Chapter 22

New Data on Miocene Biostratigraphy and Paleoclimatology of Olkhon Island (Lake Baikal, Siberia)

GUDRUN DAXNER-HÖCK, MADELAINE BÖHME, AND ANNETTE KOSSLER

Lake Baikal, located in the East Siberian Baikal Rift System, is the deepest, most voluminous, and oldest freshwater body on Earth. Its morphology is characterized by three basins, the older Southern and Central basins and the younger Northern Basin. The Southern and Central basins are thought to have existed permanently since the Paleogene, whereas the Northern Basin did not develop before the Miocene. Olkhon Island (Irkutsk region, Russia) is located in the transitional zone between the Central and the Northern basins of Lake Baikal. It is separated from the mainland in the west by a shallow bay of the Northern Basin that extends far to the south (for localization and references, see Kossler 2003:fig. 1–2). From the northwestern part of Olkhon Island, two localities are known to have yielded terrestrial fossils of the Neogene, specifically the Tagay section (Logachev, Lomonosova, and Klimanova 1964; Vislobokova 1990, 1994, 2004) and the Saray section (Mats et al. 1982). Both belong to the Khalagay Formation (Khalagay Suite of Logachev, Lomonosova, and Klimanova 1964:fig. 15).

Vertebrate Assemblages of the Khalagay Formation from former investigations according to Logachev, Lomonosova, and Klimanova (1964:fig. 12), the Tagay section displays a >12-m-thick sequence of sand, clay, silty clay, and calcretes, corresponding to the carbonate-rich upper part of the lower Khalagay Formation. The vertebrate fossils were primarily recovered from the clay layers 3, 5, and 7 of the section, and are listed in Logachev, Lomonosova, and Klimanova (1964:41). Later, the ruminant fossils were reexamined by Vislobokova (1990, 1994, 2004), the fishes by Sytchevskaya (in Filippov, Erbajeva, and Sytchevskaya 2000), the turtles by Khosatzky and Chkikhvadse (1993), and the snakes by Rage and Danilov (2008). An update of the mammal fauna from the Tagay section is given in Erbajeva and Filippov (1997): *Proscalops* sp., *Talpa* sp., *Procaprolagus* sp., *Monosaulax* sp. nov., *Cricetodon* cf. *sansaniensis* Lartet (=referred to *Gobicricetodon* by Filippov, Erbajeva, and Sytchevskaya 2000), Mustelidae, Felidae, *Anchitherium* sp., *Dicerorhinus* sp., Bovidae, *Amphitragulus boulangeri* Pomel, *Lagomeryx parvulus* (Roger), *Stefanocemas* sp., *Palaeomeryx* cf. *kaupi* (Meyer), *Orygotherium tagaiensis* Vislobokova 2004, and *Brachyodus intermedius* (Mayer). The fish fauna comprises the taxa *Rutilus* sp., *Esox* sp., and *Leobergia* sp. (Logachev, Lomonosova, and Klimanova 1964; Filippov, Erbajeva, and Sytchevskaya 2000). Amphibians and reptiles are documented by *Rana* sp., *Bufo* sp., *Baicalemys gracilis*, Boinae indet., *Coluber* s.l. sp. A, *Coluber* s.l. sp. B, Colubrinae indet., and ?*Vipera* sp. (Logachev, Lomonosova, and Klimanova 1964; Khosatzky and Chkikhvadse 1993; Rage and Danilov 2008). The pond turtle *Baicalemys*, represented with more than 10,000 fragments, is by far the most common vertebrate of this locality. Stratigraphic determinations of these old collections range from Middle to Late Miocene (Logachev, Lomonosova, and Klimanova 1964; Vislobokova 1990, 1994; Filippov, Erbajeva, and Sytchevskaya 2000).

From the Saray section in the upper part of the Khalagay Formation, several fossil horizons were described and the fossils listed and dated by Mats et al. (1982). The following mammal assemblages from different horizons of the Saray section were distinguished (Mats et al. 1982; Pokatilov 1994; Erbajeva and Alexeeva 1997).

- Horizon 3 of the Saray section 1 (Saray faunistic complex) contains Soricidae gen., *Proochotona* sp., *Ochotona* sp., Leporidae gen., *Heterosminthus saraicus* Zazhigin, Lopatin et Pokatilov, *Monosaulax* sp., *Prosiphneus licenti* Teilhard, *Plesiogulo* cf. *brachygnathus* (Schlosser), *Moschus grandaevus* Schlosser, and *Pavlodaria* sp. The age is given as Late Miocene.
- Horizon 5 of the Saray section 1 (Odonim faunistic complex) contains *Hypolagus* sp., *Alilepus*? sp., *Proochotona* sp., *Ochotona* sp., *Lophocricetus (Paralophocricetus) progressus* Zazhigin, Lopatin et Pokatilov, *Microtoscoptes praetermissus* Schlosser, *M.* cf. *tjuvanensis* Zazhigin (nom. nud.), *Microtodon* cf. *atavus* (Schlosser), *Prosiphneus eriksoni* (Schlosser), and *Hipparion* sp. According to Pokatilov (1994:table 1), the assemblage is Early Pliocene or Latest Miocene (Pokatilov 1994:table 2). Erbajeva and Alexeeva (1997:243) give the age as Late Miocene.
- Horizon 6 of the Saray section 1 (Olkhonian fauna) contains Soricidae gen., *Hypolagus* sp., *Ochotonoides complicidens* (Boule and Teilhard), *Ochotona* sp., *Kowalskia* sp., *Micromys* sp., *Stachomys* ex gr. *trilobodon* Kowalski, *Promimomys insuliferus* Kowalski, *Microtodon* sp., *Eozapus* sp., and *Prosiphneus olchonicus* Pokatilov. The age is given as Early Pliocene.
- Horizon 8 of Saray section 5 (Khuzhirian fauna) and horizon 8 of section 1 are considered to be identical. There dark-brown clays contain the following fossils: *Ochotona* sp., *Sicista* sp., *Apodemus* sp., *Promimomys* cf. *gracilis* (Kretzoi), *Promimomys* sp., and *Prosiphneus chuzhirica* Pokatilov. The estimated age is Pliocene (Ruscinian, MN 15).

RECENT INVESTIGATIONS

Recently, Olkhon Island has been examined based on sedimentological, stratigraphic, and palaeontological aspects (Kossler 2003). Though several sections were carefully studied, only the Tagay and the Saray I sections (figure 22.1) yielded vertebrate fossils and molluscs. However, new collections turned out to differ considerably from the previous fossil record, making them a valuable contribution to the paleontological puzzle. Lithological descriptions of the sections and the exact position of the fossil layers are available in Kossler (2003:figs. 3–4).

Material and Methods

During the fieldwork, sediment samples from the Tagay and Saray I sections were examined for fossils and clay minerals. Numerous samples were checked for fossils by dry sieving on site. From fossil-bearing layers, bulk samples were taken for screen washing (mesh size 250 μm) and for final treatment in the laboratory. The fossils (i.e., gastropods, remains of fish, amphibians, reptiles and small mammals) were picked out from the residue under a stereomicroscope. This yielded 22 cheek teeth (fragments included) and several incisors of small mammals from the Tagay section and one lower jaw with m1–3 and an isolated incisor from the Saray I section. Almost all available cheek teeth are figured (plate 22.1). In addition to small mammals, the Tagay sample yielded several thousand isolated pharyngeal teeth and vertebrae of fishes, whereas amphibians and reptiles and gastropods are comparatively rare. About 20 plate fragments of turtles make up the most numerous herpetological material. In contrast, the Saray I section lacks fishes and reptiles and contains few bones of frogs. Gastropods from Saray section are abundant and predominantly belong to terrestrial species.

