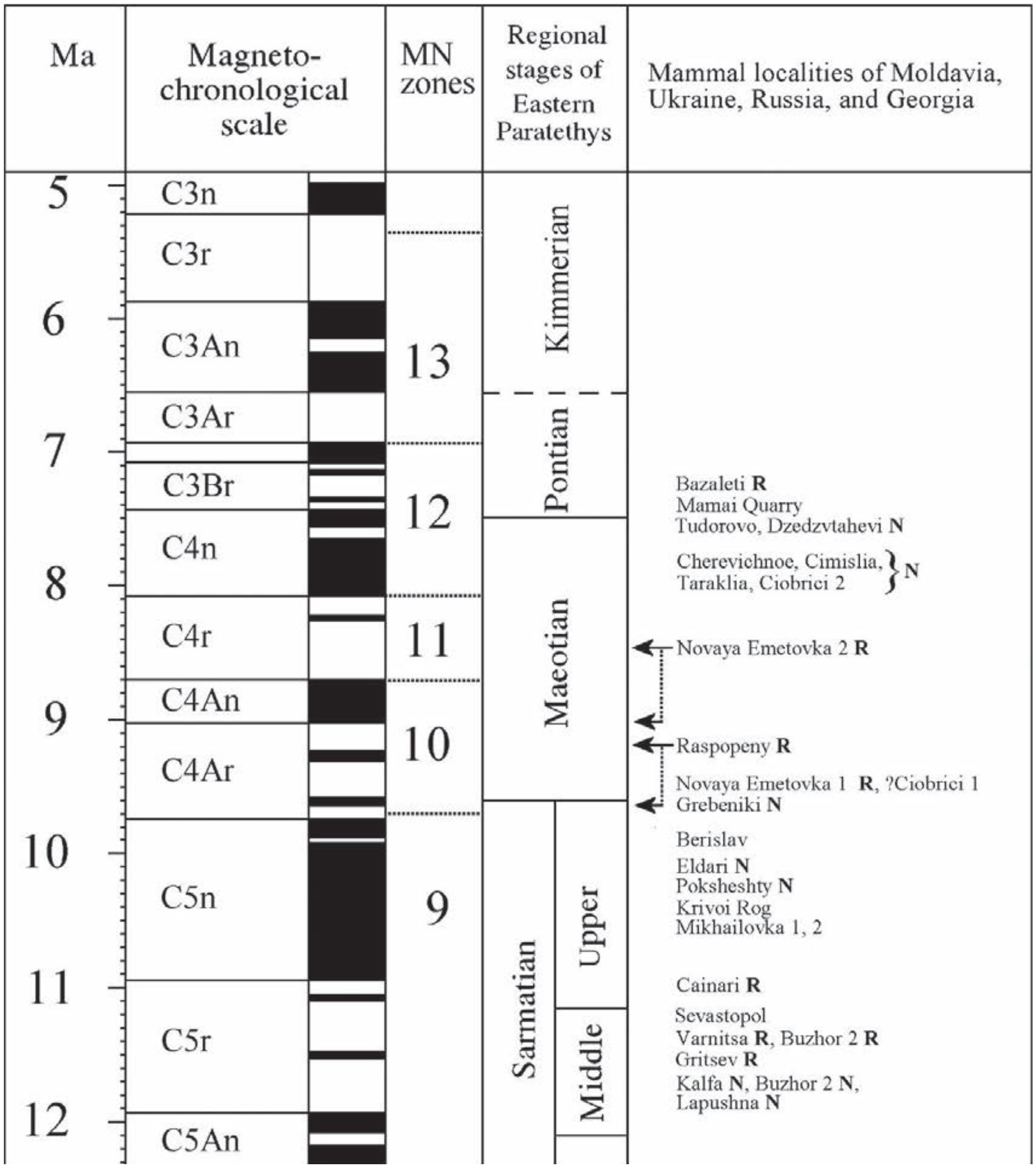

Figure 23.3 Correlation of mammal localities of eastern Paratethys with geomagnetic polarity time scale: R = reversed polarity; N = normal polarity. Modified after Vangengeim et al. (2006) and Vangengeim and Tesakov (2008a, 2008b).

several meters above the base of the Khersonian on the Taman Peninsula (Chumakov, Byzova, and Ganzei 1992; Steininger et al. 1996). The larger part of the upper Sarmatian deposits is normally magnetized (chron C5n), and only the lowermost and uppermost beds provided reversed polarities correlated with C5r.2r and C4Ar.3r (Vangengeim et al. 1989; Pevzner and Vangengeim 1993; Vangengeim and Tesakov 2008a).

A normal polarity zone correlative to subchron C4Ar.2n with the older boundary, dated at 9.6 Ma by Berggren et al. (1995) or at 9.7 Ma by Lourens et al. (2004), occurs at the base of Maeotian in the Taman section. This defines the age of the Sarmatian–Maeotian boundary. This boundary was estimated at 9.3 Ma based on the fission-track date 9.26 ± 0.74 Ma from the base of the Maeotian in east Azerbaijan (Chumakov, Byzova, and Ganzei 1992). Paleomagnetic data for Maeotian deposits are known from two sections on the Taman Peninsula. The lower part of the Maeotian was studied 2 km west of the Cape Panagia, and the upper part was studied in the Zheleznyi Rog (Iron Horn) section. The

