Late Miocene mammalian fauna of Halajin Hushu in Nei Mongol, China

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Abstract Discoveries during the past 40 years of continental Neogene fossil sites in central Nei Mongol, through the adoption of screen washing techniques, have rapidly filled previous gaps in our knowledge of late Cenozoic faunal evolution and biochronology. Small mammals have become the backbone of our efforts in serializing individual fossil assemblages and in establishing a detailed framework of faunal sequence. We present another Late Miocene fauna from a new Halajin Hushu locality that, once again, shows the "embarrassing riches" of the Mongolian Plateau. The new locality is the northern-most fossil site in this region and is capped by a sheet of basalt. The new fossil assemblage is represented by 62 taxa of small mammals and one large mammal based on more than 7000 specimens. Our collections thus captured a remarkably complete small mammal fauna, possibly including 6 reworked species. Despite this mixture of reworked taxa from strata of older age, the Halajin hushu Fauna closely represents a coherent Late Miocene small mammal assemblage and its environments. Our preliminary analysis suggests a Bahean Chinese Land Mammal age in the early Late Miocene for the Halajin Hushu Fauna, probably slightly younger than Amuwusu Fauna but older than Shala Fauna.

Key words Halajin Hushu, Nei Mongol; Miocene, Bahean; small mammals; lithostratigraphy, biostratigraphy

Citation Qiu Z D, Wang X M, Li Q et al., 2021. Late Miocene mammalian fauna of Halajin Hushu in Nei Mongol, China. Vertebrata PalAsiatica, 59(1): 19–44
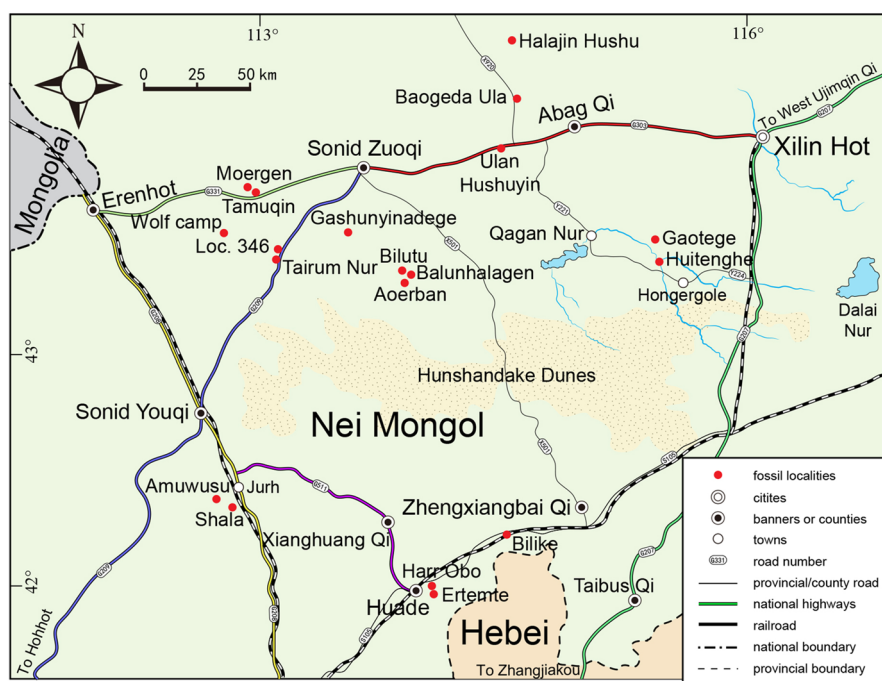
1 Introduction