SEM images of fossils were taken by a digital SEM (type Zeiss Supra 40 VP) from the Institute of Geosciences (Paleontology), Freie Universität Berlin, Section of Paleontology, and at the University of Munich, and by a Philips XL 20 scanning microscope from the Biocenter, University of Vienna.

The small mammal teeth are integrated in the collections of the Natural History Museum Vienna, Geological-Palaeontological Department (NHMW), whereas the ectothermic vertebrates are deposited in the Bavarian State Collection for Paleontology and Geology in Munich (BSPG). Gastropod remains are stored in the collections of the Freie Universität Berlin, Section of Paleontology (collection Kossler).

New Investigations of the Tagay and Saray Sections (Olkhon Island)

Lithology and Fossil Content

The Tagay section is located at the northern end of Tagay Bay, approximately 10 km southwest of the village of Khuzhir (see figure 22.1). The investigated profile corresponds approximately to the section excavated by N. A. Logachev and colleagues in 1958 (Logachev, Lomonosova, and Klimanova 1964:fig. 13) and belongs to the

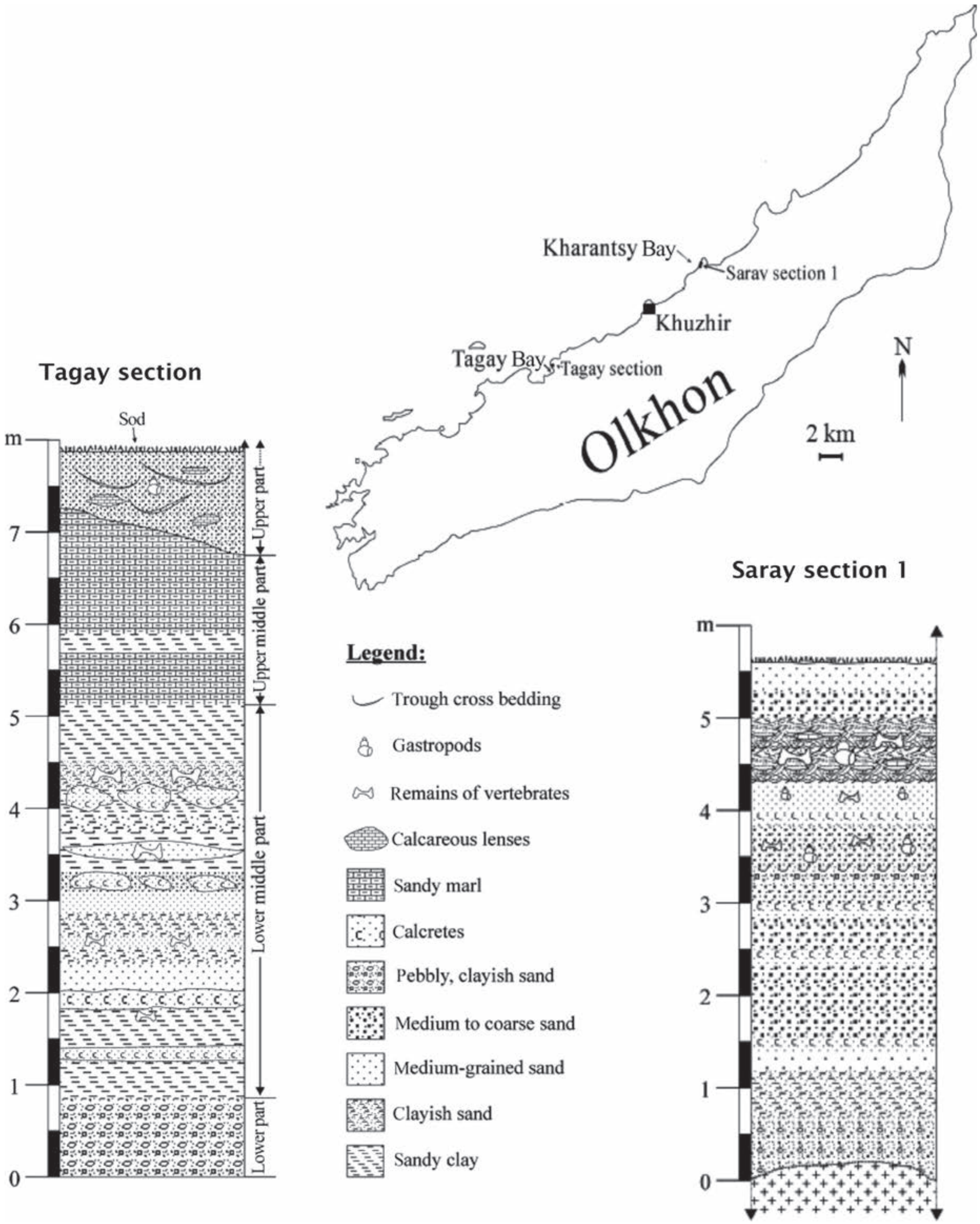

Figure 22.1 Location and description of the Tagay and Saray I sections from Olkhon Island. Modified after Kossler (2003).

carbonate-rich upper part of the lower Khalagay Formation (Tagay sequence of Mats et al. 2000). The exposure displays an 8-m-thick sediment succession. It consists of 1 m clay-sand facies in the lower part, which is followed by 6 m of alternating clay, marl, and sand layers with thick calcareous paleosols in the middle part. On top, 1 m of medium- to coarse-grained sand with calcrete lenses is exposed. The fossils were recovered from three layers in the middle part.

The Saray I section is located along the steep coast at the northern end of Kharantsy Bay. The outcrop is not well exposed. Here, the 5.6 m sediment succession overlies the metamorphic basement. Similar to the Tagay section, lacustrine sediments and paleosol horizons change, although the sequence contains more sand and corresponds to the middle part of the Khalagay Formation (Logachev, Lomonosova, and Klimanova 1964:fig. 15; Sasa sequence of Mats et al. 2000). Fossils were recovered from the higher part of the section (see figure 22.1).

Paleontological Data

TAGAY SECTION

Gastropoda, Pulmonata
- *Gastrocopta* sp.
- *Vallonia* sp.

Cypriniformes
- *Palaeocarassius* sp.
- *Palaeotinca* sp.
- Leuciscinae indet.

Esociformes
- *Esox* sp.

Anura
- *Rana* sp. (*R. temporaria* group)
- *Pelophylax* sp.

Chelonia
- ? *Baicalemys gracilis* Khosatzky and Chkikhvadse 1993

Squamata
- ? *Chalcides* nov. spec.
- *Texasophis* sp.

Insectivora
- Desmaninae gen. et spec. indet.
- Erinaceinae gen. et spec. indet.

Rodentia
- Sciurinae gen. et spec. indet.
- *Miodyromys* sp.
- *Keramidomys* aff. *mohleri* Engesser 1972 vel *K.* aff. *fahlbuschi* Qiu 1996
- *Eomyops oppligeri* Engesser 1990
- *Democricetodon* sp.

