Ann. Naturhist. Mus. Wien	108 A	1–24	Wien, September 2007

Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications

Editor: Gudrun DAXNER-HÖCK

1. Geological and stratigraphic setting

by Gudrun DAXNER-HÖCK[1] and Demchig BADAMGARAV[2]

(With 5 text-figures and 4 tables)
Manuscript submitted on February 1st 2007

Abstract

This contribution updates the integrated stratigraphy of the Valley of Lakes in Central Mongolia and the correlation chart. Three field seasons (2001, 2004 and 2006) in the Taatsiin Gol and Taatsiin Tsagaan Nuur area provided answers to hitherto unresolved stratigraphic questions and enabled fossil collections to be completed. New rodent data yielded an emended characterization of the informal biozones A, B, C, C1, D, D1/1, D1/2 and E, which serve as a biostratigraphic framework in the Oligocene and Miocene of Mongolia. A short draft of all fossil groups is given, which will be further elaborated in the special Mongolia volume.

Zusammenfassung

Die integrierte Stratigraphie des Tales der Gobiseen in der Mongolei und die Korrelationstabelle wurden verbessert. Durch drei Saisonen Feldarbeit (2001, 2004, 2006) im Taatsiin Tal und in der Region des Taatsiin Sees war es möglich, bisher offene stratigraphische Fragen zu lösen und lückenhafte Fossilaufsammlungen zu komplettieren. Die informellen Biozonen A, B, C, C1, D, D1/1, D1/2 und E konnten unter Einbeziehung neuerer Nagetier-Daten besser charakterisiert werden. Sie bilden den biostratigraphischen Rahmen für die Gliederung des Oligozäns und Miozäns in der Mongolei. In einer kurzen Übersicht werden alle Fossilgruppen vorgestellt, die in dem Mongolei-Sonderband behandelt werden.

1. Introduction

A joint Austrian-Mongolian project was carried out in the Taatsiin Gol and Taatsiin Tsagaan Nuur area in Mongolia. During three field seasons, from 1995 to 1997, extensive field activities took place. The focus was on geological mapping, concurrent age dating of the basalts, sedimentological, paleontological and stratigraphic studies in Oligocene and Miocene sediments. This continental sequence allowed a precise stratigraphic adjustment based on the evolution of mammals and the age determination of basalts as elaborated by DAXNER-HÖCK et al. (1997) and HÖCK et al. (1999). In 2001,

[1] Gudrun DAXNER-HÖCK, Naturhistorisches Museum Wien, Geologisch-Paläontologische Abteilung, Burgring 7, 1010 Wien, Austria. – E-mail: gudrun.hoeck@nhm-wien.ac.at

[2] Demchig BADAMGARAV, Paleontological Center, Mongolian Academy of Sciences, Ulaanbaatar 210644, P.O. Box 767, Mongolia. – E-mail: badamgr@yahoo.com

2004 and 2006, additional field investigations were conducted, clarifying remaining open questions. The exact locations (GPS data) of sections and the altitudes (m) are provided in tab. 1. The abbreviations for localities and sections and their Mongolian transcriptions are given in tab. 2 and fig. 1. The present contribution represents a short compendium of the integrated study (Höck et al. 1999); it also incorporates new project results.

The collected fossils are stored in the collections of the Geological-Paleontological Department, Museum of Natural History in Vienna (NHMW), and the Paleontological Center of the Mongolian Academy of Sciences in Ulaanbaatar. Almost exclusively specimens from the Vienna collection (NHMW) were investigated in this special volume.

2. Geology and Geochronology

(Höck et al. 1999: 100-113, Figs. 1, 7, 8, 10, 18)

The Pre-Altai depressions are situated in Western and South-Central Mongolia between the Mongolian Altai and the Gobi Altai Mtns in the south and the Khangai Mtns in the north. One of them is known as the Valley of Lakes. It extends across ~ 500 km in a west-east direction in Central Mongolia. It is filled, above a Proterozoic and Paleozoic basement, with continental sediments ranging continuously from the Cretaceous to the Quaternary. In this area of the Taatsiin Tsagaan Nuur, Khunug Valley, Taatsiin Gol, Tatal-Hsanda Gol, as far as Ikh Argalatyn Nuruu in the east, a Cenozoic sedimentary sequence interlayered with several basalts is exposed. It is among the best places in Mongolia where fossiliferous terrestrial sediments are associated with basalts.

Cenozoic, partly also Mesozoic, basaltic volcanism is concentrated in a relatively small approximately S-N striking corridor in Central Mongolia between 98° and 104° E longitude (Kepezhinskas 1979). It extends from China to Siberia. The Valley of Lakes is positioned within this corridor and is well known for its basalt layers in Paleogene and Neogene sediments. Three coherent basaltic layers of variable thickness were distinguished and dated by the $^{40}Ar/^{39}Ar$-method (whole rock samples), i.e. basalt I, II and III.

Basalt I erupted around 31.5 Ma (Early Oligocene), with ages ranging from 30.4 to 32.1 Ma. The individual standard deviation ranges from 0.3 to 0.8. No significant age difference is recognizable between different volcanic flows of basalt I. The basalt I occurrences are concentrated in the southern and central part of the study area. The most prominent outcrops are found east and west of the Khunug Valley, along the Taatsiin Gol (fig. 2), in a small strip along the Del fault and in the Tatal Gol area. Minor occurrences are found west of the Hsanda Gol. The thickness of basalt I varies from a minimum of 8-10 m to a maximum of 15–25 m. Sometimes the basalt I-event starts with a tuff horizon, which is locally the only volcanic layer (e.g. profiles DEL-B, TAT-C). Among the basalt flows at least two individual layers can be recognized, a deeper thicker bed and an upper thinner layer separated by a cooling horizon, and in some places by thin Hsanda Gol type sediments. Two centers of eruption were identified from which the basalt I flows originated. They form approximately 100-m-high volcanic cones and are named Barun Shir and Dsun Shir (fig. 3). Rare tuffs are associated with the cones.

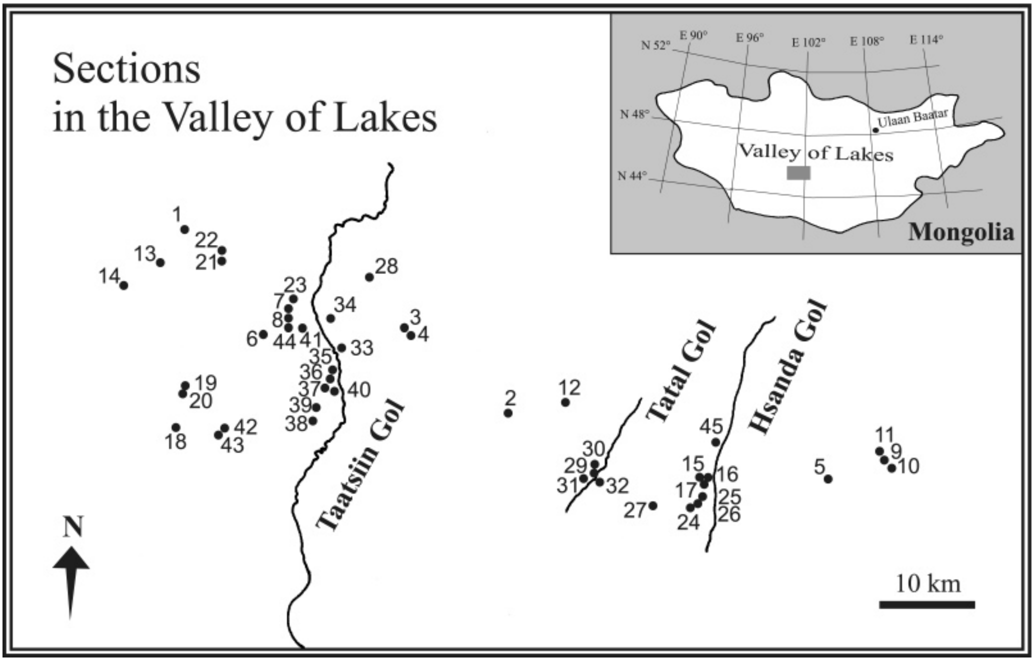


Fig. 1: Investigated vertebrate localities and sections in the Valley of Lakes, Uvurkhangai, Central Mongolia.