Neogene deposits with dense fossil records are widely distributed in the middle part of the Nei Mongol Autonomous Region (Inner Mongolia), China. Substantial advances in the study

of biostratigraphy in this area have been made in the last 40 years. Since 1980s investigations and excavations have been carried out frequently at 15 localities with fossiliferous exposures, Aoerban, Balunhalagen, Bilutu, Gashunyinadege, Moergen in Sonid Zuoqi, Loc. 346, Tairum Nur, Amuwusu, Shala in Sonid Youqi, Ulan Hushuyin, Baogeda Ula, Huitenghe in Abag Qi, Bilike in Huade County, as well as the classic localities Tunggur, Ertemte and Gaotege (Fig. 1), and 18 faunas have been recovered from the sediments ranging from Early Miocene through Early Pliocene (Fahlbusch et al., 1983; Qiu et al., 1988; Qiu, 1996; Meng et al., 1996; Qiu and Storch, 2000; Li et al., 2003; Wang et al., 2009). Based on our studies of mammals, largely by abundant small mammals, a Neogene mammal succession in this area has been developed by faunal seriation. Growth of our knowledge in mammalian biostratigraphy resulted in a sequence of finely-spaced faunal units that span from Early Miocene to much of the Pliocene. At present, a preliminary framework of Neogene biostratigraphy and biochronology has been established for this area (Qiu and Wang, 1999; Qiu et al., 2006, 2013; Wang et al., 2009; Qiu and Li, 2016).

The Halajin Hushu (Mongolian for "bold head") locality (44º27′18.4″N, 114º33′06.8″E; IVPP IM1103 loc) is another Neogene site endowed with rich mammal fossils, which is a small basalt-covered hill situated about 41 km north of Baogeda Ula Sumu, and 130 km northwest of Xilinhot (Fig. 1). In 2011, while we were prospecting in Genghis Baogedu area, Mr. Chen Haifeng, director of the Abag Museum, Nei Mongol guided us to the locality. Short surveys in the site immediately demonstrated that the grayish white sandy mudstone near the

审图号：GS (2019) 3266号

Fig. 1   Geographic location of the fossil site Halajin Hushu in Nei Mongol

top beneath the basalt is rather fossiliferous, especially suitable for small mammal screening. In that field season, we excavated and screen-washed about 2.5 tons of the sediments, with the aim of collecting fossil mammals. As a result, the sample yielded more than 7000 specimens representing at least 62 taxa, dominated by isolated teeth of small mammals. Besides the small mammals, there are a few remains of large mammals and fossil fishes, amphibians and reptiles. It is clear that Halajin Hushu is one of the most important Neogene localities producing abundant and diverse assemblage known from central Nei Mongol. In the present paper, we briefly report the preliminary results of our field campaign and discuss related items of the vertebrate microfauna. Detailed descriptions of the material will be presented in the future.

2   Geologic settings

The Central Asian Orogenic Belt (CAOB), which encompasses the study area, is an accreted complex of Paleozoic and early Mesozoic age wedged between the Siberia Craton and North China Craton (e.g., Kröner et al., 2014; Windley et al., 2007). The late Cenozoic uplift of the Mongolian Plateau, which partly coincides with the CAOB, is associated with mantle upwelling, lithospheric extension and thinning, and alkalic magmatism (Chen et al., 2015; He and Wu, 2020; He et al., 2016; Windley and Allen, 1993). Continental intraplate basalts are widespread in central Nei Mongol and named Abag-Dalai Nor Volcanic Field (Chen et al., 2013; Gong et al., 2016; Ho et al., 2008; Zhang and Guo, 2016), which extends north of the Chinese border in the Dariganga Plateau of Mongolia (Deng and Macdougall, 1992; Devyatkin and Smelov, 1980; Whitford-Stark, 1987). Within the Abag Volcanic Field, the ages of the basalts are as old as 14.57±0.36 Ma in the Middle Miocene at Baiyinxile (sample B47 of Luo and Chen, 1990), through Late Miocene (5–7 Ma) in the Baogeda Ula area plus areas south of Abag (samples 54, 55 of Ho et al., 2008; Shao et al., 2008) and Late Pliocene (2.80±0.4 Ma) at Haernudenghua near Abag (Shao et al., 2008), to as young as Pleistocene (less than 1 Ma) further south (Liu et al., 1992; Luo and Chen, 1990; Zhang and Guo, 2016).