Regional Stages of Eastern Paratethys		Korotkevich (1988), Nesin, Nadachowski (2001) Semenov (2002)		Gabunia (1986)		Lungu, Chemyrtan (1989) Lungu (1990)		Pevzner, Vangengeim (1993)		This contribution	
Pontian	Lower	13	Cherevichnoe Tudorovo	13	Mamai Bazaleti					12	Mamai Bazaleti
Maeotian	Upper / "Middle"	12b	Belka, Taraklia Cimislia	12	Tudorovo Cherevichnoe					12	Tudorovo, Dzedzvtahevi, Cherevichnoe Belka, Cimislia, Taraklia, Ciobruci u.b.
										11	Novaya Emetovka 2 Novoelizavetovka
	Lower	12a	Novaya Emetovka 2 Novoelizavetovka Novaya Emetovka 1	11	Taraklia Cimislia Novoelizavetovka Grebeniki			11		10	Novoukrainka ?Ciobruci l.b., Novaya Emetovka 1 Grebeniki ?Raspopeny
Sarmatian	Upper	11b	Staraya Kubanka Novoukrainka Grebeniki, Ciobruci	10	Cainary Berislav Eldari	10	Grebeniki Raspopeny Staraya Kubanka Krivoi Rog Poksheshty Eldari Tyaginka Berislav Cainari	10	Cainari, Raspopeny Eldari, Berislav, Staraya Kubanka, Poksheshty Krivoi Rog	9	?Staraya Kubanka Berislav, Tyaginka Eldari Poksheshty Krivoi Rog, Mikhailovka 1,2 Cainari
		11a	Poksheshty, Raspopeny, Berislav, Tyaginka, Krivoi Rog, Mikhailovka 2								
	Middle	10	Mikhailovka 1 Sevastopol Varnitsa Zheltokamenka Atavaska Kalfa, Buzhor	9	Sevastopol Varnitsa Zhelto-kamenka Buzhor, Kalfa	9	Sevastopol Buzhor 2, Varnitsa, Gritsev Buzhor 1 Atavaska, Kalfa, Zheltokamenka	9	Sevastopol Gritsev, Varnitsa Buzhor 2 Lapushna Buzhor 1, Kalfa, Kishinev, Atavaska, Zhelto-kamenka	9	Sevastopol Varnitsa, Gritsev, Buzhor 2 Lapushna, Buzhor 1 Kalfa, Kishinev, Atavaska, Zheltokamenka
		9	Gritsev, Klimentovichi								

Figure 23.4 Correlation of Late Miocene mammal localities of eastern Paratethys with MN zones according to different authors. Modified after Vangengeim and Tesakov (2008b).

zone of normal polarity in the lower part of Maeotian (17 m, the Panagia Cape section) is followed by a thick zone (60 m) of reversely magnetized sediments correlated to chron C4Ar. On the Kerch Peninsula, deposits of the lower Maeotian contain the nannoplankton boundary of zones NN9/10 (Bogdanovich and Ivanova 1997) dated at 9.4 Ma (Berggren et al. 1995). In the Panagia record, the higher interval of paleomagnetic section is represented by normally magnetized deposits (20 m) correlative with chron C4An. In Zheleznyi Rog, the reversely magnetized zone (18 m)

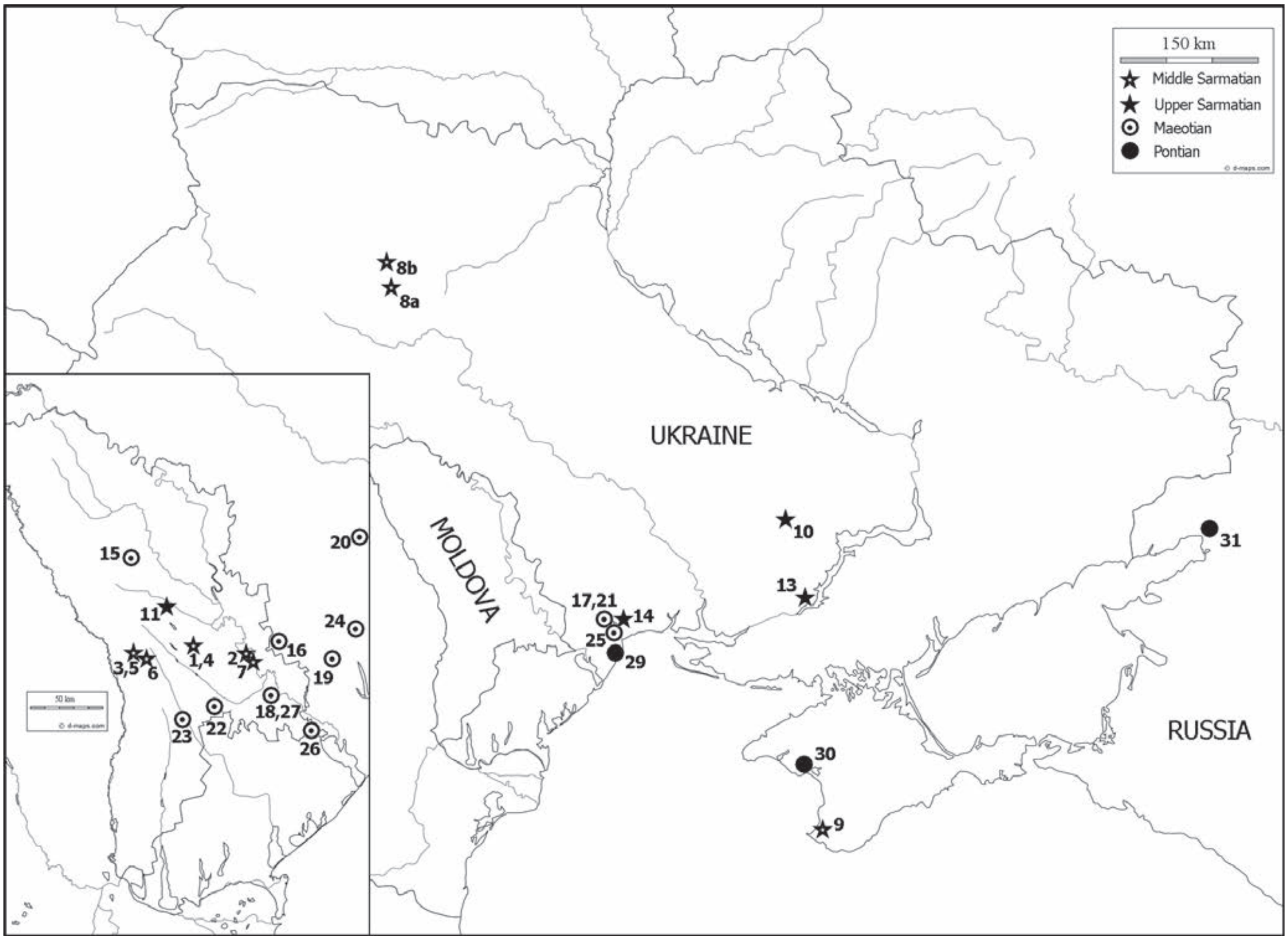

Figure 23.5 Geographic positions of reference Late Miocene mammalian localities in the North Black Sea area. Numbers correspond to locality numbers in tables 23.1–23.3.