SARAY I SECTION

Gastropoda, Pulmonata
- Succineidae gen. et sp. indet.
- *Radix* sp.
- *Carychium* sp.
- *Vallonia subcyclophorella* (Gottschick 1911)
- *Vallonia tokunagai* Suzuki 1944
- *Vertigo* (*Ungulidenta*) *uncata* Steklov 1967
- *Gastrocopta* (*Kazachalbinula*) cf. *ucrainica* Steklov 1966
- *Gastrocopta* (*Sinalbulina*) *intorta* Steklov 1967

Anura
- *Bufo* aff. *calamita* (Laurenti 1768)

Rodentia
- *Eozapus intermedius* (Bachmayer and Wilson 1970)

Remarks

Tagay

Both gastropod genera from the upper part of the Tagay section are common in the Miocene of Europe and Asia (e.g., Steklov 1966; Gerber 1996). The small mammal assemblage from the Tagay section comprises two insectivore taxa and five rodent taxa. The scarce insectivore remains represent a talpid (see plate 22.1 [1–3]) and an erinaceid (see plate 22.1 [4]). They do not allow identification below the subfamily level. Dormice are represented by two teeth of a small, so far unknown species of *Miodyromys* Kretzoi 1943, which atypically displays a high number of very thin lophs (see plate 22.1 [6–7]). The eomyid rodent *Keramidomys* Hartenberger 1966 is well represented by maxillary and mandibular molars (see plate 22.1 [8–15]). Its pronounced pentalophodont dental pattern and the large size indicate close affinities with *K. mohleri* Engesser 1972 (from Anwil, Switzerland) as well as with *K. fahlbuschi* Qiu 1996 (from Moergen II, China). The Siberian material, however, seems to be transitional between these two species in dental pattern and possibly represents a new species. The second eomyid species resembles *Eomyops* Engesser 1979 and *Leptodontomys* Shotwell 1956 in molar pattern. The Siberian specimen (see plate 22.1 [16]) is within the size range and the morphological variability of *Eomyops oppligeri* Engesser 1990 (from Anwil, Switzerland); it is clearly smaller than *Leptodontomys lii* Qiu 1996 (from Moergen II, China). The cricetid *Democricetodon* Fahlbusch 1964 is represented by a very small species (see plate 22.1 [17–19]). Though being smaller, it shares dental characters with two species that are well known from the Middle Miocene of Europe—that is, *D. crassus* Baudelot 1972 and *D. brevis* (Schaub 1925). It is even smaller than *D. tongi* Qiu 1996, the smaller of two *Democricetodon* species from Moergen II in China. Because of the scarce fossil record, the species determination of *Democricetodon* from Tagay remains open.

The ectothermic vertebrate fauna from Tagay contains nine taxa. Most frequent is the cyprinid *Palaeocarassius* sp., which could be conspecific with a species described from the North Alpine Foreland Basin (Böhme 1999, 2010) and which may also occur in different Early to Middle Miocene (MN 4–6) localities in Russia, Kazakhstan (Zaissan Basin, Lake Aral area, Altai, and Lake Baikal) and Mongolia (Sytchevskaya 1989; Filippov, Erbajeva, and Sytchevskaya 2000; Böhme, unpubl.). Both other cyprinids, Leuciscinae indet. and *Palaeotinca*, are comparatively rare. The latter taxon is reported here for the first time from Asia outside Kazakhstan. *Palaeotinca* is a typical minnow of the Late Oligocene and the Early Miocene of central and western Europe (MP 25 to MN 4b; Kvaček et al. 2004; Böhme 2008). It is described by Sytchevskaya (1989) from the late Early Miocene (*Palaeotinca* cf. *egeriana*, Shamangorin Formation) and the late Middle to Late Miocene (*Palaeotinca* sp., Sarybulak Formation) of the Zaissan Basin (Kazakhstan). This genus was also found recently in Kazakh localities from Altyn Chokysu (Aral Formation) and Mynsualmas (Shomyshtin Formation), indicating that *Palaeotinca* was probably a common Central Asian taxon. The predatory fish *Esox* is documented by isolated teeth, cranial bones, and vertebrae. Amphibians are represented by two ranid species, the water frog *Pelophylax* and the brown frog *Rana* (*R. temporaria* group). The oldest known brown frog, *Rana* cf. *temporaria*, is described from the Early Miocene (MN 3) of Germany (Böhme 2001). Members of the *Rana temporaria* group are known in Asia from the early Middle Miocene of Mynsualmas (Lake Aral area; Böhme unpubl.) and from the Late Miocene of Kabutoiwa (Japan; Sanchiz 1998).

The rare finds of squamate reptiles belong to a new species of skink (? *Chalcides* nov. sp.) and to the colubrid snake *Texasophis*. Both taxa are recorded for the first time from Asia. *Texasophis* is known from the latest Oligocene to the late Middle Miocene of Europe and North America (Szyndlar 1991; Holman 2000; Böhme 2008). The Tagay material therefore represents an important biogeographic link and reveals a Holarctic distribution for *Texasophis*.

Saray I

All identified terrestrial gastropod species from the Saray I section are also described from other Miocene localities of Asia (e.g., Steklov 1966, 1967; Gerber 1996). Except for *Vallonia subcyclophorella*, which is distributed over Eurasia, the listed gastropod species seem to be restricted to the Asian faunal realm. The few fragments of *Radix* sp. and of the Succineidae do not allow identification at species level.

From the Saray I section, a mandible with m1–3 and an isolated lower incisor were recovered, which can be identified as *Eozapus intermedius* (Bachmayer and Wilson 1970) (see plate 22.1 [20a and 20b]). The first record of this species is the early Late Miocene of Europe (Austria: Kohfidisch and Eichkogel, MN 11) with first scarce occurrences in the Vallesian of Austria (MN9–10; Daxner-Höck 1996). In the lower Turolian (MN 11), however, it rapidly dispersed all over Europe (Daxner-Höck 1999). *E. intermedius* is the smallest among the three known *Eozapus* species, which are extremely conservative in dental morphology. Fahlbusch (1992) observed a size increase from the oldest toward the youngest species—that is, from *E. intermedius* (Late Miocene, MN 9–11; Europe) to *E. similis* 1992 (Late Miocene, MN 13; China) to *E. setchuanus* (Pousargues 1896; today living in China), along with minor morphological differences.

The only ectothermic vertebrate from the Saray I section is a toad, *Bufo* aff. *calamita* (plate 22.2 [9]), which is osteologically more similar to the extant *Bufo calamita* than to any other compared recent or fossil Eurasian species (*B. bufo*, *B. viridis*; Pliocene Mongolian *B. raddei*; Early and Middle Miocene European *B. viridis* sp. and *B. priscus*). So far, the oldest fossil record of *Bufo calamita* is the early Messinian of Spain (MN 12; Sanchiz 1998).

Biostratigraphy

Tagay

All identifiable rodent genera are well represented in the Miocene of Europe and Asia.