Except the above volcanism, a relatively stable tectonic setting in the study region prevailed with terrestrial sedimentations being typically thin-bedded with low rate of sedimentation. All deposits are flat-lying, overbank and flood plain sediments, and show no sign of tectonic deformation. As elsewhere in the Mongolian Plateau, vertebrate fossils are enriched in the low-rate sedimentation environment. Most of the late Cenozoic sediments in the study region are closely associated with capping basalts of different ages, which protect underlying sediments from erosions and form steep exposures along their edges, free of vegetation coverage (Fig. 2). Within the Abag Volcanic Field, there are at least three discrete exposures containing faunas of different ages. The oldest is the Bahean Halajin Hushu fauna in the early Late Miocene (this study). The age for IM0708 loc is less certain because it includes mostly reworked specimens of Paleogene taxa (Wang and Li, 2011), but presumably the sedimentation age is somewhere in the Late Miocene. The Baogeda Ula Formation, as

represented by IM0702 in Fig. 2, has produced a Baodean fauna (Deng et al., 2016; Qiu and Wang, 1999; Qiu et al., 2006; Tseng and Wang, 2007; Wang et al., 2012). Paleomagnetic dating of the Baogeda Ula Formation (Sun et al., 2018), constrained by both radioisotopic dates and fossil mammals, yielded an age range for the strata that suggest immediate burial of the sediments by basalt flows, i.e., no significant hiatus is observable between capping basalts and underlying sediments. In a section east of the Baogeda Ula Sumu, two layers of basalts are in superpositional relationship with sediments below and in between, but, unfortunately, repeated attempts at dating the weathered basalts have failed to yield a consistent result.
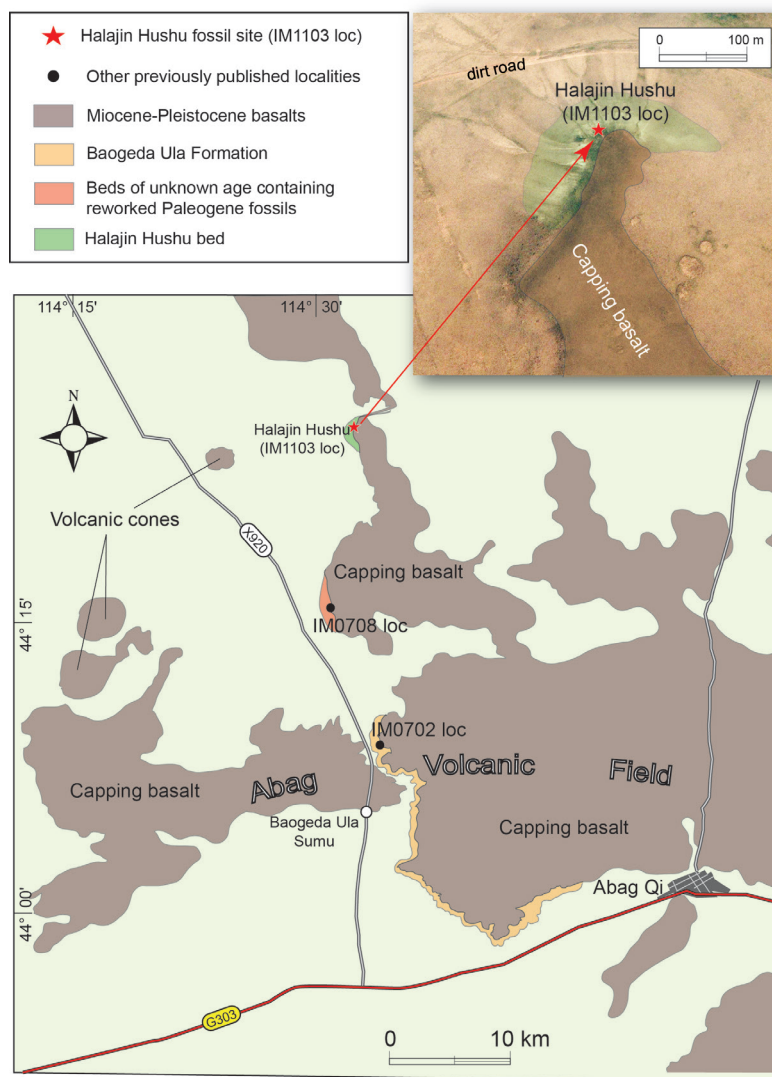

