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蒙古中部湖泊之谷沉积岩-玄武岩共存的渐新世地层:蒙古-奥地利合作项目回顾

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摘要:Taatsiin Gol 和 Taatsiin Tsagaan Nuur 地区的渐新世沉积序列具有重要的地层学意义:这里出露的三达河组和 Loh 组沉积含有多个化石层和玄武岩夹层。在蒙古-奥地利合作项目中,从研究区域的33个剖面/化石地点的85个化石层中采集了289种化石(11种腹足类、2种两栖类、9种爬行类和267种哺乳类)。本文提供了所有地点的完整哺乳动物清单,并结合大、小哺乳动物的新资料,对蒙古非正式的生物带 A, B, C 和 C1 进行了更新。$^{40}Ar/^{39}Ar$ 测年给出了至少两组玄武岩年龄:早渐新世玄武岩 I 组大约 31.5 Ma, 晚渐新世玄武岩 II 组大约 28 Ma。它们可以用作渐新世哺乳动物地层学的年代校正点。从早渐新世至晚渐新世,哺乳动物群发生了显著的变化,包括晚渐新世种数的明显减少。这种趋势在肉齿类、食肉类和反刍类中最为突出。

关键词:蒙古,渐新世,三达河组,Loh 组,$^{40}Ar/^{39}Ar$ 年龄,地层学,生物带
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OLIGOCENE STRATIGRAPHY BASED ON A SEDIMENT-BASALT ASSOCIATION IN CENTRAL MONGOLIA (TAATSIIN GOL AND TAATSIIN TSAGAAN NUUR AREA, VALLEY OF LAKES): REVIEW OF A MONGOLIAN-AUSTRIAN PROJECT

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Abstract The Oligocene sedimentary sequence of the Taatsiin Gol and Taatsiin Tsagaan Nuur area is of unique stratigraphic importance: here, the exposed sediments of the Hsanda Gol and the Loh Formations display multiple fossil horizons and interbedded basalt layers. In the frame of a Mongolian-Austrian project, 289 fossil taxa (11 Gastropoda, 2 Amphibia, 9 Reptilia and 267 Mammalia) were collected from

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85 fossil horizons of 33 sections/fossil sites of the study area. The taxa were identified by an international team of specialists. This contribution presents comprehensive mammal lists of all localities. By integrating the new data on large and small mammals, the Mongolian informal biozones A, B, C, C1 were updated. $^{40}Ar/^{39}Ar$-datings provide at least two groups of basalt ages, the Early Oligocene basalt I group around 31.5 Ma and the Late Oligocene basalt II group around 28 Ma. They serve as chronological tie points in the Oligocene mammalian stratigraphy.

From the Early to the Late Oligocene the mammal associations underwent remarkable changes involving a significant decrease of species numbers in the Late Oligocene. This trend was most striking in creodont, carnivore and ruminant communities.

Key words Mongolia, Oligocene, Hsanda Gol Formation, Loh Formation, $^{40}Ar/^{39}Ar$-ages, stratigraphy, biozonation

1 Introduction

The Valley of Lakes is one of the Pre-Altai depressions in Mongolia. It is situated between the Gobi Altai Mountains in the south and the Khangai Mountains in the north and extends across ~500 km in west-east direction in Central Mongolia. Above a Proterozoic and Paleozoic basement the basin is filled with continental sediments ranging continuously from the Cretaceous to the Quaternary.

The initial geological research and discoveries of rich fossil beds made during the Central Asiatic Expeditions by the American Museum of Natural History in the 1920s was followed by comprehensive geoscientific research in the frame of several joint expeditions. These include the Soviet-Mongolian Geological and Paleontological Expeditions, the Polish-Mongolian Paleontological Expedition, and finally Mongolian–American joint expeditions in the 1990s. After the IGCP Project 326, which focused on the "Oligocene–Miocene Transition in the Northern Hemisphere", in 1993 we started a Mongolian–Austrian joint project in the Taatsiin Gol and Taatsiin Tsagaan Nuur area which is part of the Valley of Lakes. In collaboration of the Mongolian Academy of Sciences and the Natural History Museum Vienna, fieldwork was carried out during six field seasons (1995–1997, 2001, 2004, 2006). The sediment sequences of the Hsanda Gol and the Loh Fms, long known for their fossil richness and basaltic volcanism, allow a stratigraphic adjustment based on the evolution of mammals and on the age determinations of basalts. The comprehensive geological investigations included geological mapping, lithological studies, sedimentology and tectonics, $^{40}Ar/^{39}Ar$-dating of basalts, biostratigraphy and biochronology (Höck et al., 1999). Along of 33 sections and fossil sites, between Menkhen Teeg in the west and Ikh Argalatyn Nuruu in the east (Fig. 1; Table 1), 85 Oligocene vertebrate assemblages were collected by bed-by-bed sampling and screen washing, and by surface collecting alongside the studied sections. After the collection period, a proposed (Daxner-Höck et al., 1997) and refined integrated statigraphy (Höck et al., 1999; Daxner-Höck and Badamgarav, 2007) of the study area was elaborated. Since then, numerous taxonomic descriptions have allowed an update of the Mongolian biozones A–C1.

Material and methods Numerous mandibles and several thousand isolated teeth of rodents, insectivores and lagomorphs, and a few marsupial teeth, were collected by screen washing ~ 40 tons of Oligocene sediments. The stratified fossil beds also yielded gastropods (Stworzewicz, 2007), amphibians and reptiles (Böhme, 2007). Moreover, disarticulated and mostly fragmented fossils from large mammals were selected from washing residue or collected from the surface close to the investigated section. The washing equipment consisted of sieves of 0.5, 2.5 and 5.0 mm mesh sizes, an electric water pump and a generator. The fossils were picked out of the residue and studied using head-lenses and light microscopes. For detailed investigation the teeth were coated with gold and SEM-images were taken with a Philips XL scanning microscope at the Biocenter, University of Vienna. To facilitate comparisons, all right-side teeth are figured as

mirror images (reversed) and their figure numbers are underlined, e. g. Fig. 3/$\underline{1}$ (= right m1–3).

All listed (Tables 2–6) and figured (Figs. 3–6) fossils were collected in the frame of the Mongolian–Austrian project and are integrated in the collection of the Natural History Museum Vienna (NHMW). The fossils are labelled using the abbreviation of the location – section/number of sediment layer (e. g. TGR-A/13 = Taatsiin Gol right river side – section A/layer 13). Surface collections along sections are labelled with "O", e. g. TGR-A/O.

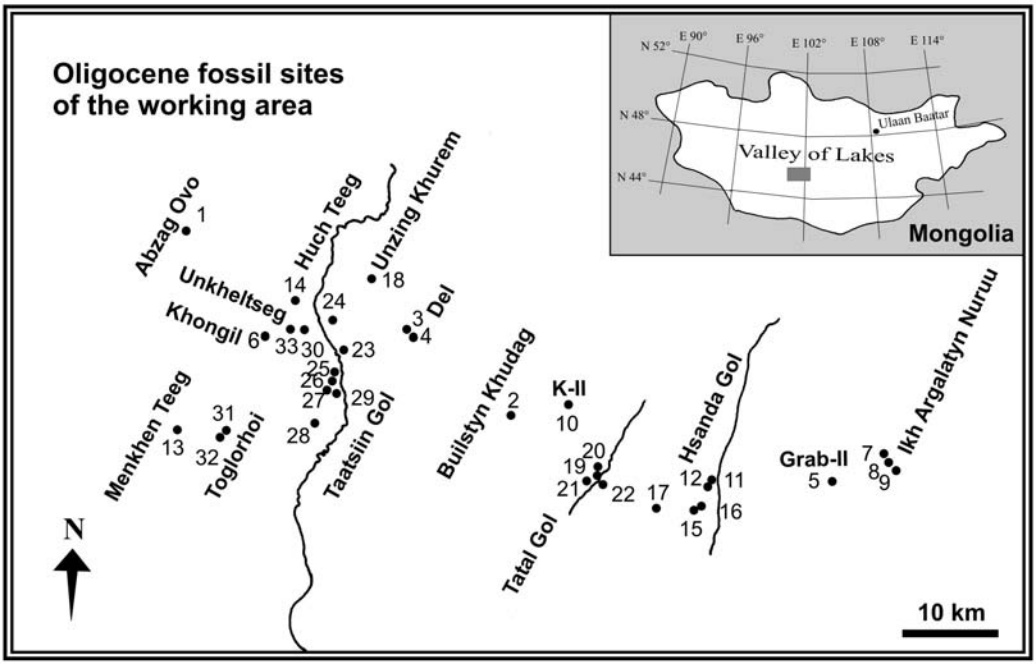

Fig. 1 Localization of Oligocene fossil sites of the working area
For explanations of numbers 1–33 see Table 1