1. Abzag Ovo (ABO-A)
2. Builstyn Khudag (BUK-A)
3.–4. Del (DEL-A, DEL-B)
5. unnamed locality west of Ikh Argalatyn Nuruu (GRAB-II)
6. Khongil (HL-A)
7. Hotuliin Teeg east (HTE)
8. Hotuliin Teeg south-east (HTSE)
9.–11. Ikh Argalatyn Nuruu (IKH-A, IKH-B, IKH-C)
13.–14. Luugar Khudag (LOG-A, LOG-B)
15.–17. Loh (LOH-A, LOH-B, LOH-C)
18.–20. Menkhen Teeg (MKT-W; MKT-1, MKT-2)
21.–22. Olon Ovoony Khurem (ODO-A, ODO-B)
23. Huch Teeg (RHN-A) = Tavan Ovoony Deng in Höck et al. (1999: Tab.1)
24.–27. Hsanda Gol (SHG-A, SHG-B, SHG-AB, SHG-C)
28. Unzing Khurem (TAR-A) = Tarimalyn Khurem in Höck et al.(1999: Tab.1)
29.–32. Tatal GOL (TAT-B, TAT-C, TAT-D, TAT-SE)
33.–34. Taatsiin Gol left side (TGL-A, TGL-B)
35.–41. Taatsiin Gol right side (TGR-A, TGR-B, TGR-AB, TGR-C, TGR-D, TGR-ZO, TGR-1564.
42.–43. Toglorhoi (TGW-A, TGW-D) = Taatsiin Gol west in Höck et al. (1999)
44. Unkheltseg (UNCH-A)
45. Ulaan Tolgoi (UTO-A)

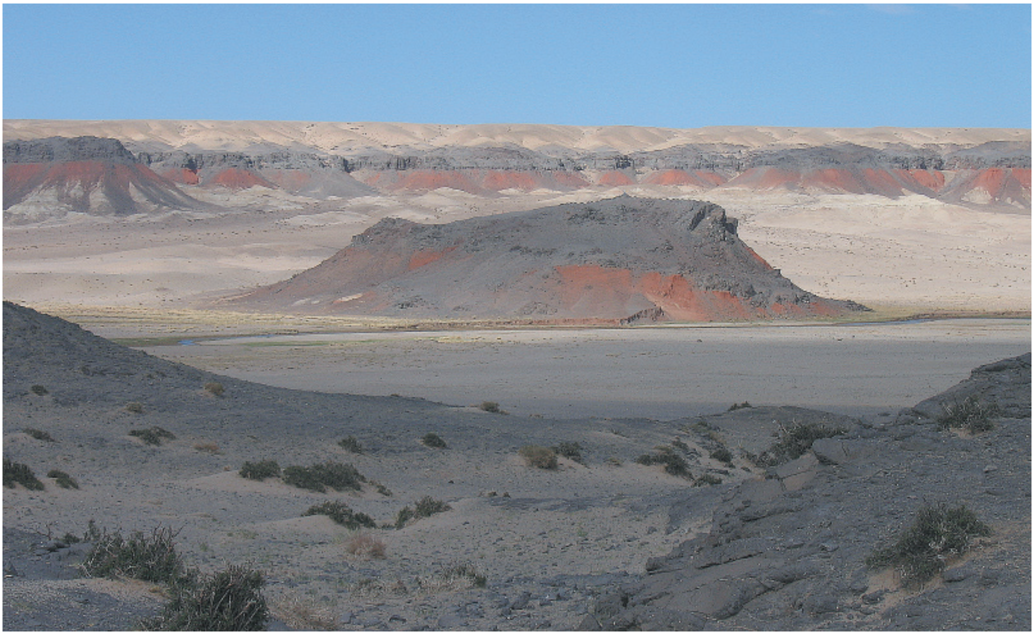


Fig. 2: Eastern rim of the Taatsiin plateau with Hsanda Gol sediments and basalt I exposed along the Taatsiin Gol (= Taatsiin river).

Fig. 3: Dzun Hsir in the Valley of Lakes, a potential centre of eruption of basalt I.

Fig. 4: Builstyn Khudag. In the foreground the photograph shows the uppermost part of the section BUK-A, where a rich small mammal fauna was found in red silts of the Loh Formation.

Fig. 5: The locality Unkheltseg (UNCH-A) at the northern rim of the Taatsiin plateau. In the middle part of the photograph, basalt I is interrupted and the red hills of the locality Unkheltseg are exposed.

Basalt II is about 28 Ma old (beginning of Late Oligocene), with ages ranging from 27 to 29 Ma. The individual standard deviation varies from 0.4 to 0.9. Basalt II is found in the very north of the mapped area near the Unzing Khurem (TAR) region (= Tarimalyn Khurem in Höck et al. 1999: suppl. 2), where it is deposited within the Loh Formation (Höck et al. 1999: Fig. 10a). More prominent outcrops occur in the northwest of the study area (ODO = Olon Ovoony Khurem), where they are partly directly overlain by basalt III, partly separated from the latter by a small horizon of Loh sediments. The thickness of this basaltic layer in the TAR area is 5–7 m; in the northwest it can exceed 25m. In some places up to eight individual lava flows were distinguished.

Basalt III has a well-defined age of 13 Ma (Middle Miocene), ranging from 12.2 to 13.2 Ma. The individual standard deviation varies from 0.2 to 0.7 Ma. Basalt III is found forming the top of the plateaus in three areas: east of the Taatsiin Gol (TGL), in the same area as basalt II, i.e. the north (Unzing Khurem), and the northwest of the mapped area (Höck et al. 1999: Fig. 10a and suppl. 1, 2). The basalt forms flows which are 10-20 m thick in the north but thin out to less than 1 m at their southern end. In many areas the basalts are highly vesicular and form blocky surfaces. Several flows were distinguished. Basalt III forms, in most of the plateaus, the uppermost layers and is only rarely overlain by the Tuyn Gol formation, e.g. in the plateau east of the Taatsiin Gol (Höck et al. 1999: suppl. 1). Basalt III is mineralogically and geochemically significantly different from the former basalts.

3. Lithostratigraphy and sedimentology
(tabs. 1–2)

Two out of five formations are the direct subject of the present study because of their fossil content and contact with basalts (I-III), e.g. the Hsanda Gol Fm. and the Loh Fm. They were formally redefined by Höck et al. (1999: 90-100) according to the International Stratigraphic Guide (Salvador 1994).

Hsanda Gol Formation: The formation name was first introduced and informally used by Berkey & Morris (1927: 234 ff). Apart from the brick-red clays and silts, the authors included coarser-grained clastics, well-rounded, fine-grained gravels and sands, but also a series of clays to the Hsanda Gol fm., sediments which now must be added to Mesozoic successions. Later, Devjatkin (1981), Devjatkin & Badamgarav (1993) and Devyatkin (1993a and b) restricted the Hsanda Gol formation to fossiliferous red beds, and partially to the coarse clastics above basalt I, and termed this succession Shand Gol formation (Russian transcription). Höck et al. (1999) did not follow the Russian transcription, but used the original name "Hsanda Gol" Fm. The latter authors restricted the lithology of the Hsanda Gol Fm. to the brick-red, poorly sorted clays (see below).

Bryant & McKenna (1995) suggested dividing the Hsanda Gol Fm. near the Tatal Gol into two members, the Tatal- and the Shand Member. Based on the regional mapping and sedimentological studies, Höck et al.(1999) came to the following interpretation: Tatal Member and Mellet Lava (= basalt I in the Tatal Gol area) as well as the lower part of the Shand Member belong to the Hsanda Gol Fm. The upper part of the Shand Member belongs to the Loh Fm. As shown in the geological map (Höck et al. 1999: suppl. 1), basalt I is not continuously present within the Hsanda Gol Fm. Thus, it can be used only locally, but never regionally as a marker to separate potential members.

Tab. 1: Localization (GPS data) and the altitude (m) of sections: completed after HÖCK et al. (1999: table 2).

Section	GPS-position	altitude (m)
1. ABO-A	N 45°34'16" E 101°02'20"	1640
2. BUK-A	N 45°23'03" E 101°30'44"	1522
3. DEL-A	N 45°27'08" E 101°22'24"	1519
4. DEL-B	N 45°27'08" E 101°22'24"	1520
5. GRAB-II	N 45°16'53" E 101°57'30"	1475
6. HL-A	N 45°27'37" E 101°09'14"	1530
7. HTE	N 45°29'15" E 101°11'85"	1515
8. HTSE	N 45°28'74" E 101°12'37"	
9. IKH-A	N 45°17'52" E 102°05'05"	1605
10. IKH-B	N 45°17'30" E 102°05'35"	1510
11. IKH-C	N 45°18'22" E 102°04'41"	1529
12. K-II	N 45°23'10" E 101°35'30"	1603
13. LOG-A	N 45°32'18" E 101°00'48"	
14. LOG-B	N 45°30'48" E 100°58'22"	
15. LOH-A	N 45°17'22" E 101°47'04"	1481
16. LOH-B	N 45°17'20" E 101°47'39"	1481
17. LOH-C	N 45°15'44" E 101°43'03"	
18. MKT-W	N 45°22'39" E 100°59'35"	
19. MKT-1	N 45°24'48" E 101°02'57"	1480
20. MKT-2	N 45°24'47" E 101°02'48"	1463
21. ODO-A	N 45°32'24" E 101°08'17"	1670
22. ODO-B	N 45°32'58" E 101°08'16"	
23. RHN-A	N 45°29'37" E 101°12'17"	1490
24. SHG-A	N 45°16'01" E 101°45'45"	
25. SHG-B	N 45°16'14" E 101°45'50"	
26. SHG-AB	N 45°16'00" E 101°46'37"	1460
27. SHG-C	N 45°15'47" E 101°43'03"	
28. TAR-A	N 45°31'06" E 101°18'23"	1650
29. TAT-B	N 45°18'02" E 101°38'03"	
30. TAT-C	N 45°18'21" E 101°38'01"	1389
31. TAT-D	N 45°17'37" E 101°37'32"	1390
32. TAT-SE	N 45°17'46" E 101°37'77"	
33. TGL-A	N 45°26'57" E 101°16'18"	1460
34. TGL-B	N 45°27'58" E 101°15'45"	1450
35. TGR-A	N 45°25'08" E 101°15'44"	1372
36. TGR-B	N 45°24'53" E 101°15'44"	1440
37. TGR-AB	N 45°24'29" E 101°15'23"	1570
38. TGR-C	N 45°23'09" E 101°14'36"	1410
39. TGR-D	N 45°24'28" E 101°34'03"	
40. TGR-ZO	N 45°24'03" E 101°16'00"	1430
41. TGR-1564	N 45°27'30" E 101°12'44"	1540
42. TGW-A	N 45°22'39" E 101°06'01"	
43. TGW-D	N 45°22'33" E 101°05'43"	
44. UNCH-A	N 45°27'41" E 101°12'05"	
45. UTO-A	N 45°20'49" E 101°50'16"	1519
UTO-a (= UTO-A/3)	N 45°20'49" E 101°50'16"	1519
UTO-b (= UTO-A/5)	N 45°20'41" E 101°50'28"	1533
UTO-c (= UTO-A/6)	N 45°20'32" E 101°50'12"	1625

Tab. 2: Investigated sections from the Valley of Lakes. The Mongolian transcriptions, and abbreviations of the sections, the formations and informal biozones of the respective fossil horizons. RHN = Huch Teeg = Tavan Ovoony Deng**, TGW = Toglorhoi = Taatsiin Gol west*, TAR = Unzing Khurem = Tarimalyn Khurem**. (** in HÖCK et al. 1999: tab. 1).