The eomyids *Eomyops oppligeri* and *Keramidomys* aff. *mohleri-fahlbuschi* and the cricetid *Democricetodon* sp. can best be compared with their relatives from the Middle Miocene of Europe and China, respectively. According to the rodent data, the estimated age of the new Tagay fauna is Middle Miocene (~13 Ma). The fauna approximately

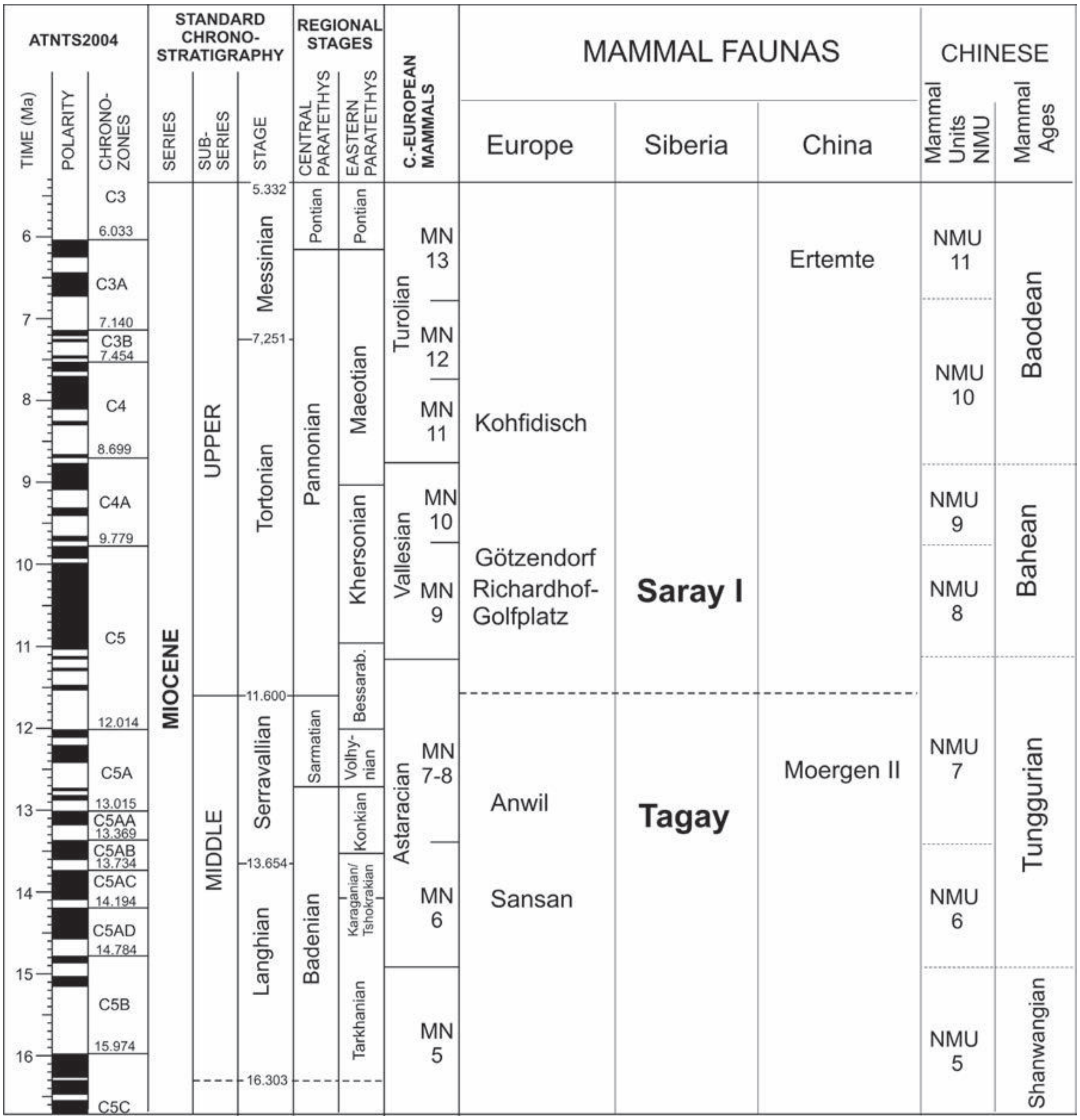

Figure 22.2 Chronostratigraphy and biostratigraphy of the Middle and Late Miocene. Modified after Harzhauser and Piller (2007). Stratigraphic position and correlation of the Tagay and Saray assemblages from Olkhon Island in Lake Baikal (Siberia).

correlates with the European Mammal Zone MN 7+8 and the Chinese Mammal Unit NMU7 (figure 22.2).

The ectothermic vertebrate fauna yield similar results. It shows closer affinities to late Early and Middle Miocene faunas of western Eurasia (Europe, Kazakhstan) than to contemporaneous faunas from eastern Eurasia (Mongolia, China). The comparatively rich Tagay association exhibits the most similarities to (yet undescribed) material from the Lake Aral region (Mynsualmas localities), where *Palaeocarassius*, *Palaeotinca*, Leuciscinae, *Esox*, *Pelophylax*, and *Rana* are present. The Mynsualmas sites (Shomyshtin fauna) are located in the northwestern part of the Ustyurt Plateau, between the Caspian and Aral Sea (SW Kazakhstan; Kordikova, Heizmann, and Pronin 2003:fig. 1). The fossil vertebrate-bearing samples are from the lower part of the Shomyshtin formation. This formation belongs to the lower part of the Tarkhanian Eastern Paratethys regional stage (Kordikova, Heizmann, and Pronin 2003), which correlates to the Langhian and Early Badenian stages of the Mediterranean and Eastern Paratethys, respectively (Andreyeva-Grigorovich and Savytskaya 2000). The Tagay assemblage differs from the Shomyshtin fauna at Mynsualmas due to the lack of the two thermophilous taxa *Channa* (snakehead fish) and *Trionyx* (softshell turtle).

Both taxa, however, are present in the early Middle Miocene assemblage of the Aya Cave, 57 km to the southwest of Tagay Bay (Filippov, Erbajeva, and Sytchevskaya 2000). This may indicate that our Tagay sample is somewhat younger than both the Shomyshtin and the Aya faunas. In conclusion, the ectothermic vertebrates from Tagay point to an age within the middle part of the Middle Miocene (14–13 Ma, Early Serravallian, Late Badenian, Karaganian-Konkian).

The fossil composition and the age dating of the new Tagay assemblage differs strikingly from the earlier investigated assemblage (Logachev, Lomonosova, and Klimanova 1964; Vislobokova 1994). This disagreement can partly be explained by different excavation techniques (screen washing with 250 µm mesh width reveals small-sized eomyids, cricetids, and cyprinids), and/or the Tagay section displays fossil horizons of different ages (old and new excavations). Nonetheless, the recognized differences underline the necessity for new investigations and for revision of older fossil collections from Tagay.

Saray I

The new fossil collection stems from a basal sediment layer of the Saray I sequence (4 m above the crystalline basement; see figure 22.1). *Eozapus intermedius* indicates a Late Miocene age, which is in agreement with the Late Miocene age of some previously investigated lower fossil horizons of this site (Mats et al. 1982; Pokatilov 1994; Erbajeva and Alexeeva 1997).

Paleoenviroment

The sediment sequences of both the Tagay and the Saray I sections are characterized by debris flows of alluvial fans and by floodplain accumulations with calcrete paleosol horizons. These horizons yielded a fossil record from three sediment layers of the Tagay section and from two layers of the Saray I section.

Tagay

The sedimentary succession is interpreted as floodplain deposits (Kossler 2003:57). Shallow-water lakes and ponds are indicated by the fish fauna (*Palaeocarassius*, *Palaeotinca*, Leuciscinae, *Esox*). The dominant small-sized cyprinid *Palaeocarassius*, which is assumed to tolerate very low oxygen conditions, shows similar mass occurrences in riparian ponds of the North Alpine Foreland Basin (Böhme 1999, 2010). This interpretation fits with the occurrence of the green water frog *Pelophylax* and the pond turtle *Baicalemys*. Whereas the environmental requirements of the colubrid snake *Texasophis* remain unclear, the brown frog (*R. temporaria* group) and the skink (?*Chalcides* nov. spec.) live in wooded and open habitats.