Table 1 Oligocene fossil localities (1–33) and abbreviations of sections of the Taatsiin Gol and Taatsiin Tsagaan Nuur area (Valley of Lakes, Central Mongolia), modified from Daxner-Höck and Badamgarav (2007; Fig. 1)

	locality	section		locality	section
1.	Abzag Ovo	ABO-A	18.	Unzing Khurem	TAR-A
2.	Builstyn Khudag	BUK-A	19.	Tatal Gol	TAT-B
3.	Del	DEL-A	20.	Tatal Gol	TAT-C
4.	Del	DEL-B	21.	Tatal Gol	TAT-D
5.	unnamed locality	GRAB-II	22.	Tatal Gol	TAT-SE
6.	Khongil	HL-A	23.	Taatsiin Gol left	TGL-A
7.	Ikh Argalatyn Nuruu	IKH-A	24.	Taatsiin Gol left	TGL-B
8.	Ikh Argalatyn Nuruu	IKH-B	25.	Taatsiin Gol right	TGR-A
9.	Ikh Argalatyn Nuruu	IKH-C	26.	Taatsiin Gol right	TGR-B
10.	unnamed locality	K-II	27.	Taatsiin Gol right	TGR-AB
11.	Loh	LOH-B	28.	Taatsiin Gol right	TGR-C
12.	Loh	LOH-C	29.	Taatsiin Gol right	TGR-ZO
13.	Menkhen Teeg	MKT-W	30.	Taatsiin Gol right	TGR-1564
14.	Huch Teeg	RHN-A	31.	Toglorhoi	TGW-A
15.	Hsanda Gol	SHG-A	32.	Toglorhoi	TGW-D
16.	Hsanda Gol	SHG-AB	33.	Unkheltseg	UNCH-A
17.	Hsanda Gol	SHG-C			

2 Basalt ages

The basalt occurrences of the study area have been dated by the $^{40}Ar/^{39}Ar$ method (whole rock samples; Höck et al., 1999). This yielded at least two groups of Oligocene basalt ages. The first is the Early Oligocene basalt I group of around 31.5 Ma (range: 30.4 ~ 32.2 Ma; errors varying from 0.3 to 0.8 Ma). The second is the Late Oligocene basalt II group, which displays age differences of at least 1 Ma between local occurrences west and east of Taatsiin Gol. The eastern basalt II flows are around 28 Ma in age (range: 27 ~ 29 Ma), the western flows around 26.5 Ma (range: 25 ~ 27 Ma). Errors of basalt II ages vary from 0.4 to 0.9 Ma (Höck et al., 1999, fig. 18).

3 Stratigraphy

The paleontological and stratigraphic focus is on sediments of the Hsanda Gol and Loh Fms, which are locally very rich in fossils. The Oligocene part of the sediment sequence is indicated by fossils of the biozones A, B, C, C1 and basalts I and II.

The Hsanda Gol Fm. consists of brick-red clays and silts divided by the 5- to 20-m-thick basalt I or its time equivalent tuff and are Early Oligocene in age. Below basalt I the red Hsanda Gol beds contain fossils of biozone A, and immediately above basalt I fossils of biozone B. The highest parts of the Hsanda Gol sediments extend to the Late Oligocene as indicated by fossils of biozones C and of the lowermost part of biozone C1. Simultaneously, sediments of the Loh Fm. were deposited in the Late Oligocene, i. e. sands, silts, gravels of more light colours (rose, yellow, white, green, brown). The lower part of the Loh Fm. locally displays fossils of biozone C immediately below or above basalt II flows: i. e. in section Abzag Ovo (ABO-A/3; Fig. 1/1) fossils of biozone C were recovered from a red silt of the Loh Fm. immediately below basalt II (27.0 ± 0.9 Ma); in section Unzing Khurem (TAR-A/2; Fig. 1/18) a white-orange silt on top of basalt II (27.4 ± 0.4 Ma) also contains fossils of biozone C. So far these are the only two occurrences of basalt II (Late Oligocene) that contact fossil beds of biozone C. All other basalt II occurrences are imbedded in more coarse-grained sediments of the Loh Fm. without preserved fossil content, or they are covered by silts of the Loh Fm. containing Miocene fossils (Höck et al., 1999).

4 Oligocene deposits of the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Most of the 33 investigated sections/fossil sites are concentrated in three regions of the working area, the Taatsiin Gol, Tatal Gol/Hsanda Gol and Ikh Argalatyn Nuruu. Moreover, some isolated sites are: Menkhen Teeg (in the west), Abzag Ovo (in the northwest), Unzing Khurem (in the north), Del (east of Taatsiin Gol), Builstyn Khudag and K-II (between Taatsiin Gol and Tatal Gol), and GRAB-II (between Hsanda Gol and Ikh Argalatyn Nuruu). For localization see Fig. 1 and Table 1. GPS-positions and the altitudes are given in Höck et al. (1999, table 2) and Daxner-Höck and Badamgarav (2007, table 1).

4.1 Early Oligocene fossil beds of biozone A

As outlined above, eighteen assemblages representing biozone A were recovered from brick-red Hsanda Gol sediments below basalt I or its equivalent tuff.

Below basalt I: Menkhen Teeg (MKT-W/O; Fig. 1/13), Khongil (HL-A/1-2; Fig. 1/6), Taatsiin Gol right and left side of the river (TGR-A/13-14; Fig. 1/25 and TGL-A/1-2; Fig. 1/23), Hsanda Gol (SHG-C/1-2; Fig. 1/17), unnamed locality (GRAB-II/1-3; Fig.

1/5).

Below tuff I or in equivalent lateral position: Del (DEL-B/2; Fig. 1/4), Tatal Gol (TAT-C/1–3; Fig. 1/20 and TAT-D/1; Fig. 1/21).

4.2 Early Oligocene fossil beds of biozone B

Forty vertebrate assemblages representing biozone B were recovered from brick-red Hsanda Gol sediments above basalt I or its equivalent tuff, between two beds of basalt I, and from sections without basalt occurrences.

Above basalt I: Taatsiin Gol right side (TGR-B/1; Fig. 1/26 and TGR-AB/21–22; Fig. 1/27), Taatsiin Gol left side (TGL-A/O, 11; Fig. 1/23 and TGL-B/O; Fig. 1/24), Del (DEL-A/11; Fig. 1/3), Unkheltseg (UNCH-A/O; Fig. 1/33).

Between two beds of basalt I: Taatsiin Gol right side (TGR-ZO/1–2; Fig. 1/29 and TGR-1564; Fig. 1/30).

Above tuff I: Del (DEL-B/O, 7–8; Fig. 1/4), Tatal Gol (TAT-C/6–7; Fig. 1/20).

Sections without basalt or tuff I: Builstyn Khudag (BUK-Shg/O; Fig. 1/2), Tatal Gol (TAT-D/2; Fig. 1/21), Hsanda Gol (SHG-A/O, 1, 4, 6, 9, 10, 15, 15+20, 18+20, 20; Fig. 1/15 and SHG-AB/O, 12, 17–20, 20; Fig. 1/16), Ikh Argalatyn Nuruu (IKH-A/1–4; Fig. 1/7, IKH-B/1–4; Fig. 1/8 and IKH-C/O; Fig. 1/9).

4.3 Late Oligocene fossil beds of biozone C

Thirteen vertebrate assemblages representing biozone C were recovered from red Hsanda Gol sediments, and from red, white-orange, or gray-green silt of the Loh Fm., locally contacting basalt II.

Red clay of Hsanda Gol Fm.: Taatsiin Gol right side (TGR-C/1, 2, 5, 6, 7; Fig. 1/28).

Red-rose silty clay or silt of Loh Fm.: Toglorhoi (TGW-A/1, 2a, 2b; Fig. 1/31), Tatal Gol (TAT-SE/O; Fig. 1/22).