and 20-m-thick unsampled interval is capped by a 160-m-thick zone of normally magnetized deposits. This interval corresponds to the larger part of chron C4n. The Maeotian-Pontian boundary in this section lies in the upper part of normal polarity zone (C4n) and is dated at ca. 7.5 Ma. The fission-track date 7.14 ± 0.58 Ma was obtained for presumably lower Pontian continental Shiraki Formation in eastern Georgia (Chumakov, Byzova, and Ganzei 1992). The Shiraki Formation is correlated with undivided Maeotian and Pontian stages. The remaining part of Pontian deposits is mainly reversely magnetized and is correlated with chrons CBr–C3Ar (Pevzner 1986; Pevzner, Semenenko, and Vangengeim 2003). The observed simplified structure of paleomagnetic pattern compared to the complete set of reversed and normal chrons in the correlated interval of GPTS may be accounted for by the known erosional gap between the lower and upper Pontian (Filippova and Trubikhin 2009). This hiatus can correspond to chron C3Bn (Pevzner et al. 2004). In our view, the upper boundary of the lower Pontian can be dated at 7.1–7.2 Ma, which is, apparently, synchronous with the Messinian lower boundary (chron C3Br.1r).

The upper boundary of the Pontian in the Black Sea basin is not defined, but it is probably not younger than 6.5 Ma (the older boundary of chron C3An). A stratigraphic hiatus occurs between the Pontian and Kimmerian in the Taman Peninsula. Another hiatus is also recognized inside the Azov beds of the Kimmerian. On the Kerch Peninsula, the borehole 15 exposed Pontian deposits with reversed magnetization. The lower part of the Azov beds (about 80 m) have no paleomagnetic characteristics. The higher Azov beds show three alternating zones of reversed and normal polarity interpreted as Thvera, Sidufjall, and Nunivak (Pevzner, Semenenko, and Vangengeim 2003).

Table 23.1
Locations of Late Miocene Reference Localities

No.	Locality	Country	Geographic Position
	Middle Sarmatian (Bessarabian)		
1	Kishinev	Moldova	47°0′0″N 28°51′0″E
2	Kalfa	Moldova	46°54′20″N 29°21′30″E
3	Buzhor 1 (Bujor 1)	Moldova	46°55′41″N 28°16′4″E
4	Atavaska	Moldova	47°0′0″N 28°48′0″E
5	Buzhor 2 (Bujor 2)	Moldova	46°55′41″N 28°16′4″E
6	Lapushna	Moldova	46°53′32″N 28°24′38″E
7	Varnitsa	Moldova	47°12′0″N 28°54′0″E
8a	Gritsev	Ukraine	49°57′57″N 27°12′57″E
8b	Klimentovichi	Ukraine	50°14′20″N 27°7′0″E
9	Sevastopol	Ukraine	44°30′0″N 33°36′0″E
	Upper Sarmatian (Khersonian)		
10	Krivoi Rog	Ukraine	47°54′0″N 28°30′0″ E
11	Poksheshty	Moldova	47°14′50N 28°40′55″E
12	Eldari	Georgia	41°18′0″N 45°42′0″E
13	Berislav	Ukraine	46°50′12″N 33°25′25″E
14	Staraya Kubanka	Ukraine	46°42′0″N 30°43′0″E
	Maeotian		
15	Raspopeny	Moldova	47°27′0″N 28°21′36″E
16	Grebeniki	Ukraine	46°53′0″N 29°49′0″E
17	Novaya Emetovka 1	Ukraine	46°39′0″N 30°36′0″E
18	Ciobruci (lower bed)	Moldova	46°36′0″N 29°42′0″E
19	Novoukrainka	Ukraine	48°48′54″N 30°17′12″E
20	Novoelizavetovka	Ukraine	47°09′10″N 30°24′6″E
21	Novaya Emetovka 2	Ukraine	46°39′0″N 30°36′0″E
22	Taraklia	Moldova	46°34′0″N 29°08′0″E
23	Cimislia	Moldova	46°30′10″N 28°48′30″E
24	Belka	Ukraine	46°54′0″N 30°25′55″E
25	Cherevichnoe	Ukraine	46°39′0″N 30°36′0″E
26	Tudorovo	Moldova	46°26′20″N 30°1′30″E
27	Ciobruci (upper bed)	Moldova	46°36′0″N 29°42′0″E
	Lower Pontian		
28	Bazaleti	Georgia	41°54′0″N 45°00′0″E
29	Odessa	Ukraine	46°22′30″N 30°44′35″E
30	Eupatoria	Ukraine	45°12′0″N 33°24′0″E
31	Rostov-on-Don	Russia	47°13′0″N 39°40′0″E

Close age estimates and correlation of Central and Eastern Paratethys strata are used by Austrian geologists (Rögl and Daxner-Höck 1996; Steininger et al. 1996; Steininger 1999; Rögl 2001). The base of the Sarmatian s.l. (Eastern Paratethys) and the Sarmatian s. Suess (Central Paratethys) is dated at 13–13.6 Ma. The lower boundary of the Pannonian lies in the upper part of the middle Sarmatian in chron C5r. It is estimated close to 11.5 Ma (Vasiliev 2006), and recently it was refined at 11.42 Ma (Lirer et al. 2009). This boundary is close to the lower boundary of the Tortonian in the Mediterranean, occurring inside chron C5r at 11.1 Ma according to Berggren et al. (1995) or at 11.6 Ma according to the astronomical age by Gradstein et al. (2004) and Hilgen, Brinkhuis, and Zachariasse (2006). The Pannonian is correlative to the upper part of the middle Sarmatian, upper Sarmatian s.l., and Maeotian. The Pannonian-Pontian boundary is placed in the interval between 8 Ma and 7 Ma (Rögl and Daxner-Höck 1996:50), or recently at 6.1 Ma (Krijgsman et al. 2010).