The small mammal assemblage of the Tagay section comprises the forest-dwelling Eomyidae (*Keramidomys* and *Eomyops*) and Gliridae (*Miodyromys*), the ground-dwelling Insectivora (Desmaninae and Erinaceinae), Sciuridae (most probably a ground squirrel), and Cricetidae (*Democricetodon*). The estimated environment was a riverine woodland environment. There, Eomyidae lived in trees and bushes, while Erinaceidae and Gliridae inhabited dense thickets and undergrowth. Flowing waters were favored by the Desmaninae, and open sunny dry areas were inhabited by the burrowing ground squirrels and the hamster *Democricetodon*. Note that rodents with moderately hypsodont teeth—for example, *Plesiodipus* and *Protalactaga-Paralactaga*—are absent in our samples. They would be expected in the Middle Miocene record of Central Asia.

The interpretation of an alluvial floodplain with riparian ponds and woodlands and open landscapes, is in agreement with palynological investigations (Logachev, Lomonosova, and Klimanova 1964; Demske and Kossler 2001). The development of open-steppe conditions (Logachev, Lomonosova, and Klimanova 1964) is indicated by the palynological record—that is, broadleaved/coniferous forests (*Picea*, *Abies*, *Pinus*, *Tsuga*, *Larix*, *Alnus*, *Betula*, *Quercus*, *Fagus*, *Carpinus*, *Castanea*, *Tilia*, *Celtis*, *Acer*, *Ulmus*, *Corylus*, *Carya*, *Juglans*, and *Liquidambar*) and a significant part of herbaceous and gramineous vegetation (*Artemisia*, Chenopodiaceae, Poaceae, Cyperaceae, Nympheaceae, Ranunculaceae, Lygopodiaceae, and ferns).

Saray I

Based on sedimentology, this outcrop is also interpreted as a floodplain deposit of an ephemeral river system (Kossler 2003:59), which offered various habitats for the ground-dwelling rodent *Eozapus* and the toad *Bufo* cf. *calamita*. With the exception of *Radix* sp., an aquatic gastropod occurring in standing and flowing waters, the majority of gastropods belong to terrestrial species. Today, *Carychium*, Succineidae, and *Vallonia* frequently live in wet to humid habitats. *Gastrocopta* und *Vertigo* are known to live in various habitats, in plant litter, and under stones. According to Stworzewicz (2007), they are often washed into the depositional environment and are very common in flood debris.

Palaeoclimate

Tagay

Among the vertebrates, the skink and the pond turtle are most sensitive for paleotemperature estimation. The Central Asian emydid *Baicalemys* is morphologically related to the extant North American genera *Chrysemys*, *Pseudemys*, and *Trachyemys* (Khosatzky and Chkikvadse 1993). *Chrysemys picta belii* reaches the most northern distribution. It lives in aquatic habitats north of Lake Superior in boreal forest and cold prairie areas across Canada (Holman and Andrews 1993). The mean cold month temperature (mCMT) reaches −17°C at the northern distribution limit, with +2.5°C mean annual temperature (MAT) and +20°C warmest month temperature (WMT).

The extant Scincidae have a worldwide distribution on all continents, except Antarctica. Analyzing the climatic conditions at the margins of their distribution (Hokaido Island, Lake Aral, and Karpathian Mountains in Eurasia; 49°N and 39°S in the Americas, 46°S in New Zealand), their poleward expansion seems limited by temperature, mainly by mean cold month temperature. In Eurasia, the most extreme occurrence of a skink is reached north of Lake Aral, with a mCMT around −12°C and a mean annual temperature around +7°C. Slightly cooler conditions are found in North America at their northernmost distribution around the Great Lakes, where the mCMT reaches up to −15°C and the MAT around +3°C. The warmest month temperature is always well above 20°C. Using the more conservative values of their Eurasian distribution, mainly based on biogeographical considerations, we can estimate −12°C in mCMT, > +20°C in WMT and +7°C in MAT as minimal thermal requirements for the Tagay skink.

Considering the minimal values of both reptile groups, the Middle Miocene Tagay record would indicate warmer conditions than today (Irkutsk MAT −1.2°C, mCMT −20.9°C, WMT +17.5°C; Ulan-Ude MAT −1.7°C, mCMT −25.4°C, WMT 19.4°C; recent climate data from M. J. Müller and D. Hennings, The Global Climate Data Atlas, Climate 1, www.climate-one.de). The estimated paleotemperatures are at least 4– 8°C warmer in the winter and in the annual mean. These values are certainly underestimated because the high amount of kaolinite in the upper part of the Tagay section, and the calcretes and pedogenic gypsum (Logachev, Lomonosova, and Klimanova 1964:38; Mats et al. 2000:236) indicate alternation of warm-humid and semi-arid climatic conditions (Kossler 2003). This is in agreement with the palynological record.

Saray I

The few fossils recovered from the Saray section contribute little to our understanding of the paleoclimatology. The northern and northeastern limits of the extant distribution of the natterjack *Bufo calamita* is southern Sweden and Estonia (Gasc et al. 2004), where mean annual temperatures reach +5°C, winter temperatures −5°C, and summer temperatures at least +17°C. Again, warmer temperatures are indicated by the clay mineralogy, where the kaolinite content is low but increases toward the top (above the level with fossil vertebrates). This indicates enhanced chemical weathering under warm, humid conditions (Kossler 2003:59).

CONCLUSION

The vertebrate assemblages from the Tagay and Saray I sections show remarkable affinities to assemblages from western Eurasia, especially from Central Europe. Ectothermic vertebrates from these two sections also resemble assemblages from western Kazakhstan. Similar conclusions were drawn by Vislobokova (1994) and Rage and Danilov (2008), who studied the Tagay artiodactyls and snakes. These results support the interpretation that a largely homogeneous vertebrate fauna (at least at the genus level) may have existed in the middle latitudes of Eurasia during the Middle Miocene and perhaps during parts of the Late Miocene. Although no long and continuous sections have been studied, our paleoclimatic analysis indicates that repeated strong fluctuations in humidity affected the Baikal Lake area during both the Middle and Late Miocene.

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REFERENCES

Andreyeva-Grigorovich, A. S. and N. A. Savytskaya. 2000. Nannoplankton of the Tarkhanian deposits of the Kerch peninsula (Crimea). *Geologica Carpathica* 51(6):399–406.

Bachmayer, F. and R. W. Wilson. 1970. Die Fauna der altpliozänen Höhlen- und Spaltenfüllungen bei Kohfidisch, Burgenland (Österreich). *Annalen des Naturhistorischen Museums Wien* 74:533–587.

Baudelot, S. 1972. Étude des Chiroptères, Insectivores et Rongeurs du Miocène de Sansan (Gers). *Thèse Université Paul Sabatier Toulouse* 496:1–364.

Böhme, M. 1999. Die miozäne Fossil-Lagerstätte Sandelzhausen. 16. Fisch- und Herpetofauna—Erste Ergebnisse. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 214(3):487–495.

Böhme, M. 2001. The oldest representative of a brown frog (Ranidae) from the Early Miocene of Germany. *Acta Palaeontologica Polonica* 46(1):119–124.

Böhme, M. 2008. Ectothermic vertebrates (Teleostei, Allocaudata, Urodela, Anura, Testudines, Choristodera, Crocodylia, Squamata) from the Upper Oligocene of Oberleichtersbach (northern Bavaria, Germany). *Courier Forschungs-Institut Senckenberg* 260:161–183.