Fig. 2   Map of Abag Volcanic Field showing contact relationships of Neogene sediments and capping basalts
The Halajin Hushu locality is the northern-most fossil site associated with basalts. Only one fossil site is shown for each formations or beds that contain a discrete fauna. Cenozoic exposures and basalts are drawn from satellite images in Google Earth Pro (Version 7.3.3.7699) (2020), as is the inset (upper right) with semitransparent color enhancements of basal and Cenozoic exposures

The Halajin Hushu locality is the northern-most exposure with abundant fossils capped by a thin, weathered basalt. The basalt is weathered to a narrow, north-south oriented band, and sediments, about 200 m in lateral extent, are mostly exposed toward the northern end of the basalt band (inset in Fig. 2). We measured 36 m for a total thickness of Halajin Hushu bed, although the lower 18 m are covered by soil and vegetation, i.e., the observable section is only about 18 m in thickness (Fig. 3). Sediments are predominantly siltstones and mudstones with a few layers of carbonate nodules and one finely laminated lacustrine bed containing plant fragments (at 28 m). The fine-grained sediments are mostly reddish brown (mudstones) and light yellowish grey (nodular zones) in color, the latter giving a light gray tone where carbonate nodules (thin-bedded ones likely of *in situ* precipitation but thicker beds possibly secondarily enriched) are abundant (Fig. 3B). We interpret the sediments as floodplain deposits with several horizons of paleosols containing pedogenic mottling and carbonate nodules, plus one thin layer of ponded, indurated bed at 28 m. A semiarid climate is indicated by the precipitation
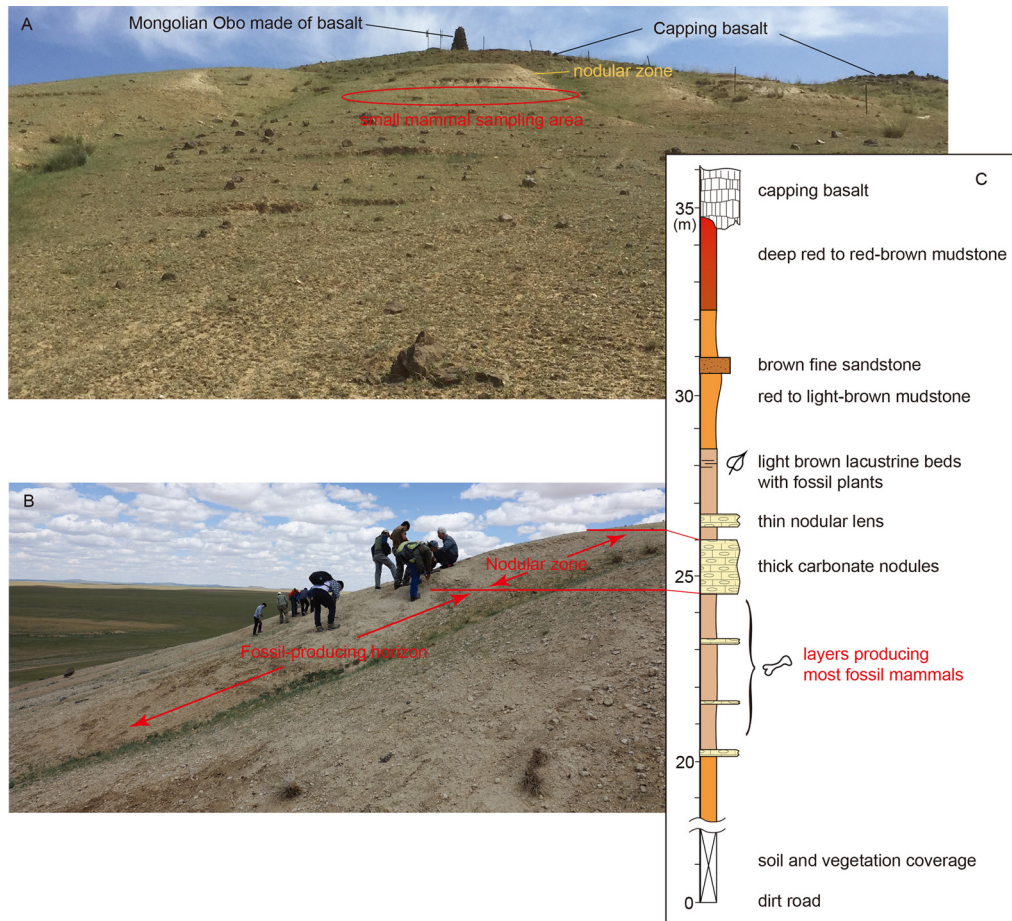