Gray-green silt of Loh Fm.: Huch Teeg (RHN-A/6; Fig. 1/14).

Above basalt II, white-orange silt of Loh Fm.: Unzing Khurem (TAR-A/2; Fig. 1/18).

Below basalt II, red silt of Loh Fm.: Abzag Ovo (ABO-A/1; Fig. 1/1).

4.4 Late Oligocene fossil beds of biozone C1

Fourteen vertebrate assemblages representing biozone C1 were recovered from the uppermost Hsanda Gol sediments, and from red-rose, brown, yellow and green silty clay or silt of the Loh Fm.

Red silt of Hsanda Gol Fm.: Del (DEL-B/12; Fig. 1/4).

Red-rose silty clay or silt of Loh Fm: Toglorhoi (TGW-A/5; Fig. 1/31 and TGW-D/O; Fig. 1/32), Tatal Gol (TAT-SE/O; Fig. 1/22, TAT-D/3; Fig. 1/21 and TAT-B/10; Fig. 1/19), Loh (LOH-C/1; Fig. 1/12 and LOH-B/3; Fig. 1/11), Ikh Argalatyn Nuruu (IKH-A/5, Fig. 1/7 and IHK-B/5; Fig. 1/8).

Brown, yellow and green silt of Loh Fm.: Huch Teeg (RHN-A/7, 8, 9, 10; Fig. 1/14).

5 Emended biostratigraphy and biochronology of informal biozones A–C1

Since the initial establishment of the stratigraphic concept in the Taatsiin Gol and Taatsiin Tsagaan Nuur area (Daxner-Höck et al., 1997; Höck et al., 1999), additional field activities and detailed systematic-taxonomic investigations on different fossil groups have been conducted. These have further improved our knowledge (Böhme, 2007; Daxner-Höck, 2000, 2001; Daxner-Höck and Wu, 2003; Daxner-Höck and Badamgarav, 2007; Erbajeva, 2003, 2007; Erba-

jeva and Daxner-Höck, 2001; Göhlich, 2007; Heissig, 2007; Koenigswald and Kalthoff, 2007; Morlo and Nagel, 2002, 2006, 2007; Nagel and Morlo, 2003; Schmidt-Kittler et al., 2007; Stworzewicz, 2007; Vislobokova and Daxner-Höck, 2002; Ziegler et al., 2007).

The initial characterization of the biozones was based on preliminarily determined rodents. It included an integrated rodent list, the first/last records, the most abundant/characteristic taxa, the lithostratigraphic position and relation to one of the basalt events. New data allow an update of the informal biozones (A–C1). Integrated mammal lists (Tables 2–6) show the stratigraphic ranges of Marsupialia and Insectivora (Table 2), Lagomorpha (Table 3), Rodentia (Table 4), Carnivora, Creodonta, Didymoconidae (Table 5), Rhinocerotidae and Ruminantia (Table 6) from the study area. All were collected in the frame of the Mongolian–Austrian project. The present characterization displays the most abundant mammals of each biozone, some last occurrences, and updated time estimations (Fig. 2). Moreover, Figs. 3–6 show selected small mammal teeth of the respective biozones.

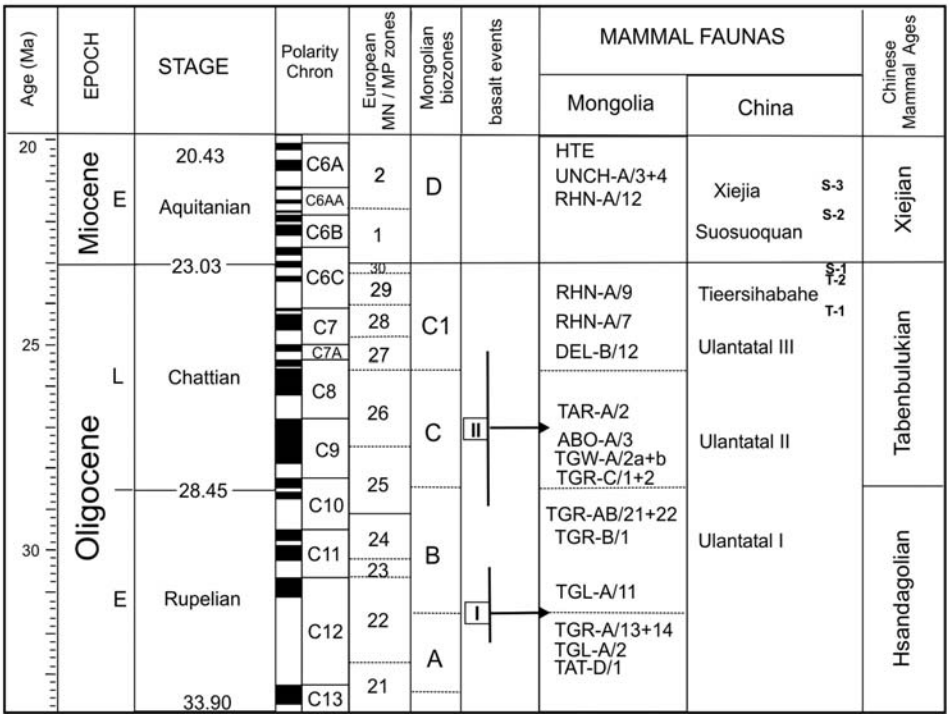

Fig. 2 Subdivision and correlation of Oligocene mammalian biozones of the Taatsiin Gol and Taatsiin Tsagaan Nuur area, Mongolia

Geologic time scale after Gradstein et al. (2004); European Land Mammal Zones, Neogene MN-Zones after Steininger (1999); Paleogene MP-Zones after Luterbacher et al. (2004); Chinese Mammal Ages after Deng (2006); correlations of the Chinese faunas Xiejia, Suosuoquan and Tieersihabahe after Meng et al. (2006); correlation of Ulantatal I–III after Schmidt-Kittler et al. (2007)

5.1 Biozone A (Figs. 2, 3)

Integrated mammal list: Tables 2–6.

Most abundant taxa: *Zaraalestes minutus*, *Desmatolagus gobiensis*, *D. youngi*, *Selenomys mimicus*, *Cricetops dormitor*, *Karakoromys decessus*, *Heosminthus* sp. 1, *Cyclomylus* div. spec.