Locality	section/layer	Formation	bioz.
Menkhen Teeg	MKT-W/O	Hsanda Gol	A
Khongil	HL-A/2		
	HL-A/1		
Taatsiin Gol right	TGR-A/14		
	TGR-A/13		
Taatsiin Gol left	TGL-A2		
	TGL-A/1		
Del	DEL-B/2		
unnamed	KII-O		
Tatal Gol	TAT-C/3		
	TAT-C/2		
	TAT-C/1		
	TAT-D/1/Hü6		
	TAT-D/1/Hü5		
	TAT-D/1/Hü4		
	TAT-D/1/Hü3		
	TAT-D/1/Hü2		
	TAT-D/1/Hü1		
Hsanda Gol	SHG-C/2		
	SHG-C/1		
unnamed	GRAB-II/3		
	GRAB-II/2		
	GRAB-II/1		
Unkheltseg	UNCH-A/5 (mixed with D)	Hsanda Gol (Loh)	B
	UNCH-A/4 (mixed with D)		
	UNCH-A/3 (mixed with D)		
	UNCH-A/O (mixed with D)		
Taatsiin Gol right	TGR-AB/22	Hsanda Gol	
	TGR-AB/21		
	TGR-ZO/2		
	TGR-ZO/1		
	TGR-1564		
	TGR-B/1		
Taatsiin Gol left	TGL-D/O		

Locality	section/layer	Formation	bioz.
Taatsiin Gol left	TGL-A/11c	Hsanda Gol	B
	TGL-A/11b		
	TGL-A/11a		
	TGL-A/11		
	TGL-A/O		
Del	DEL-A/11		
	DEL-A/O		
	DEL-B/7		
	DEL-B/6		
	DEL-B/O		
Builstyn Khudag	BUK-Shg.		
Tatal Gol	TAT-D/2		
Hsanda Gol	SHG-AB/20->		
	SHG-AB/17-20		
	SHG-AB/12		
	SHG-AB/O		
	SHG-A/20		
	SHG-A/18+20		
	SHG-A/15+20		
	SHG-A/15		
	SHG-A/10		
	SHG-A/9		
	SHG-A/6		
	SHG-A/4		
	SHG-A/1		
	SHG-A/O		
Ikh Argalatyn Nuruu	IKH-C/O		
	IKH-B/2		
	IKH-B/1+2 (= IKH-B/a)		
	IKH-B/O		
	IKH-A/3-4		
	IKH-A/2		
	IKH-A/1		
	IKH-A/O		
Abzag Ovoo	ABO-A/3	Loh	C
Toglorhoi	TGW-A/2b		
	TGW-A/2a		

Tab. 2: Investigated sections from the Valley of Lakes (continued).

Locality	section/layer	Formation	bioz.
Toglorhoi	TGW-A/2	Loh	C
	TGW-A/1		
	TGW-A/O		
Huch Teeg	RHN-A/6		
Taatsiin Gol right	TGR-C/1O	Hsanda Gol	
	TGR-C/5		
	TGR-C/2		
	TGR-C/1		
	TGR-C/Bad.6		
	TGR-C/Bad.5		
	TGR-C/O		
Unzing Khurem	TAR-A/2	Loh	
Tatal Gol	TAT-SE (mixed with C1?)	Hsanda Gol	
Toglorhoi	TGW-A/5	Loh	C1
Huch Teeg	RHN-A/10		
	RHN-A/9		
	RHN-A/8		
	RHN-A/7		
Del	DEL-B/12	Hsanda Gol	
Tatal Gol	TAT-SE (mixed with C)		
	TAT-B/10		
	TAT-D/3		
Loh	LOH-C/1		
	LOH-B/3		
Ikh Argalatyn Nuruu	IKH-B/5		
	IKH-A/5		
Luugar Khudag	LOG-A/1	Loh	D
Huch Teeg	RHN-A/12		

Locality	section/layer	Formation	bioz.
Hotuliin Teeg	HTSE-10	Loh	D
	HTE-12		
	HTE-9		
	HTE-8		
	HTE-7		
	HTE-5		
	HTE-4		
	HTE-3		
	HTE-O		
Unkheltseg	UNCH-A/4 (mixed with B)	Loh (Hsanda Gol)	
	UNCH-A/3 (mixed with B)		
	UNCH-0 (mixed with B)		
Luugar Khudag	LOG-B/1	Loh	D1/1
Uolon Ovoony Khurem	ODO-A/6		
	ODO-A/2		
	ODO-B/1		
Ulaan Tolgoi	UTO-A/6 (= UTO-c)		D1/2
	UTO-A/5 (= UTO-b)		
	UTO-A/3 (= UTO-a)		
Loh	LOH-A/2 (= LOH-b)		
	LOH-A/O		
Builstyn Khudag	BUK-A/12+14		E
	BUK-O		E?

Following (Höck et al. 1999: 90-91, supp. 1 & 2) the type area of the Hsanda Gol Fm. is situated in the central part of the Valley of Lakes. It includes the region from the Khunug Valley west of the Taatsiin Gol to the east of the Hsanda Gol and south of Mt. Ushgoeg. In terms of geographic coordinates this area ranges from 100° 00' to 102° 00' E and from 45°10' to 45° 40' N. The profile TGR-B (Taatsiin Gol right) was selected as the type profile of the formalized Hsanda Gol Fm. The reference profiles are SHG-C, SHG-A and SHG-AB (Hsanda Gol) from footwall to hangingwall. Sediments of the Hsanda Gol Fm. were additionally studied in the following sections: DEL-B; HL-A; GRAB-II; K-II; IKH-A, IKH-B, IKH-C; LOH-B, LOH-C; MKT-W, MKT-1, MKT-2; TAT-B, TAT-C,TAT-D, TAT-SE; TGL-A, TGL-B; TGR-A, TGR-AB, TGR-C, TGR-D (fig. 1, tabs. 1–2).

The lower boundary towards the Tsagaan Ovoo Fm. (at 1460 m altitude) in TGR-B is marked by a significant decrease in grain size from gravel and sand to clay and silt together with a change in color from white to brick-red. The upper boundary to the Loh Fm. (altitude 1500 m) is in turn characterized by an increase in grain size and the predominance of lighter colors. For the exact location, geographical coordinates and altitude of the base of the profile see tab. 1.

Short description (Höck et al. 1999: 91, 95-97)**:** The Hsanda Gol Fm. consists of fine clastic red beds just below and above basalt I, which becomes part of this formation. Massive, horizontally bedded layers with non-erosive boundaries are common. Within these sediments, caliche horizons are present. They are very rich in fossils. The total thickness of the Hsanda Gol Fm. varies from zero (e.g. Huch Teeg area) to about 70 m. The thickness generally increases towards the center of the Valley of Lakes.

The geochronologic situation of the Hsanda Gol Fm. is determined by the position of the brick-red clays and silts immediately above and below basalt I, which has been dated at 31.5 Ma. The range is Early Oligocene to the beginning of Late Oligocene.

Loh Formation: It was first described informally by Berkey & Morris (1927). Höck et al. (1999: 91) left the term unchanged but the lithological content was broadened. Berkey & Morris (1927) restricted the Loh fm. to Miocene olive green clays. Devjatkin (1981) and Devjatkin & Badamgarav (1993) used this formation name for Miocene light-grey sands interbedded with green clays plus pebble material. Liskun & Badamgarav (1977) added to this description white sands and brownish clays in a profile whose position is almost identical with the profiles LOH-A and LOH-B. The name of the formation refers to the locality named Loh near Hsanda Gol.

Following Höck et al. (1999: 91, suppl. 1 and 2) the type area is situated in the central part of the Valley of Lakes. It includes the region from west of the Taatsiin Gol to east of the Hsanda Gol and south of Mt. Ushgoeg. In terms of geographic coordinates this area ranges from 100° 00' to 102° 00' E and from 45°10' to 45° 40'N. The profile TGR-B (Taatsiin Gol right) was selected as the type profile (Höck et al. 1999: suppl. 1-2). The reference profiles are TAR-A (Unzing Khurem), LOH-A, LOH-B (Loh) and BUK-A (Builstyn Khudag, fig. 4). Profile TAR-A is as an important reference profile because it contains basalt II and basalt III, and the Loh sediments are of wide lithological variability and great thickness.