Fig. 3   Stratigraphic section of Halajin Hushu
A. photograph of Halajin Hushu section (photo looking southward and taken on August 4, 2015 by X. Wang);
B. closeup of exposures at fossiliferous horizon and a nodular zone immediately above (photo looking eastward and taken on June 18, 2018 by X. Wang); C. measured section of Halajin Hushu strata

of soil carbonates. The capping basalt is thin, about 1 m or less, and is extensively weathered. The basalt sheet dips southward, presumably following an ancient topographic surface of similar dip (assuming no post-depositional disturbance). As is the case in IM0708 loc (Wang and Li, 2011) and Aoerban (Wang et al., 2009), the Halajin Hushu bed also contains reworked taxa, presumably by transportation from older strata nearby (see Mammal assemblage below).

3   Mammal assemblage

The Halajin Hushu assemblage includes at least 63 forms in 17 families and 5 orders of mammals. Table 1 is a nominal list of the mammals recognized in the collection and numbers of the specimens yielded from the locality.

Eulipotyphla   Three families of the order, Erinaceidae, Talpidae, and Soricidae are represented in the sample. It is one of the richest insectivore assemblages in the Neogene of central Nei Mongol, both in taxonomic diversity and abundance of materials.

Erinaceidae are the most abundant insectivores in the collection despite their low diversity. Eleven hundred and forty-two isolated teeth, showing distinct variation in size, are identical to the hedgehogs reported as *Mioechinus*? *gobiensis* ranging from Aoerban of Early Miocene to Shala of early Late Miocene. An M2 and an M3 are referred to an indeterminate species of *Erinaceus*. The two molars are evidently larger than those of *M.*? *gobiensis* with a short crest connecting the strong protocone and the conical hypocone on M2, which are comparable to the fragments assigned to an indeterminate Erinaceinae from Moergen (Qiu, 1996). Further work may prove that records of *Erinaceus* should be earlier than expected.

The Talpidae include four forms belonging to two subfamilies, Talpinae and Desmaninae. One hundred and seventeen teeth are referred to *Yanshuella*, and 52 teeth to *Quyania* of Talpinae from Ertemte and Harr Obo of Huade (Storch and Qiu, 1983). In morphology, the Halajin Hushu *Yanshuella* is similar to *Y. primaeva* from Huade, but differs in having stronger cusps and crests, and the oblique crista extending more lingually on m1 (Fig. 4); the *Quyania* is similar to *Q. chowi*, but different in having more lingual extension of the oblique crista on m1–2. The development of cusps and crests, and the direction of oblique crista deserve further attention because of a lack knowledge of these characters. One hundred fifty-five isolated teeth can be identical as Desmaninae and referred to *Desmanella storchi* known from Moergen (Qiu, 1996). Forty-one teeth represent another talpine in this assemblage. On the basis of the relatively small size, presence of prominent conules on P4 and M1–2, and a lingual furrow between the protocone and protoconule on upper molars, and the oblique crista extending towards or connecting with the metastylid on lower molars, these teeth probably represent an undescribed talpine, but no generic assignment can be made at this time.