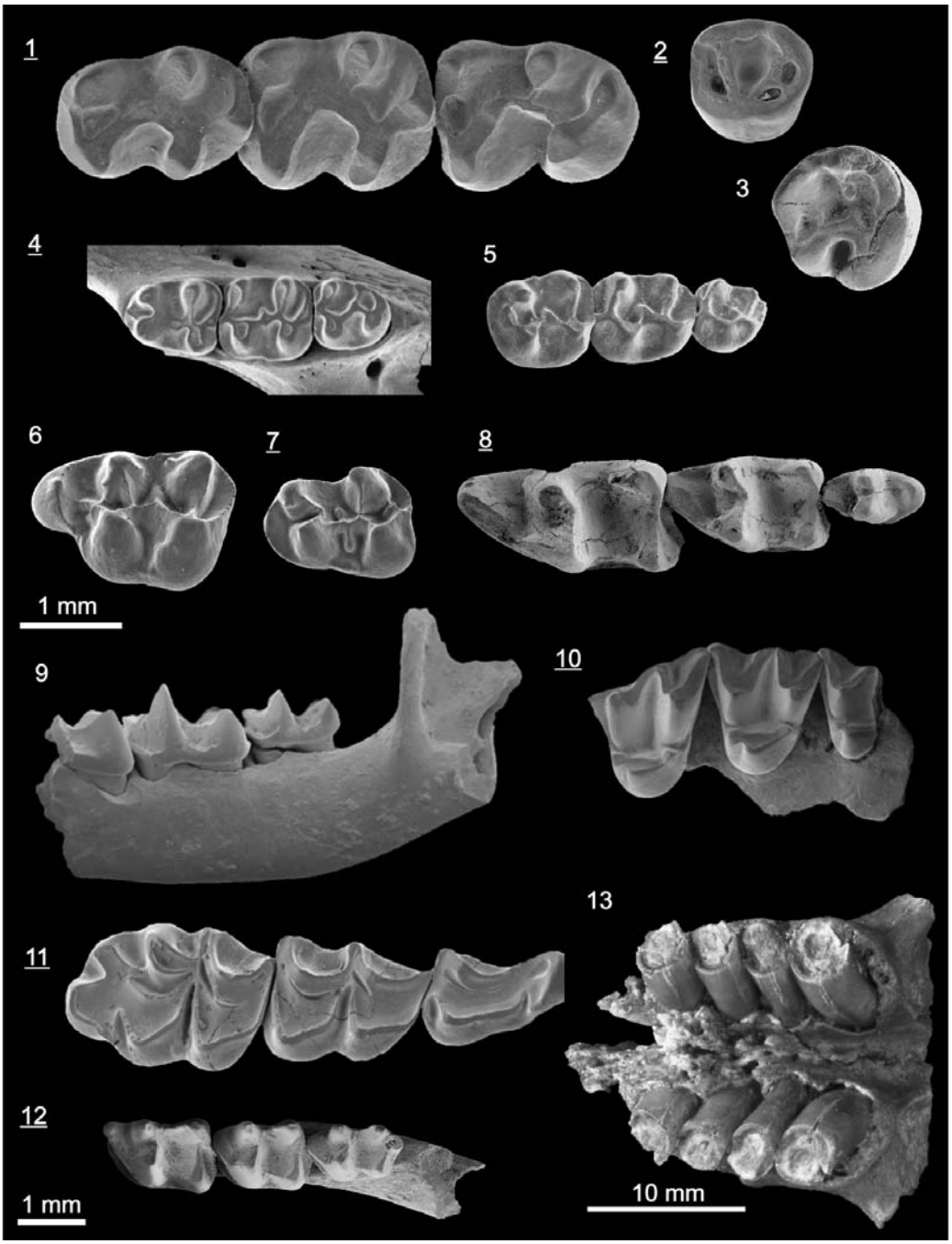

Fig. 3 Insectivora and Rodentia from biozone A (early Early Oligocene) of the Taatsiin Gol and Taatsiin Tsagaan Nuur area, Mongolia

1. *Karakoromys decessus* Matthew & Granger, 1923, right m1–3 (reversed), occlusal view, NHMW2009z0129/0001, Tatal Gol (TAT-D/1); 2 – 3. *Ardynomys* sp.: 2. right M1/2 (reversed), occlusal view, NHMW2009z0130/0001, Tatal Gol (TAT-D/1); 3. left m1/2, occlusal view, NHMW2009z0131/0001, Hsanda Gol (SHG-C/1); 4–5. *Allosminthus khandae* (Daxner-Höck, 2001): 4. right m1–3 (holotype, reversed), occlusal view, NHMW2001z0032/0001/8), Tatal Gol (TAT-D/1); 5. left M1 – 3, occlusal view, NHMW2001z0032/0001/4, Tatal Gol (TAT-D/1); 6–7. *Eucricetodon caducus* (Shevyreva, 1967): 6. left M1, occlusal view, NHMW2009z0132/0001, Hsanda Gol (SHG-C/1); 7. right m1 (reversed), occlusal view, NHMW2009z0132/0002, Hsanda Gol (SHG-C/1); 8. *Palaeoscaptor tenuis* Ziegler et al., 2007, right m1–3 (holotype, reversed), occlusal view, NHMW2005z0103/0001), Tatal Gol (TAT-D/1); 9–10. *Mongolopala tathue* Ziegler et al., 2007: 9. left mandibular fragment with m1–3, labial view, NHMW2006z0055/0002, Tatal Gol (TAT-D/1); 10. right M1–3 (holotype, reversed), occlusal view, NHMW2006z0055/0001, Tatal

Table 2 Marsupialia and Insectivora from the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Marsupialia and Insectivora:	Oligocene biozones			
from Ziegler et al. (2007: table 15)	A	B	C	C1
Didelphidae				
Asiadidelphis zaissanensis Gabunia et al., 1990	×	×		
Asiadidelphis tjutkovae Emry et al., 1995	×			
Erinaceomorpha				
Brachyericinae				
Exallerix pustulatus Ziegler et al., 2007			×	
Erinaceidae				
Tupaiodontinae				
Zaraalestes minutus (Matthew & Granger, 1924)	×	×		
Zaraalestes sp.		×		
Erinaceinae				
Palaeoscaptor acridens Matthew & Granger, 1924	×	×	×	×
Palaeoscaptor cf. *P. rectus* Matthew & Granger, 1924	×	×	×	×
Palaeoscaptor tenuis Ziegler et al., 2007	×	×	×	
Palaeoscaptor gigas Lopatin, 2002		×	×	
Amphechinus taatsiingolensis Ziegler et al., 2007			×	
Amphechinus minutissimus Ziegler et al., 2007				×
Amphechinus major Ziegler et al., 2007				×
Erinaceinae gen. et sp. indet. I	×			
Soricidae				
Heterosoricinae				
Gobisorex kingae Sulimsky, 1970	×	×	×	×
Heterosoricinae gen. et sp. indet. 1–2		×		
Heterosoricinae gen. et sp. indet. 3				×
Crocidosoricinae				
Taatsiinia hoeckorum Ziegler et al., 2007		×		
Tavoonyia altaica Ziegler et al., 2007				×
Crocidosoricinae gen. et sp. indet. 1–6		×		
Crocidosoricinae gen. et sp. indet. 7			×	×
Crocidosoricinae gen. et sp. indet. 8			×	
Talpidae				
Mongolopala tathue Ziegler et al., 2007	×			
Talpidae gen. et sp. indet. 1–3	×			
Talpidae gen. et sp. indet. 4–6		×		
Talpidae gen. et sp. indet. 7			×	
Talpidae gen. et sp. indet. 8				×
Soricomorpha incertae sedis				
cf. *Asiapternodus meckennai* Lopatin, 2003	×			

Some last occurrences: *Mongolopala tathue*, *Desmatolagus* aff. *D. vetustus*, *Ardynomys* sp., *Allosminthus khandae*, *Lophiomeryx*.

Gastropoda: from Hsanda Gol beds below basalt I (Stworzewicz, 2007).

Amphibia and Reptilia: (Böhme, 2007).

Gol (TAT-D/1); 11. *Selenomys mimicus* Matthew & Granger, 1923, right M1–3 (reversed), occlusal view, NHMW2009z0133/0001, Taatsiin Gol (TGL-A/2); 12. *Zaraalestes minutus* (Matthew & Granger, 1924), right m1–3 (reversed), occlusal view, NHMW2006z0121/0003, Tatal Gol (TAT-D/1); 13. ? *Cyclomylus* sp., maxillary fragment with right and left P4–M3, occlusal view, NHMW2009z0134/0001, Tatal Gol (TAT-D/1); 1–8, 9–12, and 13 are in the same scale respectively