The interpretation presented here of paleomagnetic data contrasts with the views of Trubikhin (1989, 1998; Nevesskaya et al. 2004; Popov, Nevesskaya, and Pinchuk 2007): "Pontian and the Azov beds [of the Kimmerian] . . . correspond to the lower part of the Gilbert Chron, and the Maeotian, to Chrons 5 [= chron C3An] and 6 of normal and reversed polarity, respectively. This pair (Pontian and Maeotian) . . . corresponds to the Messinian of the Mediterranean and, probably, to the Pannonian of the Pannon and Vienna Basin" (Trubikhin 1998:13). According to this interpretation, the Maeotian lower boundary has the age of 7.4 Ma (chron C3Br), and that of Pontian, 6.15 Ma (in chron C3n.1n). "The underlying Sarmatian sequence belongs to chrons 7 and 8 (mainly upper Sarmatian) [C4Ar–C4n, our note], 9 (mainly middle Sarmatian) [chron C5n, our note] and, finally, 10 (mainly lower Sarmatian) of the magnetochronological scale" (Trubikhin 1998:16; see also Popov et al. 1996). Correlation of the upper Sarmatian (Khersonian) with chrons C4Ar–C4n with predominantly reversed polarity contradicts the observed mostly normal magnetization of the upper Sarmatian in sections of the Taman Peninsula and east Georgia.

The group of Dutch and Romanian researchers (Snel et al. 2006) used the Turbikhin correlation scheme for the Dacic Basin, at least, for the Maeotian and Pontian, with the lower boundary of Pontian at 6.15 Ma, and the Pontian–Kimmerian boundary at 5.3 Ma. The recent restudy of the Maeotian-Kimmerian interval of the Zheleznyi Rog section (Krijgsman et al. 2010) produced similar results and correlations. Worth mentioning is the recent micropaleontological study of the same section that bracketed the Maeotian-Pontian boundary between 6.1 Ma and 5.9 Ma based on the short-lived presence of index species of oceanic diatoms (Radionova and Golovina 2009).

Zone MN9: Early Vallesian ([?]12–9.7 Ma)

Localities of the Middle Sarmatian

The lower boundary of the middle Sarmatian (Bessarabian), dated at ca. 12 Ma, lies in the upper part of chron C5An (Pevzner 1986; Steininger et al. 1996).

The oldest localities with hipparion remains are known in bioherm limestones of the lower (?) bed of middle Sarmatian near Chisinau (=Kishinev, Moldova; Lungu and Chemyrtan 1989; Lungu 1990). They include *Thalassictis robusta* Nordmann, *Deinotherium* sp., "*Hipparion*" sp., *Alicornops simorrense* (Lartet), and *Microstonyx antiquus* Kaup. The locality Zheltokamenka (Ukraine) of similar geological age yielded *Machairodus* cf. *aphanistus* Kaup, *Gomphotherium* cf. *angustidens* (Cuvier), and *Anchitherium* sp. (a single record). No hipparion remains have been found (Pidoplichko 1956). These sites do not have paleomagnetic records.

The localities Kalfa, Buzhor 1, and Lapushna (Moldova) are associated with marine deposits of the middle Sarmatian. Normal magnetization of bone-bearing beds suggests a correlation with the subchron C5r.2n (dated in ATNTS2004 at 11.554–11.614 Ma), or alternatively with the upper part of chron C5An (Vangengeim, Lungu, and Tesakov 2006). The appearance of hipparions (i.e., that mark the beginning of the Vallesian) in the middle Sarmatian in these sites thus can be dated at 11.5 Ma (or at 12 Ma as an older alternative). This is at least 0.3 myr older than the estimate of this datum (11.2 Ma) in western and central Europe (Steininger et al. 1996; Actes du Congrés BiochroM'97 1997; Vangengeim, Lungu, and Tesakov 2006; Lirer et al. 2009; and others).

Progonomys is known from 12 Ma onward in Pakistan (Flynn et al. 1995). The oldest lower Vallesian records of *Progonomys* in North Africa, Asia Minor, and Europe may be as old as 10.3 Ma (van Dam 1997; Sen 2003; Wessels 2009). Murid material described as *Progonomys cathalai* Schaub from Buzhor 1 (Lungu 1981) probably contains two different forms, with one of them showing a very primitive "*Mus*"-like morphology (Mein, Martín-Suárez, and Agustí 1993) and another representing *Parapodemus* morphology. The similar mixture of *Progonomys and Parapodemus* morphologies (lineages?) was described in lower Vallesian of Turkey (Sen 2003).

The observed diachrony of the Vallesian lower boundary could be minimized if the alternative correlation with the GPTS of Can Llobateres (Spain) and Kastellios (Greece), the sites with hipparionine horses and *Progonomys*, is considered. Until recently, these sites were placed in chron C4Ar (Sen 1996; Agustí, Cabera, and Garcés 2001). Aguilar with coauthors (Aguilar et al. 2004; Costeur et al. 2007) provided evidence for their placement in chron C5r. According to this viewpoint, Can Llobateres 1 is correlated to subchron C5r.3r, Can Llobateres 2, to C5r.2n, and Kastellios, to chrons C5r.3r–C5r.1r. See discussion in Wessels (2009) for rejection of this correlation in favor of younger (C4Ar) age of these records.

The upper (and larger) part of the middle Sarmatian belongs to a zone of reversed polarity correlative to chron C5r. This interval includes localities Buzhor 2, Varnitsa, Viveritsa (Moldova), Gritsev, and Klimentovichi (northwestern Ukraine). The Ukrainian paleontologists (e.g., Topachevsky et al. 1996) consider Gritsev and Klimentovichi as the oldest Vallesian sites of eastern Europe. They correlate these localities to the lower middle Sarmatian. The bone-bearing deposits of these sites, however, represent fissure fillings associated with the erosional surface (and, accordingly, a stratigraphic hiatus) on the lower middle Sarmatian deposits.

The Gritsev fauna contains two forms of hipparions: *Hippotherium primigenium* and "*Hipparion*" sp. (Krakhmalnaya 1996b), which is not common for the earliest Vallesian. Small mammals are represented by abundant and diverse soricids and glirids, and carnivorans, by abundant mustelids, indicating widespread forested environment. The fauna contains a significant number of Astaracian forms (Nesin and Topachevsky 1999). These features markedly distinguish the fauna of Gritsev from faunas of more southern Moldavian sites that show drier and more open conditions. This evidently places the two areas into different paleozoogeographic provinces, the central European (Gritsev) and southeastern (Moldavian sites) (Bernor 1996b; Fortelius, Van der Made, and Bernor 1996) or central European and east European (Lungu 1990). The Gritsev fauna shares numerous genera with a slightly younger Rudabánya fauna in Hungary, which also belongs to the central European province (Bernor et al. 2004).