Additional investigated sections are: ABO-A; LOG-A, LOG-B; LOH-C; HTE; ODO-A, ODO-B; RHN-A; TGL-A, TGL-B; TGR-C, -N; TGS; TGW-A, TGW-D; UNCH-A; UTO-A (fig. 1, tabs. 1–2).

The lower boundary is exposed in the type profile TGR-B (at 1500 m altitude) and is marked by a change in grain size from silt and clay to sand and gravel together with a change in color from brick-red to a variety of lighter colors, i.e. yellow, green, white, pink, orange, brown. The upper boundary is only exposed in the type profile TGR-B (at 1520 m altitude), where the Loh Fm. is overlain by gravels of the Tuyn Gol Fm.

Short description: The maximum outcropping thickness of the Loh Fm. is 150 m in the north of the mapped area, more precisely in the north of the Unzing Khurem - Tarimalyn Khurem region. Daxner-Höck et al. (1997) already proposed to considerably extend the lithological variety of the Loh Fm. to create a mappable lithological unit. The separation between Hsanda Gol Fm. and Loh Fm. is often difficult to achieve. In the field, all sediments above the brick-red clay of the Hsanda Gol Formation are assigned to the Loh Formation because the sandy character and the change in color to a variety of the above-mentioned lighter colors becomes visible.

The geochronologic situation is determined by the position of basalts II (28 Ma) and III (13 Ma) in the reference profile TAR-A. In this section Loh sediments range from the Late Oligocene to the Middle Miocene, in other sections to the Late Miocene.

4. Paleontology

As outlined above, paleontological investigations were carried out in sediments of the Hsanda Gol Fm. and the Loh Fm., mostly within the mapped area (Höck et al. 1999: suppl. 1 & 2). During the field seasons 1995-1997 and 2001-2006, more than 120 vertebrate faunas from 45 profiles and fossil sites were collected.

The red silt and clay of the Hsanda Gol Fm. are very rich in fossils. Fossils were recovered from below and above basalt I and from sediment layers between two individual lava flows of basalt I (TGR-ZO/1 & 2; TGR-1564). Above basalt I, fossil concentrations were observed in specific clay layers, and above or inside caliche horizons. The preservation of mammal teeth is excellent. Above basalt I they are mostly black. Fossils from the caliche horizons are partly incrusted by carbonate. Bones are less well preserved than teeth. Teeth can sometimes be found in their original position, whereas the corresponding mandible or maxilla is decomposed. The coarser-grained sediments of the Loh Fm. are less fossil-rich, except for concentrations in paleo-soil and in reworked carbonate layers.

Importantly, basalt I is interrupted in the locality Unkheltzeg (UNCH-A, fig. 5) at the northern rim of the Taatsiin plateau. Here, the red Hsanda Gol clays are directly covered by red silts of the Loh Fm. The whole sequence is topped by a reworked carbonate layer. Locally, the cover of Loh sediments is very thin or eroded. On some places Hsanda Gol sediments are only covered by carbonate nodules. However, fossil collections from the surface and from washed samples (UNCH-A/O, UNCH-A/3-4) yielded a mixed rodent fauna: e.g. *Cricetops dormitor, Ulaancricetodon badamae* and *Tsaganomys altaicus* (Early Oligocene) occur together with *Tachyoryctoides kokonorensis, Heterosminthus firmus* and *Democricetodon* sp. (Early Miocene). One explanation would be that, in the Early Miocene, rodents built their burrows in Hsanda Gol sediments which already contained fossils from the Early Oligocene. According to another interpretation, repeated erosions and re-depositions caused this mixture of fossils representing different epochs.

Methods: The profiles were carefully selected according to the occurrence of fossil horizons, to the contact with basalt flows, and to fine grain-sizes. Along these sections, paleontological samples were taken and numbered from bottom to top. The numbers of fossil horizons are visible on the right hand side of the respective profile (e.g. TGR-C/**1-30**). Fossils collected from the surface along the profiles were indicated with **O** (e.g. TGR-C/**O**).

The test samples were of 20 to 50 kg sediment. After wet-screening, more than 50 % of the test samples turned out to be rich in fossils. From these fossil horizons large samples of 500 to 3000 kg each were taken. The 60 tons of wet-screened sediments yielded more than 120 well-stratified vertebrate faunas. Wet-screening, selecting fossils from the washing remains, sorting and the first identification of fossils was carried out in the field camp at the Taatsiin Gol. For wet screening, sieves with mesh sizes of 0.5, 2.5 and 5.0 mm were used. A generator (Lombardi IM 359) powered the water-pumps (Asira 304) and the microscope lights. SEM-photos of small mammals were taken using a scanning electron microscope (Philips XL 20) at the Biocenter / University of Vienna.

Fossils: The washing remains of stratified samples yielded numerous small mammal fossils. Sporadically egg shells, gastropods, jaws and bones of amphibians and reptiles were found. There is no fossil record of plants (leaves, seeds, pollen), fish or ostracods. However, mandibles and isolated teeth of insectivores, rodents and lagomorphs are very abundant, whereas remains of didymoconids, carnivores, creodonts and ruminants from these stratified samples are rather rare. Larger specimens, e.g. skulls and bones from tsaganomyids, carnivores, creodonts, ruminants, rhinocerotids and proboscideans, were mostly collected from the surface along the investigated profiles (Daxner-Höck et al. 1997; Höck et al. 1999). Some taxonomic-systematic descriptions of mammals are already published, others are included in this special volume. Certain contributions are in preparation. This special volume, however, incorporates at least preliminary results of all fossil groups (collected 1995–2001). Only parts of the fossil collections from 2004 and 2006 have been published.

Gastropoda (Stworzewicz 2007):

Shells and internal moulds were recovered from the red Hsanda Gol clays below basalt I of three profiles (TGR-A/13-14; TGL-A/1-2; GRAB-II), and from reddish silts of the Loh Fm. below basalt II (ABO-A/3). They are rarely preserved in Hsanda Gol sediments (TGR-C/1, 5) and Loh sediments (UNCH-A/3) next to basalts. Some fossil layers (TGW-A/2, TGL-A/1-2) yielded gastropod eggs.

Amphibia and Squamata (Böhme 2007):

Only a few skull fragments of amphibians were recovered from Hsanda Gol clays of two sections (TAT-D/1; SHG-C/1-2). Squamata are evidenced by skull fragments, osteoderms, and vertebras from 9 profiles and 12 fossil horizons (TAT-D/1; TGR-A/13-14; TGR-ZO/2; TGL-A/2,11a; SHG-C/2; SHG-A/1; IKH-A/1; ODO-A/2, 6; BUK-A/12+14). The occurrences are from red clays of the Hsanda Gol Fm. below and above basalt I and from silts of the Loh Fm.

Didymoconidae, Creodonta and Carnivora (Nagel & Morlo 2003; Morlo & Nagel, in press; Morlo & Nagel 2007):

Didymoconidae are very rare elements in the investigated area and were found in washing remains of 6 profiles and 7 fossil horizons. Ranging from the Early Oligocene to the Oligocene/Miocene transition, they were recovered from sediments of the Hsanda Gol and the Loh Formations. Being predators of smaller and larger mammals, Creodonta and Carnivora were very diverse in the Oligocene of Mongolia.

Marsupialia, Erinaceomorpha and Soricomorpha (Ziegler et al. 2007):

Except for marsupials, these small mammal groups are very well represented. Although varying in composition, they occur in almost all 117 fossil layers (tab. 2). They are abundant in Hsanda Gol and Loh sediments ranging from the Early Oligocene to the Late Miocene. Only marsupials are restricted to the Lower Oligocene part of the Hsanda Gol sediments and to the biozones A and B (SHG-A/15+20; TGR-B/1; TGR-AB/21, 22; GRAB-II/2). Erinaceomorpha and Soricomorpha are very abundant in Hsanda Gol and Loh sediments ranging from the Early Oligocene to the early Early Miocene. The Early to Late Miocene record is very poor.

Lagomorpha (Erbajeva & Daxner-Höck 2001; Erbajeva 2003; Erbajeva 2007):

So far 45 taxa of lagomorphs have been identified. They were collected from 80 fossil horizons between 1995 and 1997. Ranging from the Paleogene to the Neogene, lagomorphs are one of the most successful vertebrate families in the investigated area. Among them, *Desmatolagus* and *Sinolagomys* are very rich in species. *Desmatolagus*, which ranges from the Early Oligocene to the beginning of the Miocene, shows the highest species diversity. *Sinolagomys* is most abundant in the Late Oligocene and earliest Miocene. Note that, in the investigated area, the genera *Amphilagus* and *Eurolagus* are limited to faunas of biozone D. The genera *Alloptox* and *Ochotona* were recovered from the Early and Late Miocene, respectively.

Rodentia (tab. 3; Daxner-Höck 2000; Daxner-Höck 2001; Daxner-Höck & Wu 2003; Schmidt-Kittler et al. 2007):

Rodents were collected by wet screening from all investigated fossil horizons from the Taatsin Gol and Taatsiin Tsagaan Nur area in the Valley of Lakes. They represent nine families, i.e. Dipodidae, Muridae, Ctenodactylidae, Tsaganomyidae, Aplodontidae, Sciuridae, Eomyidae, Clindrodontidae and Gliridae. Rodents from the Valley of Lakes show the largest species diversities among all vertebrate groups and are of highest biostratigraphic importance. Moreover, for the first time the enamel microstructure of molars and incisors was compared (Koenigswald & Kalthoff 2007).