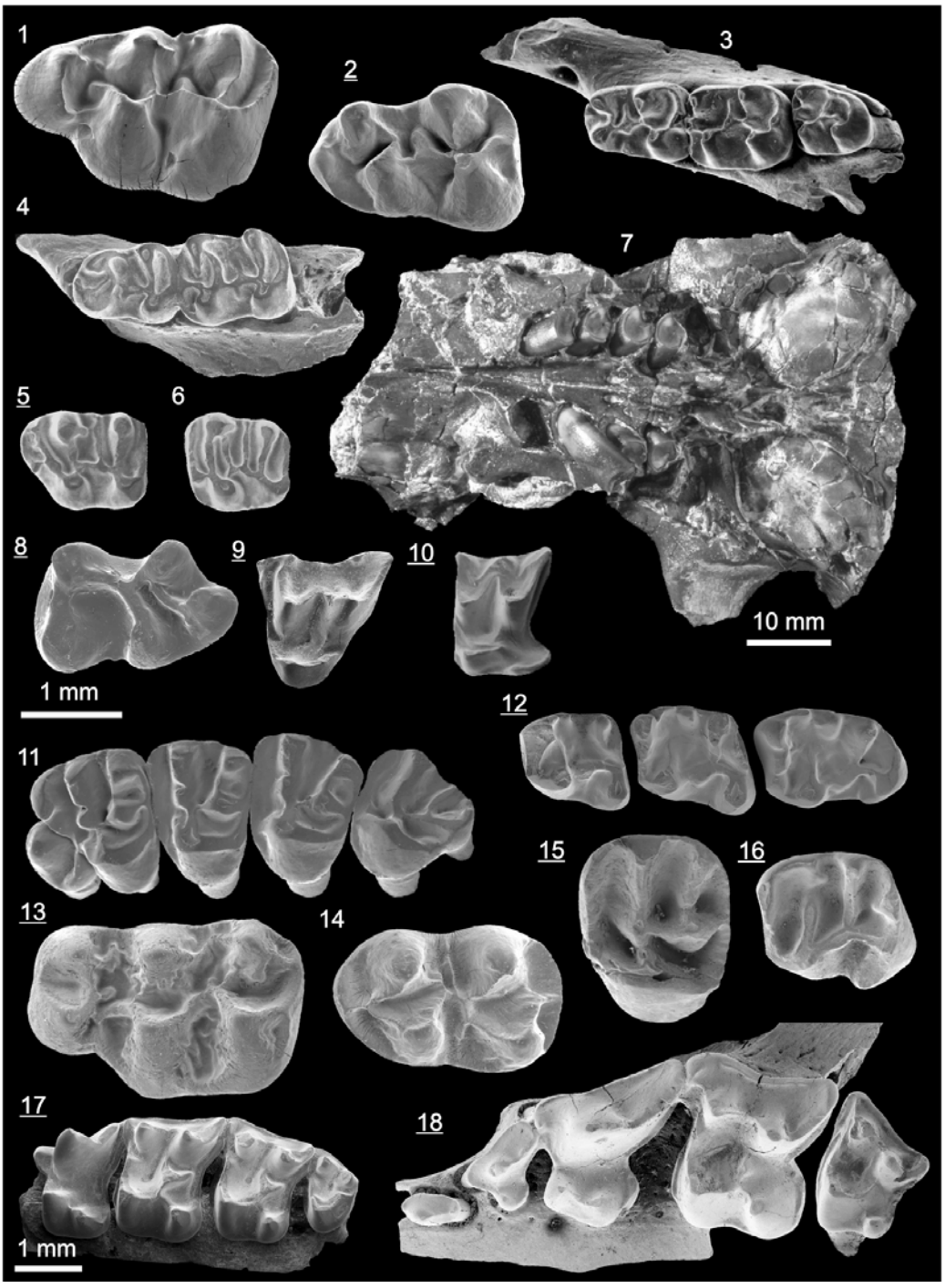

Fig. 4 Marsupialia, Insectivora and Rodentia from biozone B (late Early Oligocene) of the Taatsiin Gol and Taatsiin Tsagaan Nuur area, Mongolia

1–2. *Eucricetodon asiaticus* (Matthew & Granger, 1923): 1. left M1, occlusal view, NHMW2009z0135/0001, Taatsiin Gol (TGR/B1); 2. right m1 (reversed), occlusal view, NHMW2009z0135/0002, Taatsiin Gol (TGR/B1); 3. *Shamosminthus sodovis* Daxner-Höck, 2001, left mandibular fragment with m1–3, occlusal view, NHMW2001z0034/0010/3, Ikh Argalatyn Nuruu (IKH-A/3–4); 4–6. *Ulaancricetodon badamae* Daxner-Höck, 2000: 4. left m1–2, occlusal view, NHMW1999z0083/0037/6, Taatsiin Gol (TGR-AB/22); 5. right M1 (reversed), occlusal view, NHMW1999z0083/0009/1, Ikh Argalatyn Nuruu (IKH-A/3–4); 6. left M2, occlusal view, NHMW1999z0083/0036/2, Taatsiin Gol (TGR-B/1); 7. *Tsaganomys altaicus* Matthew & Granger, 1924, fragmentary skull with left P4–M3 and right M1–3, occlusal view, NHMW2009z0136/0001, Taatsiin Gol (TGR-B/0); 8. *Huangomys frequens* Schmidt-Kittler et al., 2007, right m3 (reversed), occlusal

Table 3 Lagomorpha from the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Lagomorpha: revised from Erbajeva (2007: table 1)	Oligocene biozones A	B	C	C1
Palaeolagidae				
Desmatolagus ex. gr. *D. youngi* (Gureev, 1960)	×			
Desmatolagus aff. *D. youngi* (Gureev, 1960)	×			
Desmatolagus cf. *D. youngi* (Gureev, 1960)	×	×		
Desmatolagus youngi (Gureev, 1960)	×	×		
Desmatolagus cf. *D. robustus* Matthew & Granger, 1923	×	×		
Desmatolagus aff. *D. vetustus* Burke, 1941	×			
Desmatolagus aff. *D. gobiensis* Matthew & Granger, 1923	×			
Desmatolagus gobiensis Matthew & Granger, 1923	×	×	×	
Desmatolagus cf. *D. gobiensis* Matthew & Granger, 1923	×	×	×	×
Desmatolagus cf. *D. chinensis* (Erbajeva & Sen, 1998)				×
Desmatolagus aff. *D. chinensis* (Erbajeva & Sen, 1998)			×	×
Desmatolagus aff. *D. simplex* (Argyropulo, 1940)			×	
Desmatolagus sp.	×	×		×
Desmatolagus sp. A		×	×	
Desmatolagus cf. *D. orlovi* (Gureev, 1960)	×	×	×	
Desmatolagus aff. *D. orlovi* (Gureev, 1960)		×		
Desmatolagus cf. *D. shargaltensis* Bohlin, 1937			×	
Desmatolagus sp. 1	×		×	
Desmatolagus sp. 2	×		×	
Desmatolagus sp. 3	×			
Leporidae				
Ordolagus cf. *O. teilhardi* (Burke, 1941)		×	×	
Ordolagus sp.		×		
Ochotonidae				
Bohlinotona sp.			×	×
Sinolagomys cf. *S. kansuensis* Bohlin, 1937			×	×
Sinolagomys kansuensis Bohlin, 1937			×	×
Sinolagomys sp.		×	×	×
Sinolagomys cf. *S. tatalgolicus* Gureev, 1960				×
Sinolagomys aff. *S. major* Bohlin, 1937				×
Sinolagomys major Bohlin, 1937			×	×
Sinolagomys ulungurensis Tong, 1989				×

Lithostratigraphy and biochronology: fossils representing biozone A were recovered from Hsanda Gol sediments below basalt I (~31.5 Ma) or its tuff. They are of early Early Oligocene age, i.e. older than ~31.5 Ma.

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view, NHMW2006z0068/0006, Taatsiin Gol (TGR-B/1); 9. *Asiadidelphis zaissanensis* Gabunia et al., 1990, right M1 (reversed), occlusal view, HNMW2006z0116/0002, Taatsiin Gol (TGR-AB/22); 10. *Taatsiinia hoeckorum* Ziegler et al., 2007, right M2 (reversed), occlusal view, NHMW2006z0036/0003, Taatsiin Gol (TGR-B/1); 11. *Prosciurus* sp. 1, left P3–M3, occlusal view, NHMW2009z0137/0001, Taatsiin Gol (TGR-B/1); 12. *Prosciurus* sp. 2, right m1–3 (reversed), occlusal view, NHMW2009z0138/0001, Taatsiin Gol (TGR-B/1); 13–14. *Cricetops dormitor* Matthew & Granger, 1923: 13. right M1 (reversed), occlusal view, NHMW2009z0139/0001; 14. left m1, occlusal view, NHMW2009z0139/0002, Taatsiin Gol (TGR-AB/22); 15–16. *Anomoemys lohiculus* (Matthew & Granger, 1923): 15. right M1/2 (reversed), occlusal view, NHMW2009z0140/0001, Del (DEL-B/7; 16. right m1/2 (reversed), occlusal view, NHMW2009z0141/0001, Ikh Argalatyn Nuruu (IKH-A/2); 17. *Zaraalestes minutus* (Matthew & Granger, 1924), right P4–M3 (reversed), occlusal view, NHMW2006z0175/0002, Taatsiin Gol (TGR-B/1); 18. *Palaeoscaptor acridens* Matthew & Granger, 1924, right maxillary fragment with P2–M2 (reversed), occlusal view, NHMW2005z0133/0005, Taatsiin Gol (TGR-AB/22); 1–6 and 8–9, 7, and 11–18 are in the same scale respectively