The youngest middle Sarmatian locality, lying close to the boundary with the upper Sarmatian, is Sevastopol in the Crimea (Lungu 1990; Pevzner and Vangengeim 1993; Vangengeim, Lungu, and Tesakov 2006).

The early Vallesian faunas of Eastern Paratethys (tables 23.2 and 23.3) show the appearance of *Machairodus*, *Hippotherium primigenium* (Meyer), *Microstonyx antiquus* (Kaup), a chilothere, and *Progonomys cathalai* Schaub, and many Astaracian elements are retained. Only the middle Sarmatian faunas document the presence of *Eomellivora wimani piveteaui* Ozansoy, *Sansanosmilus*, *Thalassictis*, *Protictitherium crassum* (Deperet), *Metailurus pamiri* (Ozansoy), *Pseudaelurus turnauensis* (Hoernes), *Alicor-*

Table 23.2
Stratigraphic Distribution of Large Mammals (Carnivora) in Eastern Paratethys

	MN 9		MN 10	MN 11	MN 12/?MN 13
	Sarmatian		Maeotian–Lower Pontian		
	Middle	Upper	Lower Maeotian	Middle Maeotian	Upper Maeotian–Lower Pontian
Simocyon primigenius	8 sp.	10	19		
Indarctos sp.	8				
Plesiogulo crassa	8 cf.				25
Plesiogulo brachygnathus	3	11 aff.			
Eomellivora wimani piveteaui	2, 3, 8				
Eomellivora wimani wimani			16	21	
Palaeomeles sp.	8				
Promeles sp.	2				
Promeles palaeattica					23
Proputorius aff. *medius*	3				
Parataxidea aff. *polaki*		11 sp., 14			
Promephitis maeotica			16	20, 21 sp.	28 sp.
Sansanosmilus piveteaui	2, 7, 8				
Dinocrocuta gigantea	2, 3, 8 sp.	11, 12			
Percrocuta robusta	1, 2, 3, 7				
Allohyaena sarmatica	8				
Adcrocuta eximia		10 cf.	16, 17, 19	20, 21	23–26
Miochyaenotherium bessarabicum					23, 24
Ictitherium viverrinum		10	16	20	24, 28
Ictitherium pannonicum				21	25 cf.
Sansanosmilus piveteaui	8				
Dinocrocuta gigantea				20	22–24, 26
Protictitherium crassum	2, 9	11 aff.		20, 21	
Thalassictis robusta	1				
Thalassictis montadai	2, 3				
Hyaenotherium wongii			16 cf., 17 cf., 19 cf.	21 cf.	25
Semigenetta sp.	8				
Machairodus aphanistus	8 cf.	10 cf., 11 sp.	19 cf.	?21	
Machairodus giganteus				20	22, 23, 24
Machairodus laskarevi	2, 3				
Machairodus copei			16		
Pseudaelurus turnauensis	2, 3				
Pseudaelurus sp.	2, 3, 8		19		
Metailurus pamiri	2				
Metailurus sp.		11			25
Metailurus parvulus			16	20	22, 23

Mammal localities. Middle Sarmatian: 1. Kishinev; 2. Kalfa; 3. Buzhor 1 (Bujor 1); 4. Atavaska; 5. Buzhor 2 (Bujor 2); 6. Lapushna; 7. Varnitsa; 8. Gritsev, Klimentovichi; 9. Sevastopol.

Upper Sarmatian: 10. Krivoi Rog; 11. Poksheshty; 12. Eladari; 13. Berislav; 14. Staraya Kubanka.

Maeotian: 15. Raspopeny; 16. Grebeniki; 17. Novaya Emetovka 1; 18. Ciobruci (lower bed); 19. Novoukrainka 1; 20. Novoelizavetovka; 21. Novaya Emetovka 2; 22. Taraklia; 23. Cimislia; 24. Belka; 25. Cherevichnoe; 26. Tudorovo; 27. Ciobruci (upper bed). Lower Pontian: 28. Bazaleti, 29. Sporadic occurrences in lower Pontian limestone in Odessa, Eupatoria, and Rostov-on-Don.

Table 23.3
Stratigraphic Distribution of Large Mammals (Proboscidea, Perissodactyla, Artiodactyla) in Eastern Paratethys

	MN 9		MN 10	MN 11	MN 12/?MN 13
	Sarmatian		Maeotian–Lower Pontian		
	Middle	Upper	Lower Maeotian	Middle Maeotian	Upper Maeotian–Lower Pontian
Gomphotherium angustidens	8				
Choerolophodon spp.	2, 7, 9	12, 13, 14	17, 19	20, 21	
Tetralophodon gr. *longirostris-atticus*	4	11	16	20, 21,	22, 23, 29
"Mammut" gr. *obliquelophus-borsoni*				20	22, 23, 24
Deinotherium giganteum	1 sp., 2, 8, 9 sp.	10, 12, 13 sp.	15, 16, 17 sp.,19 sp.	20	22, 23, 24 sp., 25, 28 sp.
Hippotherium primigenium	1–6, 8, 9 ex gr.	12 ex gr.			
Hippotherium giganteum		11 cf., 14	15 aff., 16, 19		
"Hipparion" verae	7	11 cf., 13 cf. 14	16, 17, 18 cf., 19 cf.		
"*Hipparion*" sp.	8		17	21	25 (cf. probos-cideum), 28, 29
Cremohipparion moldavicum				20, 21, ?27 cf.	22–26
Chalicotherium goldfussi	8 cf.				
Acerorhinus sp. (= *Aceratherium incisivum* auct)			16	20, 21	22–24, 25 sp. 26, 28 cf.
Aceratherium simplex					26
Chilotherium schlosseri		14 cf.	16, 17, 19 sp.		
Acerorhinus zernowi	7, 9	10 sp., 11 cf. 12			
Chilotherium kowalevskii			15, 16		
Chilotherium sarmaticus		11 aff., 13			
Alicornops simorrensis	1, 2, 3, 4, 5, 8				
"*Dicerorhinus*" sp.	2, 7, 9				25
Diceros gabuniai		12			
Ceratotherium neumayri					29 cf.
Ancylotherium pentelicum			19 cf.		
Schizochoerus vallesiensis	2				
Microstonyx antiquus	1, 2	12, 13 cf.			
Microstonyx major			15, 16, 17, 19	20, 21	22, 23, 24, 25 sp., 28 sp.
Propotamochoerus palaeochoerus	8				
Lagomeryx flerovi	2–7, 9				
Dorcatherium sp.	8				
Hispanomeryx duriensis	8 aff.				
Amphiprox sp.	8				
Euprox furcatus	2, 3, 4, 8 sp.				
Euprox sarmaticus		10			
Procervulus sp.	8				
Cervavitus sp.		11	15, 18		
Cervavitus variabilis			16, 17, 19	20	22, 23
Cevavitus novorossiae					22, 23
Procapreolus frolovi					25