Ruminantia (Vislobokova & Daxner-Höck 2002):

Mandibles, teeth and postcranial bones from ruminants are very abundant in the investigated area. They were collected from the surface along the studied profiles. The washed samples yielded only a few teeth. In our working area, however, ruminants are well represented in all localities of the Hsanda Gol Fm. They are abundant in Loh depositions of the Late Oligocene, but rare in the Miocene part of the Loh Fm.

Rhinocerotidae (Heissig 2007):

Findings of Rhinocerotidae are very artificial: the specimens were collected from the surface, where they were obviously left behind by collectors from former expeditions. However, they provide additional information about environmental and climatic conditions during the Late Oligocene and the Miocene. Mandibles, inarticulated bones and teeth were exclusively recovered from sediments of the Loh Fm. Bones and teeth of indricotheriids were recovered from the lower part from the Huch Teeg section (RHN-A/6), indicating the Oligocene. In the areas of Unkheltseg (UNCH-A/O) and Hotuliin

Teeg (HTE/O), postcranial bones and teeth of ?*Hoploaceratherium gobiense* were frequently collected from the surface. Furthermore, different Elasmotheriini were present in Miocene fossil beds (UTO-A/3, LOH-A/2 and BUK-A/0).

Proboscidea (Göhlich 2007):

Only a few teeth and postcranial bones of Proboscidea were collected from the surface, close to the investigated profiles. They were preserved in sediments of the Loh Fm. and obviously left behind by previous collectors. We found them partly exposed in the locality Loh (LOH-A/2) and on the surface in Ulaan Tolgoi (UTO-A/3) and Builstyn Khudag (BUK-A/O).

5. Rodent biostratigraphy and biochronology
(Tabs. 3–4)

It is important to note that the Oligocene-Miocene sediment sequences are very thin throughout the investigated area; this reflects the long time of potential sedimentation, i.e. at least more than twenty-five million years. Possible interpretations include low sedimentation-rates, and/or gaps in sedimentation, and/or erosion phases. There is no evidence of a continuous sedimentation and evolution of animals over long time intervals. Nevertheless, the investigated sections display fossil layers which differ significantly from those in higher or lower levels of the same sections but are correlative with fossil beds in the respective lithostratigraphic position of other sections. The first biostratigraphy based on 5 characteristic rodent assemblages (A, B, C, D, E) in the Valley of Lakes was established by Daxner-Höck et al. (1997: 172). Since then, new geological, paleontological and radiometric data have become available and the stratigraphic concept has been improved, whereby the number of informal biozones has been extended from 5 to 8, i.e. A, B, C, C1, D, D1/1, D1/2 and E. Each informal biozone was defined by its lithostratigraphic position and the characteristic rodents from all respective fossil horizons. The description of each biozone comprises: an integrated rodent list, the characteristic species, the first and last record of species, the characterization and/or most abundant rodents, and, finally, the localization and lithostratigraphic position (Höck et al., 1999: 115-122, Figs. 20-22).

In the meantime, additional field activities and detailed systematic-taxonomic investigations on different vertebrate groups have been conducted, further improving our knowledge. The biozones have been updated according to the new data. The new rodent data are from: Daxner-Höck (2000), Daxner-Höck (2001), Daxner-Höck & Wu (2003) and Schmidt-Kittler et al. (2007*).

Updated informal biozones (rodent data tab. 3):

biozone A:

Characteristic taxa: *Selenomys mimicus, Cricetops dormitor, Cyclomylus* div. spec*., Karakoromys decessus*, Heosminthus* sp. 1*, Parasminthus* sp. 1

First record: *Tatalsminthus khandae, Shamosminthus sodovis, Ulaancricetodon badamae, Selenomys, Cricetops, K. decessus*, Heosminthus* sp. 1, *Anomoemys lohiculus*, *Ardynomys* sp., *Parasminthus* sp. 1, *Eucricetodon caducus*, *Eucricetodon asiaticus*, Eomyidae indet., *Prosciurus*.

Last record: *T. khandae, Ardynomys* sp.

Most abundant taxa: *Heosminthus* sp., *S. mimicus, Cyclomylus, K. decessus**

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 Oligocene age, i.e. older than 31.5 Ma (tab. 4).

biozone B:

Characteristic taxa: *S. sodovis, S. mimicus, Cricetops dormitor, Tsaganomys altaicus, Heosminthus* sp. 1, *K. decessus**

First record: *Heosminthus minutus, T. altaicus, Tataromys sigmodon*, Huangomys frequens*, Yindirtemys shevyrevae**

Last record: *S. sodovis, U. badamae, S. mimicus, C. dormitor, H. minutus, Y. shevyrevae*, K. decessus**

Most abundant taxa: *T. altaicus, C. dormitor, Heosminthus* sp. 1, *H. frequens**

Lithostratigraphy and biochronology: Fossils of biozone B are well documented from Hsanda Gol sediments above basalt I and between two lava flows of basalt I. Only a few of them were found in Loh sediments close to or above basalt II. The estimated age is Early Oligocene, i.e. between 31.5 and 28 Ma (tab. 4).

biozone C:

Characteristic taxa: *Aralocricetodon* sp., *Tachyoryctoides obrutschewi*, *Parasminthus parvulus*, *Eucricetodon* sp. 2, *Eucricetodon* sp. 3, *Prosciurus* sp. 4, *Tataromys minor longidens**

First record: Sciuridae indet., *Aralocricetodon* sp., *T. obrutschewi*, *Eucricetodon* sp. 2, *Eucricetodon* sp. 3, *Litodonomys, Tataromys minor longidens**, *Yindirtemys* aff. *ulantatalensis**

Last record: *H. frequens**, *T. sigmodon**

Most abundant taxa: *P. parvulus*, *T. minor longidens**, *Aralocricetodon* sp., *Eucricetodon* sp. 2, *Eucricetodon* sp. 3

Lithostratigraphy and biochronology: Fossils of biozone C are known from: upper levels of the Hsanda Gol sequences (TGR-C/1-4; TAT-SE), from Loh sediments immediately below basalt II (ABO-A/3), and above basalt II (TAR-A/2), and without basalt-contact (TGW-A/1-2; RHN-A/6). The estimated age is the early Late Oligocene, i.e. ~ 28 Ma and younger (tab. 4).

biozone C1:

Characteristic species: *Plesiosminthus* cf. *asiaticus*, *Plesiosminthus promyarion*, *Yindirtemys deflexus**, *P. parvulus*, *Heterosminthus* cf. *firmus*

Tab. 3: Rodent taxa from the Valley of Lakes (Mongolia) related to the biozones A-E. The marked species (*) are from SCHMIDT-KITTLER et al. (2007).

	A	B	C	C1	D	D1/1	D1/2	E
Aplodontidae:								
Prosciurus sp. 1	x	x						
Promeniscomys sp.	x	x						
Prosciurus sp. 2	x	x						
Prosciurus sp. 3	x	x						
Prosciurus sp. 4			x	x				
Aplodontidae indet.					x			
Ansomys sp.							x	
Sciuridae :								
Spermophilinus sp.			x		x		x	
Sciuridae indet. 1					x			
Kherem sp.				x	x			
Sciuridae indet. 2					x			
Sciuridae indet. 3						x		
Sciuridae indet. 4								x
Prospermophilus cf. *orientalis* (QIU, 1991)								x
Gliridae:								
Microdyromys sp.							x	
Eomyidae:								
Eomyidae indet. 1	x	x						
Eomyidae indet. 2			x	x	x			
Keramidomys sp.							x	
Eomyops sp.1							x	
Eomyidae indet. 3							x	
Eomyidae indet. 4								x

	A	B	C	C1	D	D1/1	D1/2	E
Ctenodactylidae:								
Karakoromys decessus MATTHEW & GRANGER, 1923*	x	x						
Huangomys frequens nov. gen. nov. spec.*		x	x					
Tataromys sigmodon MATTHEW & GRANGER, 1923*		x	x					
Tataromys minor longidens nov. spec.*			x	x				
Tataromys plicidens MATTHEW & GRANGER, 1923*				x				
Yindirtemys shevyrevae VIANEY-LIAUD et al., 2006*		x						
Yindirtemys aff. *ulantatalensis* (HUANG, 1985)*			x					
Yindirtemys deflexus (TEILHARD DE CHARDIN, 1926)*				x				
Yindirtemys suni (LI & QIU, 1980)					x			
Distylomys sp.					x			
Sayimys cf. *intermedius* (SEN et al., 1979)*							x	
Cylindrodontidae:								
Ardynomys sp.	x							
Anomoemys lohiculus (MATTHEW & GRANGER, 1923)	x	x						
Tsaganomyidae:								
Cyclomylus lohensis MATTHEW & GRANGER, 1923	x	x						
Cyclomylus intermedius WANG, 2001	x	x						
Cyclomylus biforatus WANG, 2001	x	x						
Cyclomylus sp.	x	x	x					
Coelodontomys asiaticus WANG, 2001		x						
Coelodontomys sp.		x						
Tsaganomys altaicus MATTHEW & GRANGER, 1923		x	x	x				