Böhme, M. 2010. Ectothermic vertebrates (Osteichthyes, Allocaudata, Urodela, Anura, Crocodylia, Squamata) from the Miocene of Sandelzhausen (Germany, Bavaria): Their implication for environmental reconstruction and palaeoclimate. *Paläontologische Zeitschrift* 84(1):3–41.

Daxner-Höck, G. 1996. Faunenwandel im Obermiozän und Korrelation der MN-"Zonen" mit den Biozonen des Pannons der Zentralen Paratethys. *Beiträge zur Paläontologie Wien* 21:1–9.

Daxner-Höck, G. 1999. Family Zapodidae. In *The Miocene Land Mammals of Europe*, ed. G. E. Roessner and K. Heissig, pp. 337–342. Munich: Dr. Friedrich Pfeil.

Demske, D. and A. Kossler. 2001. Lokale Vegetationsentwicklung am Bajkalsee im späten Neogen als Abbild von Paläoklima-Wechseln in Zentral-Asien. *Terra Nostra 2001* (6):28.

Engesser, B. 1972. Die obermiozäne Säugetierfauna von Anwil (Baselland). *Inauguraldissertation. Tätigkeitsberichte der Naturforschenden Gesellschaft Baselland* 28:37–363.

Engesser, B. 1979. Relationships of some insectivores and rodents from the Miocene of North America and Europe. *Bulletin of Carnegie Museum of Natural History* 14:1–68.

Engesser, B. 1990. Die Eomyidae (Rodentia, Mammalia) der Molasse der Schweiz und Savoyens. *Schweizerische Paläontologische Abhandlungen* 112:1–144.

Erbajeva, M. A. and N. V. Alexeeva. 1997. Neogene Mammalian Sequence of the Eastern Siberia. In *Actes du Congrès BiochroM'97*, ed. J.-P. Aguilar, S. Legendre, and J. Michaux, pp. 241–248. Mémoires et Travaux E.P.H.E., Institut de Montpellier, 21.

Erbajeva, M. A. and A. G. Filippov. 1997. Miocene small mammals of the Baikal region. In *Actes du Congrès BiochroM'97*, ed. J.-P. Aguilar, S. Legendre, and J. Michaux, pp. 249–259. Mémoires et Travaux E.P.H.E., Institut de Montpellier, 21.

Fahlbusch, V. 1964. Die Cricetiden (Mamm.) der Oberen Süßwasser-Molasse Bayerns. *Bayerische Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse, Abhandlungen, N.F.* 118:1–136.

Fahlbusch, V. 1992. The Neogene mammalian faunas of Ertemte and Harr Obo in Inner Mongolia (Nei Mongol), China. 10. *Eozapus* (Rodentia). *Senckenbergiana Lethaea* 72:199–217.

Filippov, A. G., M. A. Erbajeva, and E. K. Sytchevskaya. 2000. Miocene deposits in Aya cave near Baikal. *Geologia i Geofisika* 41(5):755–764 (in Russian).

Gasc, J. P., A. Cabela J. Crnobrnja-Isailovic, D. Dolmen, K. Grossenbacher, P. Haffner, J. Lescure, H. Martens, J. P. Martínez Rica, H. Maurin, M. E. Oliveira, T. S. Sofianidou, M. Veith, and A. Zuiderwijk. 2004. *Atlas of Amphibians and Reptiles in Europe*. Collection Patrimoines Naturels 29. Paris: Societas Europaea Herpetologica, Muséum National d'Histoire Naturelle & Service du Patrimoine Naturel.

Gerber, J. 1996. Revision der Gattung *Vallonia* RISSO 1826 (Mollusca: Gastropoda: Vallonidae). *Schriften zur Malakozoologie* 8:1–227.

Gottschick, F. 1911. Aus dem Tertiärbecken von Steinheim a. A. *Jahreshefte des Vereins für Vaterländische Naturkunde in Württemberg* 67:496–534.

Hartenberger, J. L. 1966. Les rongeurs de Vallésien (Miocène supérieur) de Can Llobateres (Sabadell, Espagne): Gliridae et Eomyidae. *Bulletin de la Société géologique de France* 8/7:596–604.

Harzhauser, M. and P. W. E. Piller. 2007. Benchmark data of a changing sea—palaeogeography, palaeobiogeography and events in the Central Paratethys during the Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 253:8–31.

Holman, J. A. 2000. *Fossil Snakes of North America: Origin, Evolution, Distribution, Paleoecology*. Bloomington: Indiana University Press.

Holman, J. A. and K. D. Andrews. 1993. North American Quaternary cold-tolerant turtles: Distributional adaptations and constraints. *Boreas* 23(1):44–52.

Khosatzky, L. I. and V. M. Chkikhvadse. 1993. New data about Miocene turtles of the genus Baicalemys. *Bulletin of the Academy of Science of Georgia* 148(3):155–160 (in Russian).

Kordikova, E. G., E. P. J. Heizmann, and V. G. Pronin. 2003. Tertiary litho- and biostratigraphic sequence of the Ustyurt Plateau area, SW Kazakhstan, with the main focus on vertebrate faunas from the Early to Middle Miocene. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 227(3):381–447.

Kossler, A. 2003. Neogene sediments of Olkhon and Svyatoy Nos (Baikal Rift System, East Siberia): Suggestions about the development of Lake Baikal. *Berliner Paläobiologische Abhandlungen* 4:55–63.

Kretzoi, M. 1943. Ein neuer Muscardinide aus dem Ungarischen Miozän. *Különlenyomat a Földtani Közlöny* 73(1–2):271–273.

Kvaček, Z., M. Böhme, Z. Dvořák, M. Konzalova, K. Mach, J. Prokop, and M. Rajchl. 2004. Early Miocene freshwater and swamp ecosystems of the Most Basin (northern Bohemia) with particular reference to the Bílina Mine section. *Journal of the Czech Geological Society* 49(1–2):1–40.

Laurenti, J. N. 1768. *Specimen Medicum, Exhibens Synopsin Reptilium Emendatam cum Experimentis circa Venena et Antidota Reptilium Austriacorum*. Vienna: J. T. N. de Trattnern.

Logachev, N. A., T. K. Lomonosova, and V. M. Klimanova. 1964. *Cenozoic Deposits of the Irkutsk Amphitheatre*. Moscow: Nauka Press (in Russian).

Mats, V. D., O. M. Khlystov, M. Batist, S. de, Ceramicola, T. K. Lomonosova, and A. Klimansky. 2000. Evolution of the Academician Ridge accommodation zone in the central part of the Baikal rift, from high-resolution reflection seismic profiling and geological field investigation. *International Journal of Earth Science* 89:229–250.

Mats, V. D., A. G. Pokatilov, S. M. Popova, A. Ya. Kravchinsky, N. V. Kulagina, and M. K. Shimaraeva. 1982. *Pliocene and Pleistocene of the Middle Baikal*. Novosibirsk: Nauka Press (in Russian).

Pokalitov, A. G. 1994. Neogene-Quaternary biostratigraphy of the south east Siberia. Ph.D. diss., Novosibirsk State University (in Russian).

Qiu, Z.-d. 1996. *Middle Miocene Micromammal Fauna from Tunggur, Nei Mongol*. Beijing: Science Press (in Chinese with extended English Summary).