Shrews are the most diverse insectivores in the assemblage, and eight forms belonging to at least six genera of Soricidae are recognized. A large M1/2 with quadrate occlusal outline and wide hypoconal flange, and an m3 with low buccal reentrant valley and pronounced cingulum

Table 1   Taxa and specimen number (N) of the Halajin Hushu assemblage

Taxa	N	Taxa	N
Eulipotyphla		Zapodidae	
Erinaceidae		*Parasminthus tangingoli**	11
Mioechinus? *gobiensis*	1142	*P. parvulus**	5
Erinaceus sp.	2	*Eozapus major*	13
Talpidae		*Sinozapus parvus*	264
Yanshuella cf. *Y. primaeva*	117	*Sicista* sp.	257
Quyania cf. *Q. chowi*	52	*Heterosminthus orientalis*	931
Desmanella storchi	155	*Lophocricetus xianensis*	1119
Talpinae indet.	41	Zapodidae indet. 1	17
Soricidae		Zapodidae indet. 2	7
Mongolosorex sp.	2	Dipodidae	
Sorex cf. *S. minutoides*	12	*Protalactaga lantianensis*	4
Sorex ertemteensis	128	*Paralactaga shalaensis*	4
Petenyia cf. *P. katrinae*	28	Cricetidae	
Cokia kowalskae	19	*Alloeumyarion* sp.*	3
Paranourosorex cf. *P. inexspectatus*	171	*Democricetodon lindsayi*	8
Paenelimnoecus obtusus	2	*Plesiodipus leei**	10
Soricidae indet.	2	*P. progressus*	7
Chiroptera		*P. robustus*	4
Chiroptera indet.	1	*Gobicricetodon robustus*	5
Rodentia		*Gobicricetodon* aff. *G. flynni*	3
Ctenodactylidae		*Khanomys baii*	72
Tataromys sp.*	2	*Colloides xiaomingi*	8
Aplodontidae		*Colloides* sp. nov.	35
Ansomys borealis	9	*Kowalskia shalaensis*	233
A. lophodens	21	*Microtoscoptes* sp.	1
Pseudaplodon amuwusuensis	1	*Ischymomys* sp.	2
Sciuridae		*Epimeriones* sp. nov.	116
Tamias ertemtensis	339	Baranomyinae indet.	98
Spermophilinus sp.	13	Spalacidae	
Atlantoxerus sp.	5	*Pararhizomys qinensis*	3
Prospermophilus orientalis	76	Gerbillidae	
Hylopetes sp.	3	*Myocricetodon* sp.*	3
Gliridae		Myospalacidae	
Orientiglis wuae	227	*Prosiphneus qiui*	199
Eomyidae		Lagomorpha	
Leptodontomys gansus	405	Ochotonidae	
L. lii	52	*Desmatolagus* sp.	23
Keramidomys fahlbuschi	41	*Ochotona* sp.	364
K. magnus	254	Artiodactyla	
Castoridae		Moschidae	
Monosaulax tungurensis	10	Moschidae indet.	15
Castor sp.	1		

* presumed to be a reworked element.

demonstrate some similarities to the corresponding teeth of *Dinosorex* from Europe (Engesser, 1972), and to the m3 of *Mongolosorex qiui* from Moergen, which was named based on only lower dentition (Qiu, 1996). The two teeth are assigned to Heterosoricinae and referred to an indeterminate species of *Mongolosorex* due to slightly smaller size and scarce material. Soricinae, including five genera, are more common than the Heterosoricinae in the sample.