	A	B	C	C1	D	D1/1	D1/2	E
Dipodidae:								
Tatalsminthus khandae DAXNER-HÖCK, 2001	x							
Heosminthus sp.1	x	x	x					
Heosminthus minutus DAXNER-HÖCK, 2001		x						
Heosminthus cf. *minutus* DAXNER-HÖCK, 2001					x			
Plesiosminthus sp. A			x					
Plesiosminthus cf. *asiaticus* DAXNER-HÖCK & WU, 2003				x				
Plesiosminthus promyarion SCHAUB, 1930				x				
Plesiosminthus sp. B				x				
Plesiosminthus barsboldi DAXNER-HÖCK & WU, 2003					x			
Shamosminthus sodovis DAXNER-HÖCK, 2001	x	x						
Shamosminthus sp.		x						
Heterosminthus cf. *firmus* ZAZHIGIN & LOPATIN, 2000				x	x			
Heterosminthus firmus ZAZHIGIN & LOPATIN, 2000					x			
Heterosminthus mongoliensis ZAZHIGIN & LOPATIN, 2000						x	x	
Heterosminthus gansus ZHENG, 1982								x
Parasminthus sp.1	x	x	x					
Parasminthus cf. *tangingoli* BOHLIN, 1946			x	x				
Parasminthus cf. *asiae-centralis* BOHLIN, 1946			x	x				
Parasminthus cf. *debruijni* LOPATIN, 1999			x	x				
Parasminthus parvulus BOHLIN, 1946	x	x	x	x				
Parasminthus sp. 2			x	x				
Litodonomys sp. 1			x	x	x			
Litodonomys sp. 2					x			
Litodonomys sp. 3					x			
Dipodidae indet. 1							x	

	A	B	C	C1	D	D1/1	D1/2	E
Protalactaga sp.								x
Eozapus sp.								x
Dipodidae indet. 2								x
Muridae:								
Selenomys mimicus MATHEW & GRANGER, 1923	x	x						
Cricetops dormitor MATTHEW & GRANGER, 1923	x	x						
Ulaancricetodon badamae DAXNER-HÖCK, 2000	x	x						
Eucricetodon caducus (SHEVYREVA, 1967)	x	x						
Eucricetodon asiaticus (MATTHEW & GRANGER, 1923)	x	x						
? *Eucricetodon* sp. 1		x	x					
? *Eucricetodon* sp. 2			x					
? *Eucricetodon* sp. 3			x					
Aralocricetodon sp.			x	x				
Tachyoryctoides sp. 1			x					
Tachyoryctoides obrutschewi BOHLIN, 1937			x	x				
Tachyoryctoides sp. 2					x			
Tachyoryctoides kokonorensis LI & QIU, 1980					x			
Democricetodon sp.1					x			
Democricetodon sp.2						x		
Democricetodon cf. *lindsayi* QIU, 1996							x	
Democricetodon cf. *tongi* QIU, *1996*							x	
Democricetodon sp. 3								x
Megacricetodon sp.1						x		
Megacricetodon cf. *sinensis* QIU et al., 1981							x	
? *Allocricetus* sp.								x
Prosiphnaeus sp.								x
Myocricetodon sp.								x
Gerbillinae indet.								x

First record: *Plesiosminthus* cf. *asiaticus*, *Plesiosminthus promyarion*, *Heterosminthus*, *Y. deflexus**, *Tataromys plicidens**

Last record: *P. parvulus*, *T. obrutschewi*, *Tsaganomys altaicus*, *T. minor longidens**, *Y. deflexus**

Most abundant taxa: *P. parvulus*, *Y. deflexus**

Lithostratigraphy and biochronology: Fossils of biozone C1 are found on top of Hsanda Gol sequences with fauna B (DEL-B/12; IKH-A/5; IKH-B/5; TAT-D/3; TAT-B/10), and in Loh sediments above fauna C (TGW-A/5) and below fauna D (RHN-A/7-10). There is no immediate age control based on basalts, but evolutionary lines of rodents provide biostratigraphic control, e.g. *Plesiosminthus* (*P.* cf. *asiaticus* / C1 – *P. promyarion* / C1 – *P. barsboldi* / D), *Yindirtemys* (*Y. deflexus** / C1 – *Y. suni* / D). The estimated age is the late Late Oligocene because of the position between biozone C (mostly above basalt II) and biozone D (tab. 4).

biozone D:

Characteristic species: *Tachyoryctoides kokonorensis*, *Heterosminthus firmus*, *Litodonomys* sp., *Yindirtemys suni*, *Distylomys* sp., *Plesiosminthus barsboldi*, *Democricetodon* sp., *Kherem* sp.

First record: *Litodonomys* sp. 2 and *L.* sp. 3, *Y. suni*, *T. kokonorensis*, *H. firmus*, *P. barsboldi*, *Distylomys*, *Democricetodon*, *Kherem*

Last record: *Plesiosminthus*, *Litodonomys*, *Y. suni*, *T. kokonorensis*, *H. firmus*

Most abundant taxa: *T. kokonorensis*, *Y. suni*, *H. firmus*

Lithostratigraphy and biochronology: Fossils of biozone D are exclusively recovered from sediments of the Loh Fm. In the section RH-A/6-12, faunas of the biozones C – C1 – D follow successively. There is no immediate age control based on basalts, but the first occurrence of *Democricetodon* and advanced species of *Yindirtemys* (*Y. suni*), Tachyoryctoides (*T. kokonorensis*) and *Plesiosminthus* (*P. barsboldi*) indicate the beginning of the Miocene. The estimated age of fauna D is early Early Miocene because of the position above biozone C1 and below D1/1 (tab. 4).

biozone D 1/1:

Characteristic species: *Heterosminthus mongoliensis*, *Democricetodon* sp., *Megacricetodon* sp.

First record: *Megacricetodon*, *H. mongoliensis*

Lithostratigraphy and biochronology: The record of this biozone is poor. However, a few small faunulae of biozone D1/1 were recovered from red silty sands of the Loh Fm. In one profile of Olon Ovoony Khurem (ODO-B/1) the fossil horizon is sandwiched between basalt II (28 Ma) and basalt III (13 Ma). In the profiles (ODO-A/1-6) and Luugar Khudag (LOG-B/1) the fossil layers are situated below basalt III. As controlled by basalt III the fossils are older than 13 Ma. According to the evolutionary stage of rodents they are more advanced than fossils of biozone D but more primitive than those of biozone D1/2. Most probably they are of Early Miocene age (tab. 4).

biozone D1/2:

Characteristic species: *H. mongoliensis*, *Democricetodon* cf. *lindsayi*, *D.* cf. *tongi*, *Megacricetodon* cf. *sinensis*, *Ansomys* sp., *Microdyromys* sp., *Keramidomys* sp., *Eomyops* sp. 1, *Saimys* cf. *intermedius**

First record: *Ansomys*, *Microdyromys*, *Keramidomys*, *Eomyops*, *Saimys*

Last record: *H. mongoliensis*

Lithostratigraphy and biochronology: The sediments are white, rose, grey, brown, red silts and sands of the Loh Fm. There is no age control based on basalts. The fossil record of biozone D1/2 is characterized by diverse rodent species (documented by only one or a few specimens) from the deposits Ulan Tolgoi (UTO-A) and Loh (LOH-A). The rodents indicate a late Early or early Middle Miocene age (tab. 4).

biozone E:

Characteristic species: *Heterosminthus gansus*, *Prosiphnaeus* sp., *Protalactaga* sp., *Prospermophilus* cf. *orientalis*, *Eozapus* sp., *Democricetodon* sp. 3, *Myocricetodon* sp.

First record: *H. gansus*, ?*Allocricetus* sp.

Last record: *H. gansus*

Most abundant taxa: *H. gansus*, ? *Allocricetus* sp.