Rage, J.-C. and I. G. Danilov. 2008. A new Miocene fauna of snakes from eastern Siberia, Russia. Was the snake fauna largely homogenous in Eurasia during the Miocene. *Comptes Rendus Palevol* 7:383–390.

Sanchiz, B. 1998. Salientia. *Encyclopedia of Paleoherpetology* 4/4, ed. P. Wellnhofer, 1–275. Munich: Dr. Friedrich Pfeil.

Schaub, S. 1925. Die hamsterartigen Nagetiere des Tertiärs und ihre lebenden Verwandten. *Abhandlungen der Schweizerischen Paläontologischen Gesellschaft* 14:1–111.

Shotwell, J. A. 1956. Hemphillian mammalian assemblages from north-eastern Oregon. *Bulletin of the Geological Society of America* 67:717–736.

Steklov, A. A. 1966. *Terrestrial Neogene Molluscs of Ciscaucasia and Their Stratigraphic Importance*. Academy of Sciences of the USSR Transactions 163. Moscow: Nauka Press (in Russian).

Steklov, A. A. 1967. Land molluscs from the Neogene of Touva. *Trudy Zoologicheskogo Instituta Leningrad* 42:269–279 (in Russian).

Stworzewicz, E. 2007. Molluscan fauna (Gastropoda: Pulmonata: Pupilloidea): A systematic review. In *Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia)*, ed. G. Daxner-Höck, pp. 25–41. *Annalen des Naturhistorischen Museums Wien* 108A.

Suzuki, K. 1944. Quaternary land and fresh-water shells from Kuhsiangtung, Habin, Manchoukou. *Miscellaneous Reports of the Research Institute for Natural Resources* 1(3):319–390.

Sytchevskaya, E. K. 1989. *Neogene Freshwater Fish Fauna of Mongolia*. Trudy Sovmestnaya Sovetsko-Mongolkaya Paleontologitcheskaya Ekspeditija, vol. 39. Moscow: Nauka Press (in Russian).

Szyndlar, Z. 1991. A review of Neogene and Quaternary snakes of Central and Eastern Europe. Part I: Scolecophidia, Boidae, Colubridae. *Estudios Geologicos* 47:103–126.

Vislobokova, I. 1990. On the artiodactyls from the Lower Miocene of Tagai bay of Olhon Island (Baikal). *Paleontological Journal* 2:134–138 (in Russian).

Vislobokova, I. 1994. The Lower Miocene artiodactyls of Tagay Bay, Olhon Island, Lake Baikal (Russia). *Palaeovertebrata* 23(1–4):177–197.

Vislobokova, I. 2004. New species of Orygotherium (Palaeomerycidae, Ruminantia) from the Early and Late Miocene of Eurasia. *Annalen des Naturhistorischen Museums Wien* 106A:371–385.

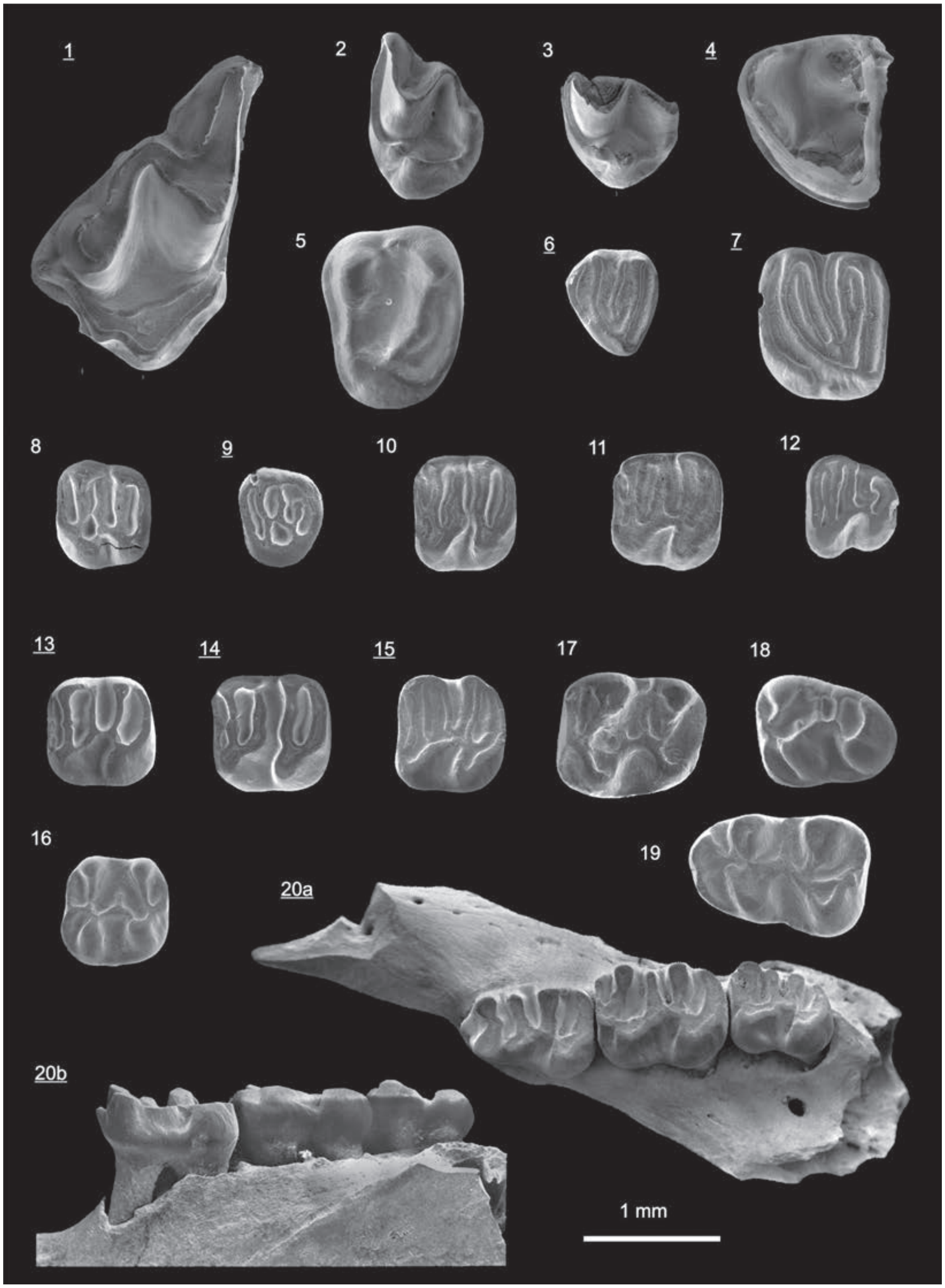

Plate 22.1 Insectivora and Rodentia from the Tagay and Saray I sections of Olkhon Island (Lake Baikal, Siberia), Kalagay Formation. To facilitate comparisons, all right side teeth of small mammals are figured as mirror images, and their figure numbers are underlined.