	MN 9		MN 10	MN 11	MN 12/?MN 13
	Sarmatian		Maeotian–Lower Pontian		
	Middle	Upper	Lower Maeotian	Middle Maeotian	Upper Maeotian–Lower Pontian
Procapreolus ukrainicus		12	16 cf., 19	20 cf.,	24 cf.
Palaeotragus (Achtiaria) expectans	1, 6, 7, 9				
Palaeotragus (Achtiaria) bereslavicus		13			
Palaeotragus (Achtiaria) moldavicus		11 aff.	15, 16 sp., 17 sp.		
Palaeotragus (Achtiaria) borissiaki		12, 14 sp.			
Palaeotragus pavlowae			16		
Palaeotragus rouenii				20, 21	22, 23, 24
Palaeotragus sp.			17., ?18, 19		28
Chersonotherium eminens			19 sp.	20	
Samotherium maeoticum		13 sp., 14 sp.	19 sp.	21	24 sp.
Samotherium boisseri					22, 24 sp.
Helladotherium duvernoyi					22, 23
Procapra capricornis		13 cf., 14	16, 17 cf., 19		23
Procapra rodleri				21 aff.	22, 24
Procapra longicornis					25
Gazella gracile		11, 12, 13	15		
Gazella pilgrimi				20, 21	23
Gazella schlosseri			16, 17, 19		
"Protragocerus" leskewitschi	9	11, 12 aff.	16, 19		
Miotragocerus pannoniae	2, 3, 8 cf.				
Miotragocerus borissiaki	9				
Tragocerus frolovi			18, 19	20	23, 26
Mesotragocerus citus				21	
Graecoryx valenciennesi		12, 13 cf.			
Graecoryx bonus					22, 24
Protragelaphus skouzesi		14 sp.	16		22
Palaeoreas lindermayeri					23
Procobus melania				21	22
Procobus brauneri					22
Moldoredunca amalthea	7, 9				
Palaeoryx pallasi				21	23, 29
Palaeoryx majori			16, 17 sp.		22, 26
Tragoreas oryxoides					22

NOTE: Mammal localities. Middle Sarmatian: 1. Kishinev; 2. Kalfa; 3. Buzhor 1 (Bujor 1); 4. Atavaska; 5. Buzhor 2 (Bujor 2); 6. Lapushna; 7. Varnitsa; 8. Gritsev, Klimentovichi; 9. Sevastopol.

Upper Sarmatian: 10. Krivoi Rog; 11. Poksheshty; 12. Eldari; 13. Berislav; 14. Staraya Kubanka.

Maeotian: 15. Raspopeny; 16. Grebeniki; 17. Novaya Emetovka 1; 18. Ciobruci (lower bed); 19. Novoukrainka 1; 20. Novoelizavetovka; 21. Novaya Emetovka 2; 22. Taraklia; 23. Cimislia; 24. Belka; 25. Cherevichnoe; 26. Tudorovo; 27. Ciobruci (upper bed). Lower Pontian: 28. Bazaleti, 29. Sporadic occurrences in lower Pontian limestone in Odessa, Eupatoria, and Rostov-on-Don.

nops simorrensis (Lartet), *Lagomeryx*, *Euprox*, *Amphiprox*, *Palaeotragus (Achtiaria) expectans* (Borissiak), and *Gomphotherium angustidens* (Cuvier). *Propotamochoerus palaeochoerus* (Kaup) is found only in northwestern Ukraine, in the central European province (Lungu 1990; Wolsan and Semenov 1996; Krakhmalnaya 2008).

From the mid-middle Sarmatian, hipparionine horses show a marked differentiation. In addition to the typical *Hippotherium primigenius*, other forms as "*H.*" sp. (Gritsev), "*Hipparion*" cf. *verae* Gabunia (Varnitsa), and *Hippotherium sebastopolitanum* (Borissiak; Sevastopol) appeared. Forsten (1978) considered the latter species as an independent local form, parallel to *H. primigenium*.

Localities of the Late Sarmatian

The middle–late Sarmatian boundary is dated at about 11.2 Ma (below subchron C5r.1n). This transition is marked by a considerable marine regression and possibly related changes in the composition of mammalian fauna (Muratov and Nevesskaya 1986; Pevzner and Vangengeim 1993). The lowermost beds of marine upper Sarmatian contain the small mammal locality Cainari (Moldova) with *Progonomys* cf. *cathalai* Schaub and *P. woelferi* Bachmayer et Wilson (Lungu and Chemyrtan 1989; Lungu 1990). The reversely magnetized deposits in Cainari are correlated with subchron C5r.1r (Vangengeim and Tesakov 2008a).

No reliably dated large mammal sites corresponding to the early late Sarmatian are known yet. The site Krivoi Rog (Ukraine) is located close to northern coastal line of the maximum late Sarmatian marine transgression. The small mammal locality Mikhailovka (Ukraine) has a similar geological age. The lower bone-bearing bed (Mikhailovka 1) occurs in lacustrine-fluviatile sequence upon the erosional surface truncating upper middle Sarmatian deposits. The higher bone-bearing bed of Mikhailovka 2 occurs in limestones of the maximum late Sarmatian transgressions (Nesin and Topachevsky 1999; Vangengeim and Tesakov 2008a). Ukrainian paleontologists refer the lower bed to the upper middle Sarmatian and refer the upper bed to the beginning of the Upper Sarmatian. There are no paleomagnetic data for this site. Because the precise age of the maximum late Sarmatian transgressions is currently unknown, we by convention correlate sites Krivoi Rog and Mikhailovka 1 and 2 to the middle of chron C5n. Both bone beds of Mikhailovka yielded remains of microtoid cricetid *Ischymomys quadriradicatus* Zazhigin (Nesin and Topachevsky 1999).