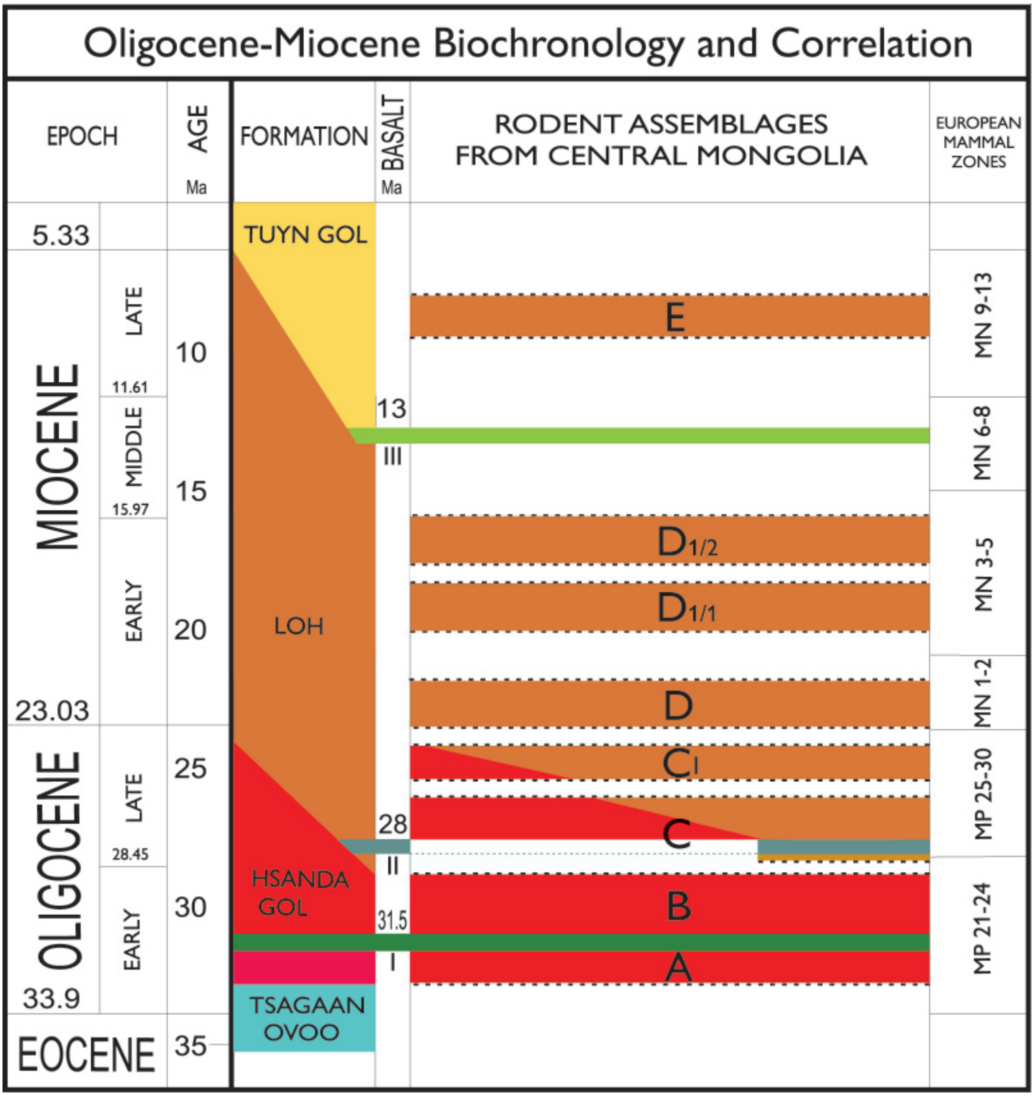
Lithostratigraphy and biochronology: Fossils are known from rose-red silts of the Loh Fm. in the section Builstyn Khudag (BUK-A). Only one horizon in a high position of the section (BUK-A/12+14) yielded the characteristic small mammal fossils indicating biozone E. There is no age control based on basalts. The investigated fossils indicate the Late Miocene (tab. 4).

6. Correlation
(Tab. 4)

The hitherto used correlation chart Höck et al. (1999: Fig. 22) was slightly modified. The boundaries between epochs are drawn according to new data from the geologic time scale (Gradstein & Ogg 2004): i.e. Eocene / Oligocene = 33.9 Ma, Oligocene / Miocene = 23.03 Ma, Miocene / Pliocene = 5.33 Ma. Subdivision-boundaries of epochs are: Early / Late Oligocene = 28.45 Ma, Early / Middle Miocene = 15.97 Ma, Middle / Late Miocene = 11.61 Ma. These new data confirm that basalt I (31.5 Ma) is of Early Oligocene age, basalt II (28 Ma) was deposited around the Early/Late Oligocene transition, and basalt III (13 Ma) is of Middle Miocene age. Hence, the red beds of the Hsanda Gol Fm. below basalt I were deposited in the Early Oligocene, and large parts of the Tsagan Ovo Fm. are of Eocene age (Höck et al. 1999). This is in agreement with magnetostratigraphic data (Kraatz et al., 2005), showing reversed polarity (correlated to Chron C1 2r) below basalt I and normal polarity (correlated to C1 3n) at the base of the Hsanda Gol Fm.

The correlation of the Mongolian biozones A–B to the Early Oligocene, and C–C1 to the Late Oligocene (Höck et al. 1999) is still valid. The biozones A and B can be correlated to the Chinese vertebrate fauna Wulanbulage (Wang 1997). The Ulan Tatal faunas

Tab. 4: Correlation chart modified after Höck et al. (1999: fig. 22). Oligocene-Miocene biochronology of Central Mongolia based on informal biozones and on basalt datings. Tentative correlation to European Mammal Zones. The boundaries between epochs are drawn according to Gradstein & Ogg (2004).



were hitherto correlated to the Early Oligocene, and Ulan Tatal provided the name for the Ulantatalian Mammal Age (Tong et al., 1995). Schmidt-Kittler et al. (2007) have good arguments for the correlation of Ulan Tatal I to biozone B (Early Oligocene), Ulan Tatal II to part of biozone C, and Ulan Tatal III to the lower part of biozone C1 (Late Oligocene). However, correlation to Chinese Mammal Ages is omitted in tab. 4 because at least some of them need re-interpretation (e.g. Ulantatalian; as used in Höck et al. 1999: Fig. 22).

In China the Tieersihabahe section from Xinjiang displays the Oligocene-Miocene transition, directly between the fauna Tieersihabahe and the fauna 99005. Tieersihabahe is most similar with Taben Buluk. It is of Late Oligocene age and correlative to the biozones C and C1 from Mongolia, and fauna 99005 is correlative to faunas of biozone D from Mongolia (Ye et al., 2005). In Mongolia the biozone D indicates the Early Miocene rather than the end of the Oligocene, because of first occurrences of typical Miocene mammals (e.g. *Democricetodon*). So far, the Mongolian faunas of biozone D were correlated to the small but unique Chinese fauna Xieja, which gave the name to the Chinese Mammal Age Xiejian (early Early Miocene; Tong et al. 1995). Future investigations will prove correlations to the Chinese fauna of Gashunyinadege (Qiu et al. 2006). The biozones D1/1 and D1/2 correlate with the Early Miocene rather than with the Middle Miocene, and biozone E correlates with the Late Miocene (Höck et al. 1999).

Acknowledgements

The project was carried out in a cooperation between the Paleontological Center, Mongolian Academy of Sciences and the Museum of Natural History in Vienna. All these persons and institutions are gratefully acknowledged for logistic, financial and scientific support: The Mongolian scientists R. Barsbold, D. Badamgarav, Y. Khand, and J. Sodov (Paleontological Center, Mongolian Academy of Sciences, Ulaanbaatar) and several Mongolian drivers, cooks and helpers. From the European side, geological investigations were carried out by V. Höck, G. Furtmüller, O. Montag and E. Öttl (University Salzburg). H.-P. Schmid and M. Haas (University Vienna) were responsible for sedimentology and lithostratigraphy. W. Frank (Geochronology laboratory, University of Vienna) dated the basalts. The paleontological field investigations were supported by O. Fejfar (University Prag) and T. Bolliger (University Zürich). The final sorting of washing remains was carried out by F. Topka, T. Englert, K. Huttunen and E. Preis, and E. Höck helped with the organization and the inventory of the fossil collection in Vienna. Zd. Qiu reviewed the manuscript and M. Stachowitsch corrected the English.

The field work was funded in the frame of the FWF-projects: P-10505-GEO and P-15724-N06 of the Austrian National Science Fund.

References

Berkey, C. P. & Morris, F. K. (1927): Geology of Mongolia. – In: Natural History of Central Asia.- American Museum of Natural History, **2**: 1- 475. – New York.

Bohlin, B. (1937): Oberoligozäne Säugetiere aus dem Shargaltain-Tal (Western Kansu). – Paleontologica Sinica, N.S., C, **3**: 1-66. – Nanking.

—— (1946): The Fossil Mammals from the Tertiary Deposit of Tabenbuluk, Western Kansu. Part II: Simplicidentata, Carnivora, Artiodactyla, Perissodactyla, and Primates. – VI. Vertebrate Palaeontology, **4**: 1-259. – Stockholm.

Böhme, M. (2007): 3. Herpetofauna (Anura, Squamata) and paleoclimatic implications: preliminary results. – In: Daxner-Höck, G. (ed.): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 43-52. – Wien.

Bryant, J. D. & Mc Kenna, M. (1995): Cranial Anatomy and Phylogenetic Position of *Tsaganomys altaicus* (Mammalia Rodentia) from the Hsanda Gol Formation (Oligicene), Mongolia. – American Museum Novitates, **3156**: 1- 42. – New York.

Daxner-Höck, G. (2000): *Ulaancricetodon badamae* n. gen. n. sp. (Mammalia, Rodentia, Cricetidae) from the Valley of Lakes in Central Mongolia. – Paläontologische Zeitschrift, **74**/1-2: 215-225. – Stuttgart.

—— (2001): New zapodids (Rodentia) from Oligocene-Miocene deposits in Mongolia. Part 1. – Senckenbergiana lethaea, **81**/2: 359-389. – Frankfurt a. M.

—— , Höck, V., Badamgarav, D., Furtmüller, G., Frank, W., Montag, O. & Schmid, H. P. (1997): Cenozoic Stratigraphy based on a sediment-basalt association in Central Mongolia as Requirement for Correlation across Central Asia. – In: Aguilar, J. P., Legendre, S. & Michaux, J. (eds): Biochronologie mammalienne du Cénozoique en Europe et domaines reliés. – Mémoires et Travaux de l'Institut de Montpellier, E.P.H.E., **21**: 163-176. – Montpellier.

—— & Wu, W. (2003): *Plesiosminthus* (Zapodidae, Mammalia) from China and Mongolia: migrations to Europe. – DEINSEA, Ann. Nat. Hist. Mus. Rotterdam, **10**: 127-151. – Rotterdam.

Devjatkin, E. V. (1981): The Cenozoic of Inner Asia. (Stratigraphy, geochronology and correlation). – In: Nikiforova, I. (ed): The Joint Soviet-Mongolian Scientific-Research Geological Expedition, Transactions, **27:** 1-196. (in Russian).