Sorex are identified by 140 specimens based on the pigmentary teeth with distinct posterior emargination on P4 and M1, the moderate development of entocristid (entoconid crests) on lower molars and the less reduced talonid on m3. Two species can be easily distinguished by size, the smaller one (n=12) is close to *S. minutoides* from Ertemte, except for the less cuspules on lower incisor; the larger one (n=128) to *S. ertemteensis*. Twenty eight specimens, including fragmentary maxilla and mandibles, are referred to *Petenyia* based on the P4 with anteriorly projecting paracone, strong longitudinal posterior crest of protocone, rectangular molars with narrow cingulum around the bases on M1–2, high entoconid closely positioned to metaconid on m1–2, and the m3 with rather reduced talonid. They are similar to those of *P. katrinae* from Bilike, but differ in smaller size and having wider postentoconid valley (Qiu and Storch, 2000). Nineteen specimens with the parastyle of P4 not particularly protruding anteriorly, rectangular M1–2 with very slight emargination, strong protocone and distinct metaloph, quadrate m1–2 with broad and inflated labial cingulid, prominent entocristid, and protoconid rather closed to metaconid indicate similarity to *Cokia kowalskae* from Ertemte and Harr Obo. One hundred and seventy-one specimens are identical as *Paranourosorex* cf. *P. inexspectatus*. They resemble those of *P. inexspectatus* from Ertemte, but having more distinct posterior emargination on M1, and four roots on M2, characters that may be indicative of more primitive status. *Paenelimnoecus obtusus* is represented by two mandibular fragments that possess the following characters: smaller teeth, lower molars lacking entocristid, protoconid closely situated to metaconid, and obvious reduction of talonid on m3. A mandibular fragment with m1–2 and an isolated m2 are referred to an indeterminate Soricinae. Lower molars in the two specimens are distinguished from others by the lack of entoconid and entocristid, which exhibit some *Allosorex*-like characters, but it cannot be identified below the family level.

Chiroptera   Only an M2 indicates the presence of bats; at present it is only identified to an indeterminate Chiroptera.

Rodentia   Rodents are the most diverse and abundant small mammals in the sample. Thirty-three genera belonging to 12 families (Ctenodactylidae, Aplodontidae, Sciuridae, Gliridae, Eomyidae, Castoridae, Zapodidae, Dipodidae, Cricetidae, Spalacidae, Gerbillidae and Myospalacidae) are recognized.

A P4 and an M3 represent the existence of Ctenodactylidae in the collection. In size and in having a complete protoloph and metaloph on P4, a V-shaped protocone, complete metaloph joining the posterocone, straight posterior arm of protocone (also known as entoloph), and shallow sinus on M3, the two specimens are similar to the corresponding teeth of *Tataromys parvus* commonly known from the Oligocene in Central Asia. They are assigned to an indeterminate species of *Tataromys* because of the scarce material, and are considered to be a mixed one, presumably due to the reworking of deposits of Oligocene or Early Miocene age.

Thirty isolated teeth are referred to the genus *Ansomys* of Aplodontidae on the basis of the brachydont cheek teeth with high cusps and crests, distinct mesostyle forming a handle-shaped flexure of ectoloph and single metaconule on upper molars, and the anteroposteriorly

compressed main cusps and crest-like metaconid on lower molars. Based on the poorly developed or absent mesoconid on lower cheek teeth, most specimens can be identified as *A. lophodens*, a more derived species in the genus mainly known from Amuwusu, Balunhalagen and Huitenghe of early Late Miocene, and a few as *A. borealis*, a relatively primitive species known from the Early and Middle Miocene (Qiu and Li, 2016). An m1/2 represents a large-sized mountain beaver in the assemblage, which is comparable in size and morphology to that of *Pseudaplodon amuwusuensis* from Amuwusu.