The later part of marine late Sarmatian is represented by the Eldari (Georgia), Berislav, Staraya Kubanka, Yurievka, and Tyaginka (Ukraine) localities; the Poksheshty (Moldova) locality occurs in continental deposits of the Balta Formation (Gabunia 1986; Korotkevich 1988; Lungu and Chemyrtan 1989; Lungu 1990; Vangengeim and Tesakov 2008a). All these sites belong to the younger part of chron C5n (Vangengeim and Tesakov 2008a). A remarkable occurrence of murids (cf. *Progonomys*) was reported by Steklov (1966) from the Upper Sarmatian deposits of Maikop in the Northern Caucasus, Russia.

Hipparions of the later part of late Sarmatian are represented by the very large form *Hippotherium giganteum* (Gromova), accompanied by smaller forms of the *H. primigenium* group, and "*Hipparion*" *verae* (Gabunia). According to Forsten (1980), the latter species is at the base of the lineage leading to *Cremohipparion mediterraneum*. The fauna documents the last occurrences of *Dinocrocuta* and *Percrocuta*. Among newcomers are *Adcrocuta eximia* (Roth et Wagner), *Ictitherium viverrinum* Roth and Wagner, *Gazella*, *Procapra*, *Procapreolus*, *Graecoryx*, new forms of *Palaeotragus* (*Achtiaria*) (*P.* (*A.*) *borissiaki* (Alexejev), *P.* (*A.*) *berislavicus* Korotkevich), *Samotherium*, *Cervavitus* (Korotkevich 1988; Lungu 1990; Werdelin and Solounias 1991). The fauna is dominated by chilotheres and hipparions.

In Western Europe (Spain), the zone MN 9 was subdivided into two subzones: MN9 a (*Megacricedon* + *Hipparion*) and MN 9b (*Cricetulodon*), with a boundary at 10.4 Ma (Agustí et al. 1997; Agustí 1999). The younger late Sarmatian faunas can be correlated with the subzone MN 9b (Vangengeim and Tesakov 2008a).

Zone MN10: Late Vallesian (9.7–8.7 Ma)

The zone MN 10 is correlated with upper levels of the upper Sarmatian and the lower Maeotian (chron C4Ar; Vangengeim and Tesakov 2008b). The Sarmatian/Maeotian boundary lies at the base of subchron C4Ar.2n, at 9.6 Ma.

Localities of the Early Maeotian

The zone MN 10 includes the Grebeniki, Novaya Emetovka 1, Novoukrainka (Ukraine), and Raspopeny sites and the lower(?) bed of Ciobruci (Moldova). In Grebeniki, the bone-bearing bed is normally magnetized and compared to subchron C4Ar.2n; in Novaya

Emetovka 1 and Raspopeny, the bone beds show reversed polarity correlative to chron C4Ar (Vangengeim and Tesakov 2008b). The Raspopeny locality can belong to the uppermost levels of the upper Sarmatian (subchron C4Ar.3r; Vangengeim and Tesakov 2008a).

The zone MN 10 documents last occurrences of *Hippotherium giganteum* (Gromova), "*Hipparion*" *verae* Gabunia, *Machairodus* ex gr. *aphanistus*, *Chilotherium*, and *Protragocerus leskewitschi* (Borissiak). The new appearances include that of *Hyaenotherium wongi* (Zdansky), *Aceratherium incisivum* Kaup, and *Cervavitus*. According to Godina (1979), giraffes are represented by transitional forms from *Palaeotragus (Achtiaria)* to *Palaeotragus* (*P.(A.) moldavicus* Godina, *P. pavlowae* Godina, and *P.* sp.). Sarmatian *Microstonyx antiquus* (Kaup) and *Eomellivora wimani piveteaui* Ozansoy are replaced with *Microstonyx major* Gervais and *Eomellivora wimani wimani* Zdansky (Gabunia 1986; Korotkevich 1988; Krakhmalnaya 1996a; Lungu and Chemyrtan 1989; Wolsan and Semenov 1996). Hipparions and chilotheres are most abundant, followed by gazelles and procapras.

Zone MN 11: Early Turolian (9.7–8.7 Ma to 8.24–8.0 Ma)

Localities of the Middle Maeotian

Localities Novoelizovetovka and Novaya Emetovka 2 (Ukraine) belong to the zone MN 11. Bone-bearing deposits in Novaya Emetovka 2 are reversely magnetized and correlated with the upper part of chron C4Ar or chron C4r (Krakhmalnaya 1996a; Vangengeim and Tesakov 2008b).

Remarkable events in this zone include the appearance of *Cremohipparion moldavicum* (Gromova) and *Palaeotragus rouenii* Gaudry, the replacement of *Machairodus* ex gr. *aphanistus* with *M.* ex gr. *giganteus* Kaup, and the replacement of *Gazella schlosseri* M.Pavlow with *G. pilgrimi* Bohlin. Newly occurring forms include *Ictitherium pannonicum* Kretzoi, *Zygolophodon turicensis* (Schinz), *Chersonotherium*, *Tragocerus frolovi* M. Pavlow., *Mesotragocerus citus* Korotkevich, *Procobus melania* Khomenko, and *Palaeoryx pallasii* (Wagner). No chilothere remains have been found in this zone. The assemblages are dominated by hipparions; important shares belong to *Aceratherium*, procapras, gazelles, and giraffes (Korotkevich 1988; Krakhmalnaya 1996a; Krakhmalnaya and Forsten 1998).