Desmaninae gen. et sp. indet.—Tagay section, Middle Miocene (MN 7/8): (*1*) right M1, NHMW2009z0067/0001; (*2*) left M3, NHMW2009z0067/0002; (*3*) left M3 (fragmentary), NHMW2009z0067/0003. Erinaceidae gen. et sp. indet.—Tagay section, Middle Miocene (MN 7/8): (*4*) right m2 (fragmentary), NHMW2009z0068/0001 Sciurinae gen. et sp. indet.—Tagay section, Middle Miocene (MN 7/8): (*5*) left P4, NHMW2009z0069/0001. *Miodyromys* sp. (Gliridae)—Tagay section, Middle Miocene (MN 7/8): (*6*) right D4/P4, NHMW2009z0070/0001; (*7*) right M1/2, NHMW2009z0070/0002. *Keramidomys* aff. *mohleri* Engesser 1972 vel *Keramidomys* aff. *fahlbuschi*, Qiu 1996 (Eomyidae)—Tagay section, Middle Miocene (MN 7/8): (*8*) left M2, NHMW2009z0071/0001; (*9*) right M3, NHMW2009z0071/0002; (*10*) left m1/2, NHMW2009z0071/0003; (*11*) left m1/2, NHMW2009z0071/0004; (*12*) left m3, NHMW2009z0071/0005; (*13*) right m1/2, NHMW2009z0071/0006; (*14*) right m1/2, NHMW2009z0071/0007; (*15*) right m1/2, NHMW2009z0071/0008. *Eomyops oppligeri* Engesser, 1990 (Eomyidae)—Tagay section, Middle Miocene (MN 7/8): (*16*) left m1/2, NHMW2009z0072/0008. *Democricetodon* sp. (Cricetidae)—Tagay section, Middle Miocene (MN 7/8): (*17*) left M2, NHMW2009z0073/0001; (*18*) left m3, NHMW2009z0073/0002; (*19*) left m1, NHMW2009z0073/0003. *Eozapus intermedius* Bachmayer and Wilson, 1970 (Zapodidae)—Saray I section, Late Miocene: (*20*a) right mandible with m1–3 (occlusal), NHMW2009z0074/0001; (*20*b) right mandible with m1–3 (labial), NHMW2009z0074/0001. Magnifications: 25×; (all specimens in the NHMW collection Inv. Nr. NHMW2009z0067–074).

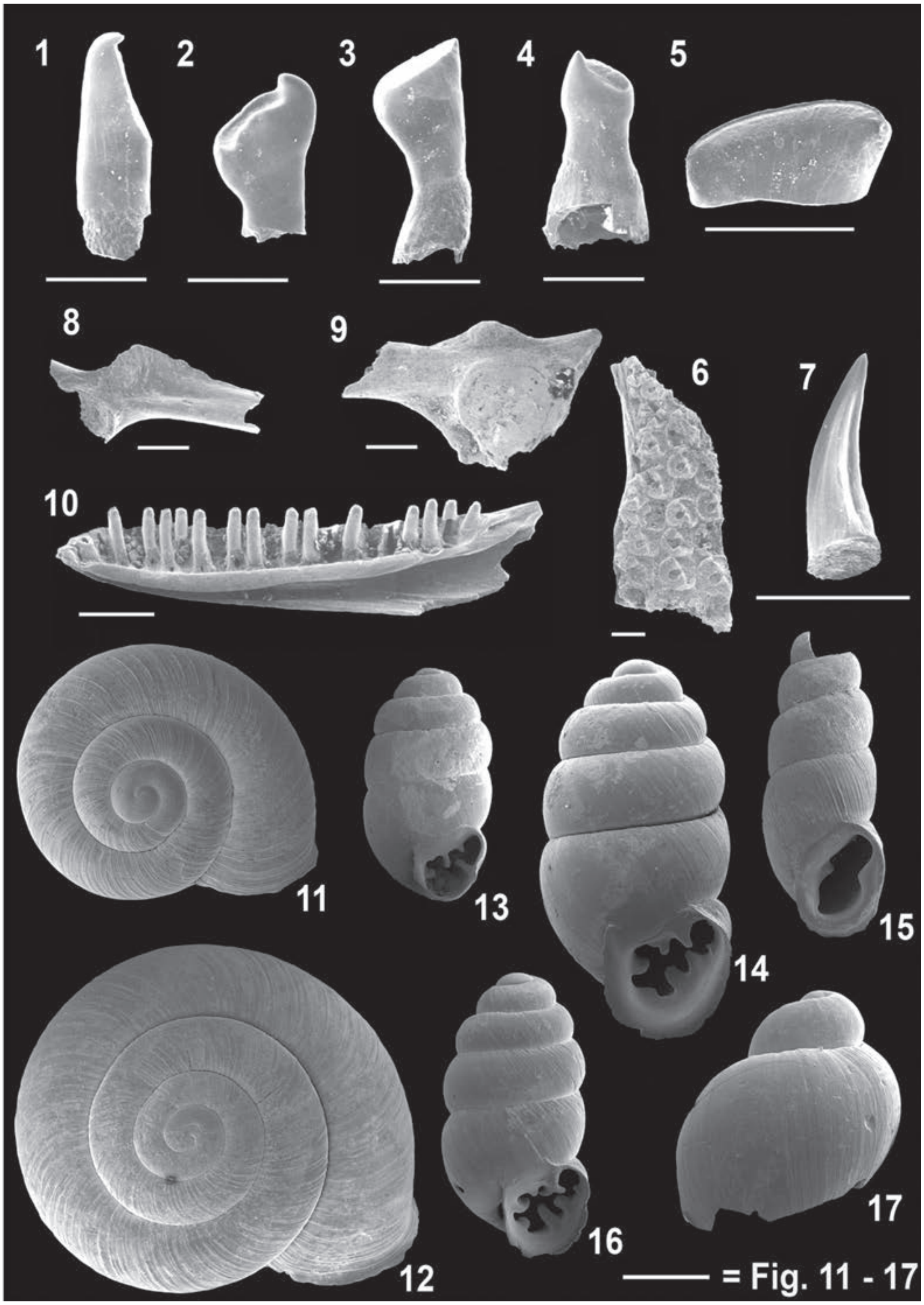

Plate 22.2 Gastropoda and ectothermic vertebrates from the Tagay and Saray I sections of Olkhon Island (Lake Baikal, Siberia); Kalagay Formation. Scale bar for figures 1–10 is 1 mm; scale bar for figures 11–17 is 500 µm. (*1*) Leuciscinae indet., pharyngeal tooth, Tagay; (*2*) *Palaeotinca* sp., pharyngeal tooth, Tagay; (*3*) *Palaeocarassius* sp., pharyngeal tooth, Tagay; (*4*) *Palaeocarassius* sp., pharyngeal tooth, A1 position, Tagay; (*5*) *Palaeocarassius* sp., pharyngeal tooth germ, Tagay; (*6*) *Esox* sp., palatine, Tagay; (*7*) *Esox* sp., tooth, Tagay; (*8*) *Rana* sp. (*R. temporaria* group), right ilium, Tagay; (*9*) *Bufo* aff. *calamita* (Laurenti 1768), left ilium, Saray I; (*10*) ?*Chalcides* nov. sp., right dental, Tagay; (*11*) *Vallonia subcyclophorella* (Gottschick 1911), apical view, Saray I-140899-8; (*12*) *Vallonia tokunagai* Suzuki, 1944, apical view, Saray I-140899-11; (*13*) *Vertigo* (*Ungulidenta*) *ancata* Steklov 1967, apertural view, Saray I-140899-8; (*14*) *Gastrocopta* (*Kazachalbinula*) cf. *ukrainica* Steklov 1966, apertural view, Saray I-140899-8; (*15*) *Carychium* sp., apertural view, Saray I-140899-10; (*16*) *Gastrocopta* (*Sinalbulina*) *intorta* Steklov 1967, apertural view, Saray I-140899-8; (*17*) *Radix* sp., lateral view of an incomplete juvenile shell, Saray I-140899-11.

FOSSIL MAMMALS OF ASIA

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