Table 4 Rodentia from the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Rodentia: from Daxner-Höck & Badamgarav (2007: table 3) and Schmidt-Kittler et al. (2007)	Oligocene biozones			
	A	B	C	C1
Aplodontidae				
Prosciurus sp. 1–3	×	×		
Prosciurus sp. 4			×	×
Sciuridae				
? *Spermophilinus* sp.			×	
Kherem sp.				×
Eomyidae				
Eomyidae indet. 1	×	×		
Eomyidae indet. 2			×	×
Ctenodactylidae				
Karakoromys decessus Mattthew & Granger, 1923	×	×		
Huangomys frequens Schmidt-Kittler et al., 2007		×	×	
Tataromys sigmodon Matthew & Granger, 1923		×	×	
Tataromys minor longidens Schmidt-Kittler et al., 2007			×	×
Tataromys plicidens Matthew & Granger, 1923				×
Yindirtemys shevyrevae Vianey-Liaud et al., 2006		×		
Yindirtemys aff. *Y. ulantatalensis* (Huang, 1985)			×	
Yindirtemys deflexus (Teilhard de Chardin, 1926)				×
Cylindrodontidae				
Ardynomys sp.	×			
Anomoemys lohiculus (Matthew & Granger, 1923)	×	×		
Tsaganomyidae				
Cyclomylus lohensis Matthew & Granger, 1923	×	×		
Cyclomylus intermedius Wang, 2001	×	×		
Cyclomylus biforatus Wang, 2001	×	×		
Cyclomylus sp.	×	×	×	
Coelodontomys asiaticus Wang, 2001		×		
Coelodontomys sp.		×		
Tsaganomys altaicus Matthew & Granger, 1923		×	×	×
Tsaganomyidae indet.		×	×	×
Dipodidae				
Allosminthus khandae (Daxner-Höck, 2001)	×			
Heosminthus sp. 1	×	×	×	
Heosminthus minutus Daxner-Höck, 2001		×		
Plesiosminthus sp. A			×	
Plesiosminthus cf. *P. asiaticus* Daxner-Höck & Wu, 2003				×
Plesiosminthus promyarion Schaub, 1930				×
Plesiosminthus sp. B				×
Shamosminthus sodovis Daxner-Höck, 2001	×	×		
Shamosminthus sp.		×		
Heterosminthus cf. *H. firmus* Zazhigin & Lopatin, 2000				×
Parasminthus sp. 1	×	×	×	
Parasminthus cf. *P. tangingoli* Bohlin, 1946			×	×
Parasminthus cf. *P. asiae-centralis* Bohlin, 1946			×	×
Parasminthus cf. *P. debruijni* Lopatin, 1999			×	×
Bohlinosminthus parvulus (Bohlin, 1946)	×	×	×	×
Bohlinosminthus sp.			×	×
Litodonomys sp. 1			×	×
Muroidea				
Selenomys mimicus Mathew & Granger, 1923	×	×		
Cricetops dormitor Matthew & Granger, 1923	×	×		
Ulaancricetodon badamae Daxner-Höck, 2000	×	×		

continued

Rodentia: from Daxner-Höck & Badamgarav (2007: table 3) and Schmidt-Kittler et al. (2007)	Oligocene biozones A	B	C	C1
Eucricetodon caducus (Shevyreva, 1967)	×	×		
Eucricetodon asiaticus (Matthew & Granger, 1923)	×	×		
? *Eucricetodon* sp. 1		×	×	
? *Eucricetodon* sp. 2–3			×	
Aralocricetodon sp.			×	×
Tachyoryctoides sp. 1			×	
Tachyoryctoides obrutschewi Bohlin, 1937			×	×

Table 5 Creodonta, Carnivora and Didymoconidae from the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Creodonta, Carnivora, Didymoconida: from Morlo & Nagel (2007)	Oligocene biozones A	B	C	C1
Creodonta				
Hyaenodontidae				
Hyaenodon eminus Matthew & Granger, 1925		×		
Hyaenodon pervagus Matthew & Granger, 1924	×	×		
Hyaenodon cf. *H. incertus* Dashzeveg, 1985	×	×		
Hyaenodon cf. *H. mongoliensis* Dashzeveg, 1964			×	
cf. *Hyaenodon gigas* Dashzeveg, 1985		×		
Carnivora				
Amphicynodon teilhardi (Matthew & Granger, 1924)	×	×		
aff. *Amphicynodon* sp.	×	×		
Amphicynodon sp.		×	×	
Amphicticeps shackelfordi Matthew & Granger, 1924	×	×		×
cf. *Amphicticeps* small species		×		
Stenoplesictidae				
Shandgolictis elegans Hunt, 1998		×	×	
Asiavorator altidens Spassov & Lange-Badré, 1995	×	×		
cf. *Asiavorator* sp.	×		×	
Asiavorator sp. nov.		×		
Nimravidae				
Nimravus mongoliensis (Gromova, 1959)		×		
cf. Viverravidae				
Palaeogale sectoria (Gervais, 1852)		×	×	
Didymoconida				
Didymoconidae				
cf. *Ergilictis* Lopatin, 1997		×		
Didymoconus colgatei Matthew & Granger, 1924	×	×	×	
Didymoconus berkey Matthew & Granger, 1924				×
Didymoconus sp.	×			

5.2 Biozone B (Figs. 2, 4)

Integrated mammal list: Tables 2–6.

Most abundant taxa: *Zaraalestes minutus*, *Palaeoscaptor acridens*, *Palaeoscaptor tenuis*, *Desmatolagus gobiensis*, *D. youngi*, *Huangomys frequens*, *Tsaganomys altaicus*, *Shamosminthus sodovis*, *Heosminthus* sp. 1, *Ulaancricetodon badamae*, *Cricetops dormitor*.

Some last occurrences: *Asiadidelphis zaissanense*, *Zaraalestes minutus*, *Taatsiinia hoeckorum*, *Desmatolagus youngi*, *Karakoromys decessus*, *Heosminthus minutus*, *Ulaancricetodon*, *Shamosminthus*, *Cricetops*, *Praetragulus gobiae*, *Gobimeryx*, *Eumeryx*, *Pseudogelocus mongolicus*, *Hyaenodon* div. spec., *Amphicynodon teilhardi*, *Asiavorator* 2 sp., *Nimravus mongoliensis*.

Reptilia: (Böhme, 2007).

Lithostratigraphy and biochronology: fossils representing biozone B were recovered from Hsanda Gol sediments above basalt I (~31.5 Ma) and between two lava flows of basalt I. The estimated age is late Early Oligocene, i.e. between ~31.5 and ~28.45 Ma.

Table 6 Rhinocerotoidea and Ruminantia from the Taatsiin Gol and Taatsiin Tsagaan Nuur area

Rhinocerotoidea: from Heissig (2007)	Oligocene biozones			
Ruminantia: from Vislobokova & Daxner-Höck (2002: fig. 8)	A	B	C	C1
Rhinocerotoidea				
Indricotheriidae				
Paraceratherium sp.			×	
cf. *Benaratherium* sp.			×	
Rhinocerotidae				
Aceratherium (*Alicornops*) cf. *A. pauliacense* (Richard, 1937)				×
Elasmotheriini vel Menoceratini indet.				×
Ruminantia				
Praetragulidae				
Praetragulus gobiae (Matthew & Granger, 1925)	×	×		
Archaeomerycidae				
Miomeryx sp.	×	×		
Gelocidae				
Gobimeryx dubius Trofimov, 1957	×			
Gobimeryx sp.	×	×		
Pseudomeryx gobiensis Trofimov, 1957	×	×		
Pseudomeryx sp.	×	×		
Prodremotherium sp.		×	×	
Pseudogelocus mongolicus Vislobokova & Daxner-Höck, 2002	×	×		
Paragelocus aff. *P. scotti* Schlosser, 1902		×	×	
Lophiomerycidae				
Lophiomeryx angarae Matthew & Granger, 1925	×			
Lophiomeryx sp.	×			
Cervidae				
Eumeryx culminis Matthew & Granger, 1924	×			
Eumeryx imbellis Vislobokova, 1983		×		
Eumeryx sp.		×		
Amphitragulus sp.				×
Dremotherium cf. *D. guthi* Jehenne, 1987			×	
Bovidae				
Palaeohypsodontus sp.			×	
? *Palaeohypsodontus* sp.				×
Bovidae gen. 1			×	
Bovidae gen. 2				×
? *Gobiocerus* sp.				×

5.3 Biozone C (Figs. 2, 5)

Integrated mammal list: Tables 2–6.