Zone MN 12: Middle Turolian (8.24–8.0 Ma to 7.1 Ma)

Localities of the Late Maeotian

The zone MN 12 includes localities of the later part of the Maeotian, such as Taraklia, Cimislia, Tudorovo (Moldova), Belka, and Cherevichnoe (Ukraine) (Gabunia 1986; Korotkevich 1988; Semenov 1989; Krakhmalnaya 1996a; Lungu and Delinschi 2008). Fossliferous deposits in Taraklia, Cimislia, and Cherevichnoe have normal magnetization correlated with chron C4n. Faunas of this zone retain many forms characteristic for MN 11. In addition, the fauna includes *Miochyaenotherium bessarabicum* Semenov, *Aceratherium simplex* Korotkevich (highly specialized form), *Pliocervus*, *Procapreolus frolovi* Korotkevich, *Helladotherium duvernoyi* Gaudry, *Palaeoreas lindermayeri* Wagner, *Tragoreas oryxoides* Schlosser, *Procapra rodleri* Pilgrim et Hopwood, and *Procobus brauneri* Khomenko. The assemblages are dominated by *Cremohipparion* ex gr. *moldavicum* and procapras.

Localities of the Early Pontian

Deposits of the early Pontian are bracketed in the range of 7.5 Ma to 7.1 Ma, from the end of chron C4n to the beginning of chron C3Bn (Pevzner, Semenenko, and Vangengeim 2003). The upper boundary of the zone MN 12 is estimated at 7.1 Ma. It coincides with the onset of the Messinian and the period of the global carbon shift from C3 to C4 plants (Bernor, Solounais, et al. 1996c; Swisher 1996). Lower Pontian limestone near Odessa and Eupatoria, and Rostov-on-Don yielded sparse remains of large mammals. This fauna includes *Tetralophodon longirostris* Kaup (according to Markov [2008], Turolian tetralophodons possibly belong to the Pikermian *T. atticus* [Wagner]), "*Mammut*" *borsoni* (Hays), *Diceros* cf. *pachygnathus* (Wagner) (=*Ceratotherium neumayri*), *Palaeoryx pallasi* (Wagner), and *P. longicephalus* Sokolov (Gabunia 1986). The hipparion is represented by *Cremohipparion* cf. *mediterraneum* (Gervais) (Gabunia, pers. comm., 1985). The most remarkable event in the early Pontian is the first occurrence of the genus *Paracamelus* (Gabunia 1986; Pevzner, Semenenko, and Vangengeim 2003; Titov and Logvinenko 2006).

The early Pontian age has been presumably assigned to the locality Bazaleti occurring in upper parts of the Dusheti Formation in Georgia. The bone-bearing deposits have reversed polarity correlative with chron C3Br. The fauna includes *Promephitis* sp., *Ictitherium veverrinum* Roth et Wagner (=*Ictitherium ibericum* Meladze), *Deinotherium* sp., "*Hipparion*" sp. (slender-limbed form), *Aceratherium* cf. *incisivum* Kaup, large sivatherine *Karsimatherium bazaleticum* Meladze, *Palaeotragus* sp., *Gazella*, peculiar specialized *Phronetragus*, and other forms (Meladze 1967; Gabunia 1986; Vangengeim et al. 1989; Semenov 2008; Vekua and Lordkipanidze 2008).

Zone MN 13: Late Turolian (7.1–[?]5.3 Ma)

No reliable record of late Pontian large mammals (correlative with zone MN 13, the older boundary 7.1 Ma) is presently known (Gabunia 1986). In Eastern Paratethys, the late Pontian is characterized by a drastic marine regression synchronous with the onset of the Messinian in the Mediterranean (Pevzner, Semenenko, and Vangengeim 2003). In western and central Europe, the zone MN 13 is characterized by a strong reduction in diversity of large mammals (Bernor et al. 1996a).

If accepted, the alternative paleomagnetic correlation of the Maeotian and Pontian (+Azov beds of the Kimmerian) to chrons C3Br–C3r (Trubikhin 1989, 1998; Krijgsman et al. 2010) would suggest a correlation of these Eastern Paratethys units with the mammal zone MN 13 (7.1–5.3 Ma). We cannot currently reconcile this correlation with the faunal evidence. Maeotian mammal fauna of the Eastern Paratethys shares numerous common taxa, faunal abundance, and diversity with middle Turolian (zones MN 12) faunas of central and western Europe. Likewise, the presence of middle Turolian (Pikermian) faunal elements in the lower Pontian deposits seemingly excludes their correlation with C3r.

CONCLUSION

Our study focused on mammalian biochronology controlled by paleomagnetic data. It resulted in a correlation model of the studied mammal faunas of eastern Paratethys to MN zones of western Europe. Vallesian and Turolian faunas of Eastern Europe were characterized. This study revealed a number of common features and distinctions of different paleozoogeographic provinces. The distinctions are caused by dissimilar physiographic conditions in these provinces. The westward increasing aridification accounts for earlier occurrences of some forms in eastern Europe in comparison with the record of central and western Europe. The central European region preserved a stable wooded environment longer than in the east and west of the continent.

The southeastern province is importantly distinct in earlier (middle part of MN 9, late middle Sarmatian) differentiation of hipparions compared to the beginning of MN 10 in the west of the continent (excluding the central European province). The appearance of genera *Gazella*, *Procapra*, *Cervavitus*, and *Adcrocuta* in the upper Sarmatian (middle part of MN 9) of the southeastern province predates the occurrence of these genera in the west (MN 10). The fossil record of eastern and central Europe documents the extinction of *Microstonyx antiquus* in the middle part of MN 9. In MN 10, this form was replaced by *M. major*, which survived untill the end of the Turolian and spread to Spain. Chilotheres in the studied part of the southeastern province are not known in faunas younger than MN 10. The western limit of their range at that time reached Bulgaria and Greece (Spassov, Tsankov, and Geraads 2006). In contrast, this genus is absent in central Europe and extremely rare in Spain. The fauna of western and central Europe includes *Aceratherium* since the beginnings of MN 9. In contrast, this genus seemingly appeared in the fauna of the southeastern province in MN 10 (but see Codrea and Ursachi 2007).

The beginning of the Turolian is marked throughout Europe by the appearance of the genus *Cremohipparion*, the replacement of *Machairodus* gr. *aphanistus* with *M.* gr. *giganteus*, and the replacement of giraffes *Palaeotragus (Achtiaria)* with *Palaeotragus rouenii*. In the middle Turolian (MN 12), *Paracamelus* migrated to southern East Europe. This genus had a short-term westward dispersal only in the Messinian (MN1 3).

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