—— (1993a): Paleomagnetic and geochronological studies of Paleogene and Miocene deposits of Mongolia. – In: Barsbold, R. & Akhmetiev, M. A.: International Geological Correlation Programme, Project 326. Oligocene-Miocene Transitions in the Northern Hemisphere, Excursion Guide-Book Mongolia: Oligocene-Miocene Boundary in Mongolia: 28-35. – Ulaan Baator and Moscow.

—— (1993b): The age and correlation of boundary horizons from the Oligocene-Miocene of Mongolia and adjacent regions of the Inner Asia. – In: Barsbold, R. & Akhmetiev, M. A.: International Geological Correlation Programme, Project 326. Oligocene-Miocene Transitions in the Northern Hemisphere, Excursion Guide-Book Mongolia: Oligocene-Miocene Boundary in Mongolia: 36-39. – Ulaan Baator and Moscow.

—— , Badamgarav, D. (1993): Geological essay on Paleogene and Neogene deposits of the Valley of Lakes and Prealtai depressions. – In: Barsbold, R. & Akhmetiev, M. A.: International Geological Correlation Programme, Project 326. Oligocene-Miocene Transitions in the Northern Hemisphere, Excursion Guide-Book Mongolia: Oligocene-Miocene Boundary in Mongolia: 7-27. – Ulaan Baator and Moscow.

Erbajeva, M. (2003): Late Miocene ochotonids (Mammalia, Lagomorpha) from Central Mongolia. – N. Jb. Geol. Paläont. Mh. **2003**/4: 212-222. – Stuttgart.

—— (2007): 5. Lagomorpha (Mammalia): preliminary results. – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 165-171. – Wien.

—— & Daxner-Höck, G. (2001): Paleogene and Neogene lagomorphs from the Valley of Lakes, Central Mongolia. – Lynx, ISSN 0024-7774, n.s., **32**: 55-65. – Praha.

Göhlich, U. B. (2007): 9. Gomphotheriidae (Proboscidea, mammalian). – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 271-289. – Wien.

Gradstein, F. M. & Ogg, J. G. (2004): Geologic Time Scale 2004 – why, how, and where next! – Lethaea, **37**: 175-181. – Oslo.

Heissig, K. (2007): 8. Rhinocerotidae (Perissodactyla, Mammalia). – In: Daxner-Höck, G.(ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 233-269. – Wien.

Höck, V., Daxner-Höck, G., Schmid, H. P., Badamgarav, D., Frank, W., Furtmüller, G., Montag, O., Barsbold, R., Khand, Y. & Sodov, J. (1999): Oligocene-Miocene sediments, fossils and basalts from the Valley of Lakes (Central Mongolia) – An integrated study. – Mitteilungen der Geologischen Gesellschaft, **90**: 83-125. – Wien.

Huang, X. (1992): Zapodidae (Rodentia, Mammalia) from the Middle Oligocene of Ulantatal, Nei Mongol. – Vertebrata PalAsiatica, **30**: 249-286. – Beijing.

Koenigswald W. v. & Kalthoff, D. (2007): The enamel microstructure of molars and incisors of Paleogene and Neogene rodents from Mongolia. – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 291-312. – Wien.

Kraatz, B. & Geisler, J. (2005): The age of the Hsanda Gol Formation, Mongolia and implications for timing of the Mongolian remodelling. – Journal of Vertebrate Paleontology, Abstracts, **25**/3: 79A.

Li, C. & Qiu, Zd. (1980): Early Miocene mammalian fossils of Xining Basin, Quinghai. – Vertebrata PalAsiatica, **18**/3: 198-214. – Beijing.

Liskun, I. G. & Badamgarv, D. (1977): Lithology of the Cenozoic of Mongolia. – The Joint Soviet-Mongolian Scientific-Research Geological Expedition, Transactions, **20**: 1-159. – Moscow. (in Russian).

Lopatin, A. V. (1999): New Early Miocene Zapodidae (Rodentia, Mammalia) from the Aral Formation of the Altynshokysu Locality (North Aral Region). – Paleontological Journal **33**/4: 429-438. – Moscow.

Matthew, W. D. & Granger, W. (1923): Nine new Rodents from the Oligocene of Mongolia. – American Museum Novitates, **102**: 1-10. – New York.

Morlo, M. & Nagel, D. (2007): 7. The carnivore guild of the Taatsiin Gol area: Hyaenodontidae (Creodonta, Carnivora and Didymoconidae). – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 217-231. – Wien.

—— & Nagel, D. (in press): New remains of Hyaenodontidae (Creodonta, Mammalia) from the Oligocene of Central Mongolia. – Ann.. Paleont. Paris.

Qiu, Zd. (1991): The Neogene mammalian faunas of Ertemte and Harr Obo in Inner Mongolia (Nei Mongol), China.- 8. Sciuridae (Rodentia). – Senckenbergiana lethaea, **71**/3-4: 223-255. – Frankfurt a.M.

—— (1996): Middle Miocene micromammalian fauna from Tunggur, Nei Mongol. – 1-213. – Beijing (Science Press).

—— & Storch, G. (2000): The early Pliocene Micromammalian Fauna of Bilike, Inner Mongolia, China (Mammalia: Lipotyphla, Chiroptera, Rodentia, Lagomorpha). – Senckenbergiana lethaea, **80**/1: 173-229. – Frankfurt a. M.

—— , Wang, Xm. & Li, Q. (2006): Faunal succession and biochronology of the Miocene through Pliocene in Nei Mongol (Inner Mongolia). – Vertebrata PalAsiatica, **44**/2: 164-181. – Beijing.

Salvador, A. (1994): International Stratigraphic Guide: a guide to stratigraphic classification, terminology, and procedure. – 2. ed. International Subcommission on Stratigraphic Classification of IUGS International Commission on Stratigraphy, ISBN 0-8137-7401-2: 1-214. – Boulder.

Schaub, S. (1930a): Fossile Sicistinae. – Schweiz. Paläont. Ges., Eclogae geol. Helvetiae, **23**/2: 616-636. – Basel.

—— (1930b): Quartäre und jungtertiäre Hamster. – Abhandl. Schweizer. Paläontol. Ges., **49**: 1-49. – Basel.

Schmidt-Kittler, N. Vianey-Liaud, M & Marivaux, L. (2007): 6. Ctenodactylidae (Rodentia, Mammalia). – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 173-215. – Wien.

Sen, S. & Thomas, H. (1979): Découverte de Rongeurs dans le Miocène moyen de la Formation Hofuf (Province du Hasa, Arabie saoudite). – C. R. Somm. Séances Soc. Géol. France, 1979/fasc. 1: 34-37. – Paris.

Shevyreva, I. (1967): Hamsters of the Genus *Cricetodon* from the Middle Oligocene of Central Kazakhstan. – Paleontological Journal, **2**: 90-98. – Moscow.[in Russian]

Stworzewicz, E. (2007): 2. Molluscan fauna (Gastropoda, Pulmonata, Pupilloidea): a systematic review. – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 25-41. – Wien.

Teilhard de Chardin, P. (1926): Mammifères tertiaires de Chine et de Mongolia. – Ann. Paléont., **15**: 1-51. – Paris.

Tong, Y., Zheng, S. & Qiu, Zd. (1995): Cenozoic Mammal Ages of China. – Vertebrata PalAsiatica, **33**: 290-314. – Beijing.

Vianey-Liaud, M., Schmidt-Kittler, N. & Marivaux, L. (2006): The Tataromyinae (Ctenodactylidae, Rodentia) from the Oligocene of Ulantatal (Inner Mongolia, China). – Palaeovertebrata **34**, in press.

Vislobokova, I. & Daxner-Höck, G. (2002): Oligocene - Early Miocene Ruminants from the Valley of Lakes (Central Mongolia). – Ann. Naturhist. Mus., **103A**: 213-235. – Wien.

Wang, B. (1997): The Mid-Tertiary Ctenodactylidae (Rodentia, Mammalia) of Eastern and Central Asia. – Bulletin of the American Museum of Natural History, **234**: 1-88. – New York.

—— (2001): On Tsaganomyidae (Rodentia, Mammalia) of Asia. – American Museum Novitates, **3317**: 1-50. – New York.

Ye, J., Meng, J. & Wu, W. (2003): Oligocene/Miocene Beds and Faunas from Tieersihabahe in the Northern Junggar Basin of Xinjiang. – Bull. Amer. Mus. Nat. Hist., **13 (**279): 568-585. – New York.

Zazhigin, V. S. & Lopatin, A. V. (2000): The History of the Dipodoidea (Rodentia, Mammalia) in the Miocene of Asia: 1. *Heterosminthus* (Lophocricetinae). – Paleontologicheskij Zhurnal, **34**: 319-332 . – Moskva.

Zheng, S. (1982): Middle Pliocene micromammals from the Tianzhu Loc. 80007 (Gansu Province). – Vertebrata PalAsiatica, **20**: 138-147. – Beijing.

Ziegler, R., Dahlmann, T. & Storch, G. (2007): 4. Marsupialia, Erinaceomorpha and Soricomorpha. – In: Daxner-Höck, G. (ed): Oligocene-Miocene Vertebrates from the Valley of Lakes (Central Mongolia): Morphology, phylogenetic and stratigraphic implications. – Ann. Naturhist. Mus. Wien, **108**A: 53-164. – Wien.