Most abundant taxa: *Amphechinus taatsiingolensis*, *Desmatolagus* cf. *D. gobiensis*, *Desmatolagus* cf. *D. orlovi*, *Tataromys sigmodon*, *Tataromys minor longidens*, *Bohlinosminthus parvulus*, *Eucricetodon* sp. 2–3, *Aralocricetodon*.

Some last occurrences: *Exallerix pustulatus*, *Palaeoscaptor tenuis*, *P. gigas*, *Desmatolagus gobiensis*, *Desmatolagus* cf. *D. orlovi*, *Ordolagus*, *Huangomys frequens*, *Tataromys sigmodon*, Gelocidae, *Dremotherium* cf. *D. guthi*, *Paraceratherium*, *Hyaenodon* cf. *H. mongoliensis*, *Shandgolictis elegans*, *Palaeogale sectoria*, *Didymoconus colgatei*.

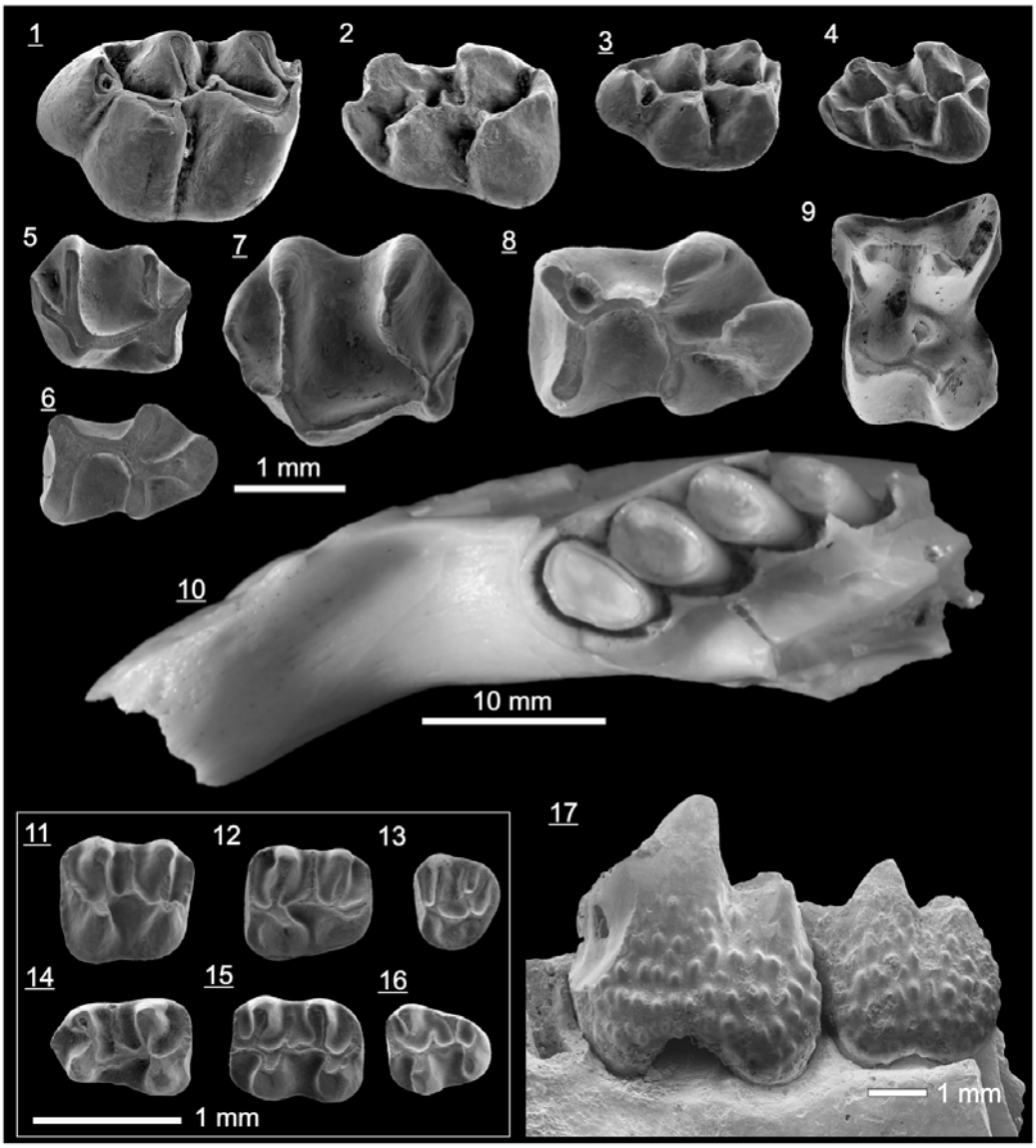

Fig. 5 Insectivora and Rodentia from biozone C (early Late Oligocene) of the Taatsiin Gol and Taatsiin Tsagaan Nuur area, Mongolia

1–2. *Aralocricetodon* sp.: 1. right M1 (reversed), lingual/occlusal view, NHMW2009z0142/0001; 2. left m1, lingual/occlusal view, NHMW2009z0142/0002, Taatsiin Gol (TGR-C/1); 3–4. *Eucricetodon* sp. 2: 3. right M1 (reversed), lingual/occlusal view, NHMW2009z0143/0001; 4. left m1, lingual/occlusal view, NHMW2009z0143/0002, Taatsiin Gol (TGR-C/1); 5–6. *Tataromys minor longidens* Schmidt-Kittler et al., 2007: 5. left M2, occlusal view, NHMW2009z0144/0001; 6. right m3 (reversed), occlusal view, NHMW2009z0144/0002, Toglorhoi (TGW-A/2a); 7–8. *Tataromys sigmodon* Matthew & Granger, 1923: 7. right M2 (reversed), occlusal view, NHMW2009z0145/0001; 8. right m3 (reversed), occlusal view, NHMW2009z0145/0002, Toglorhoi (TGW-A/2a); 9. *Amphechinus taatsiingolensis* Ziegler et al., 2007, left M1, occlusal view, NHMW2005z0152/0014, Toglorhoi (TGW-A/2a); 10. *Tsaganomys altaicus* Matthew & Granger, 1924, right fragmentary jaw with p4–m3 (reversed), occlusal view, NHMW2009z0146/0001, Taatsiin Gol (TGR-C/2); 11–16. *Bohlinosminthus parvulus* (Bohlin, 1946), occlusal view, Taatsiin Gol (TGR-C/2): 11. right M1 (reversed), NHMW2009z0147/0001; 12. left M2, NHMW2009z0147/0002; 13. left M3, NHMW2009z0147/0003; 14. right m1, NHMW2009z0147/0004; 15. right m2 (reversed), NHMW2009z0147/0005; 16. right m3 (reversed), NHMW2009z0147/0006; 17. *Exallerix pustulatus* Ziegler et al., 2007, right mandibular fragment with m1–2 (holotype, reversed), labial view, NHMW2006z0192/0001, Taatsiin Gol (TGR-C/1); 1–9 are in the same scale

Gastropoda: from red silts of the Loh Fm. below basalt II (Stworzewicz, 2007).

Lithostratigraphy and biochronology: fossils representing biozone C are known from upper levels of the Hsanda Gol Fm. and from lower levels of the Loh Fm. (locally contacting basalt II). The estimated age is early Late Oligocene, i.e. between ~28.45 and ~25.5 Ma.

5.4 Biozone C1 (Figs. 2, 6)

Integrated mammal list: Tables 2–6.

Most abundant taxa: *Amphechinus major*, *Desmatolagus* aff. *D. chinensis*, *Bohlinotona* sp., *Yindirtemys deflexus*.

Some last occurrences: *Palaeoscaptor acridens*, *Amphechinus major*, *A. minutissimus*, *Sinolagomys* cf. *S. kansuensis*, *Tataromys minor longidens*, *Yindirtemys deflexus*, *Bohlinosminthus*, *Aralocricetodon*, *Parasminthus*, *Tsaganomys altaicus*, *Amphicticeps shackelfordi*, *Didymoconus berkey*.

Lithostratigraphy and biochronology: fossils representing biozone C1 are known from uppermost levels of the Hsanda Gol Fm. and from sediments of the Loh Fm. above biozone C. The estimated age is late Late Oligocene to the Oligocene/Miocene transition, i.e. between ~25.5 Ma. and ~23 Ma.

6 Conclusions

Towards the end of the Eocene and beginning of the Oligocene the paleorelief of the Taatsiin Gol and Taatsiin Tsagaan Nuur area diminished and gave rise to flat, braided fluvial plains. These acted as source rocks for the Hsanda Gol Fm. The brick-red clay/silty clay of the Hsanda Gol Fm. is interpreted as primarily dust deposits and as lake sediments of the Early Oligocene, locally ranging up to the Late Oligocene. Sand and gravel lenses are extremely rare, although caliche horizons (paleosol), i.e. distinct layers and nodules, can be traced throughout the Hsanda Gol Fm. and frequently form its top layer. The fossil concentration is highest within the paleosol horizons, sometimes below or above it, and below and above basalt I. Around 31.5 Ma., strong volcanic activities interrupted deposition of the Hsanda Gol sediments. At that time, basalt I (5 to 25 m thick) erupted and sealed the flat surface of the lower Hsanda Gol beds. This basalt was finally covered by the upper red beds of the Hsanda Gol Fm. In the Late Oligocene, faulting processes as well as uplift of the mountains north and south of the basin were associated with reactivation of the paleorelief. The successive spread of fluvial systems is indicated by the gravely and sandy facies of the Loh Fm. Again, volcanic activities arose around 28 Ma in the northwestern, northern and northeastern parts of the study area (Höck et al., 1999).

From the Early to the Late Oligocene the mammal associations underwent remarkable changes, specifically a decrease of species numbers in the Late Oligocene and a significant decline of large mammal communities towards the end of the Late Oligocene. The total number of large and small mammal taxa is highest (88 taxa) in biozone B and lowest in biozone C1 (49 taxa). The number of large mammals was 25 taxa in biozone B; it decreased to 13 taxa in biozone C and 8 taxa in biozone C1. The mammal community of the Early Oligocene (biozones A and B) is characterized by a high diversity of mostly ground-dwelling small mammal groups, by numerous larger plant eaters, representing up to five Ruminantia families (Vislobokova and Daxner-Höck, 2002), and by Creodonta, Canidae and Didymoconidae of variable body-sizes, with *Hyaenodon* div. spec. and *Nimravus mongoliensis* being largest (Morlo and Nagel, 2007). Throughout the Late Oligocene (biozones C and C1) all large bone/meat eaters disappeared along with most Ruminantia species.

The turnover of mammal communities and diversities was accompanied by major reconstructions of landscape and paleoenvironments, as described from the investigated area (Höck et al.,

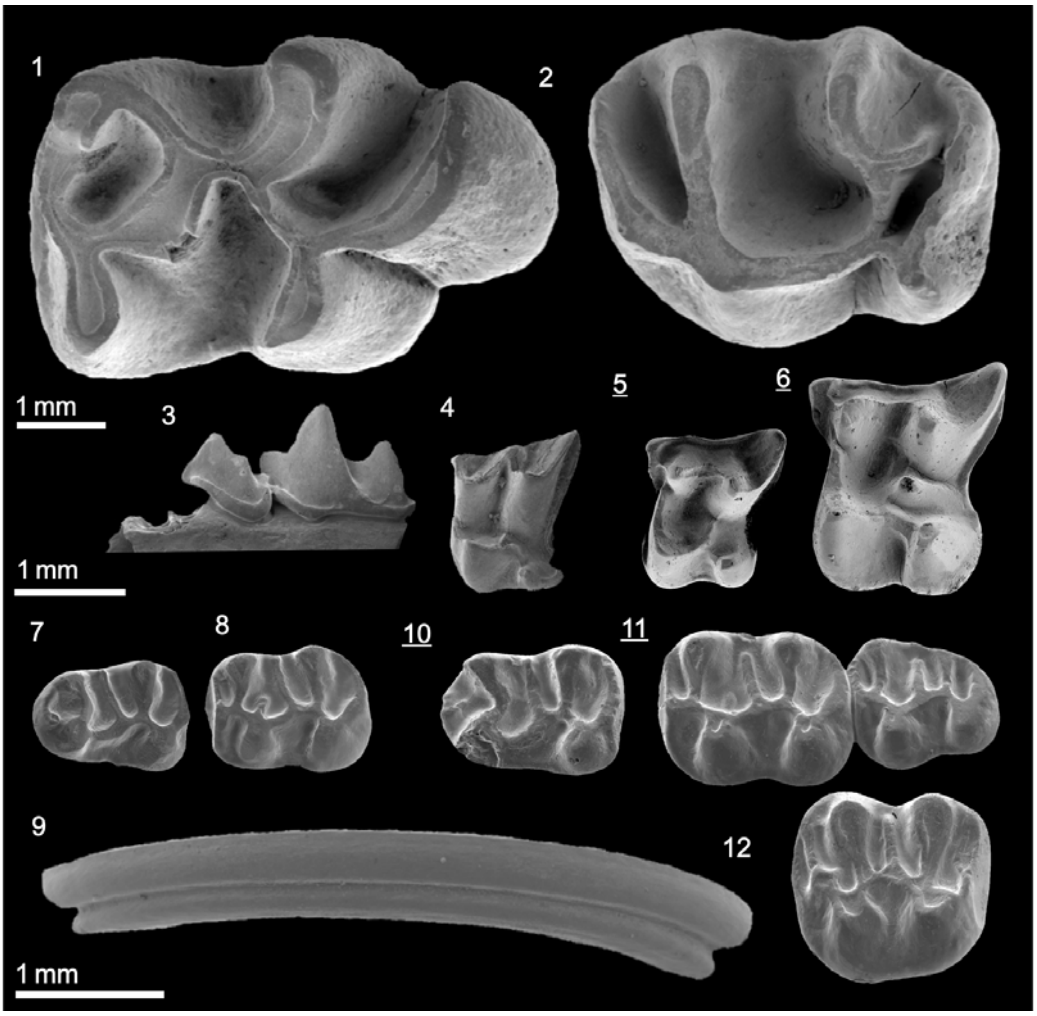

Fig. 6 Insectivora and Rodentia from biozone C1 (late Late Oligocene) of the Taatsiin Gol and Taatsiin Tsagaan Nuur area, Mongolia

1–2. *Yindirtemys deflexus* (Teilhard de Chardin, 1926): 1. left m3, occlusal view, NHMW2006z0090/00017, Huch Teeg (RHN-A/7); 2. left M3, occlusal view, NHMW2009z0148/0001, Ikh Argalatyn Nuruu (IKH-A/5); 3–4. *Tavoonyia altaica* Ziegler et al., 2007: 3. left mandibular fragment with p4–m1, labial view, NHMW2006z0037/0002; 4. left M1 (holotype), occlusal view, NHMW2006z0037/0001, Huch Teeg (RHN-A/9); 5. *Amphechinus minutissimus* Ziegler et al., 2007, right M1 (holotype, reversed), occlusal view, NHMW2005z0199/0001, Del (DEL-B/12); 6. *Amphechinus major* Ziegler et al., 2007, right M1 (reversed), occlusal view, NHMW2005z0198/0009, Del (DEL-B/12); 7–9. *Plesiosminthus promyarion* Schaub, 1930, Huch Teeg (RHN-A/9): 7. left m1, NHMW2001z0065/0001/5, occlusal view; 8. left m2, NHMW2001z0065/0001/8, occlusal view; 9. I sup., NHMW2001z0065/0001/3; 10–12. *Plesiosminthus* cf. *P. asiaticus* Daxner-Höck & Wu, 2003, occlusal view, Huch Teeg (RHN-A/7): 10. right m1 (reversed), NHMW2001z0064/0001/7; 11. right m2–3 (reversed), NHMW2001z0064/0001/9; 12. left M1, NHMW 2001z0064/0001/2; 1–2, 3–6, and 7–12 are in the same scale respectively

1999). These changes are clearly effected by the global Oligocene cooling, and by geodynamic activities that started at the Early/Late Oligocene transition and continued to the Miocene.

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