Five taxa of squirrels, including sciurids of different adaptive types, are recognized by size and morphology. Three hundred and thirty-nine isolated cheek teeth are referred to *Tamias ertemtensis*, the most frequent chipmunks known from the Early Miocene to Early Pliocene in central Nei Mongol. Thirteen specimens can be assigned to an indeterminate species of *Spermophilinus*, another larger chipmunk with heavier built, less convergence of protoloph and metaloph towards the protocone on P4–M2. *Spermophilinus* are never very frequent in the fossil record of central Nei Mongol, with their occurrence of *S. mongolicus* at Balunhalagen, Amuwusu and Bilutu of Late Miocene age. The added material seems to show somewhat heavier built in dentition than that of *S. mongolicus*. Five cheek teeth can be identified as *Atlantoxerus*, a genus of ground squirrels widely occurring in the early and middle Neogene of Palearctic Region. The taxon assigned to *Atlantoxerus* sp. in the sample can be distinguished from *A. exilis* and *A. major*, but similar to *A. orientalis* known from Moergen and Balunhalagen in smaller size, and having metaconule close or connected with the posteroloph (Qiu and Li, 2016). One maxillary fragment with M2–3 and 75 teeth are identical to *Prospermophilus orientalis* in size and in having prominent metaconule, protoloph and metaloph converging towards protocone on P4–M2, and ectolophid curving posterolingually on lower molars. *P. orientalis* is a relatively small ground squirrel known from several localities of Late Miocene and Early Pliocene in central Nei Mongol. Three molars are referred to an indeterminate species of *Hylopetes*. The only flying squirrel in the collection is characterized by its distinct entoconid, angular entoconid corner, anterolingually extending buccal valley, and crenulated enamel on surface. It resembles *H. bellus* from Balunhalagen in size and morphology.

Two hundred and twenty-seven isolated cheek teeth are identified as Gliridae. They can be all referred to *Orientiglis wuae* by small-sized cheek teeth with concave occlusal surface, relatively equal main ridges and accessory ridges in thickness, less frequent anterotropes and posterotropes, longer precentroloph than postcentroloph on M1–2, lingually free anteroloph in majority of M1, and presence of anterotropids and posterotropids on m1–2 (Fig. 4). The only species of dormouse in the sample is also known from Middle Miocene of Gansu, as well as from Early Miocene through Late Miocene in central Nei Mongol (Qiu, 2001b; Qiu and Li, 2016).

More than seven hundred specimens are referred to bunodont *Leptodontomys* and lophodont *Keramidomys* of Eomyidae. The two genera are common in several localities of early Neogene in central Nei Mongol, and as in European Miocene microfaunas they usually

occur in association. *Leptodontomys* is more frequent and can be assigned to a smaller species, *L. gansus* (n=405), with relatively weaker cusps and crests (Fig. 4) and a larger species, *L. lii* (n=52), with stronger cusps and crests. *Keramidomys* also can be distinguished by size and morphology. The smaller form is identical with *K. fahlbuschi* (n=41) and the larger with *K. magnus* (n=254).

Eleven isolated teeth represent two genera and two species of Castoridae, of which 10 are assigned to *Monosaulax tungurensis* and one to an indeterminate species of *Castor*. *M. tungurensis* frequently occurs in the Middle Miocene and the early Late Miocene in the Tunggur tableland. The added material is identical with those known from Moergen and Amuwusu in size and morphology, but with poor development of cement fill in the striae (ids). A P4 corresponds morphologically to the diagnosis of *Castor*, based on its large size, four flexi filled with thick cement, closure of flexi in distinctly different stages of wear. The premolar is close to that of *Hystricops mengensis* in size and structure, but differs in the hypostria and mesostria more extending to the bases of crown. In comparison with that of *C. anderssoni* from Ertemte, Bilike and Gaotege, the two striae show less extension, may be indicative of a more primitive status.

Zapodidae are the most abundant rodent family in the collection, and six genera and nine species are recognized. Sixteen specimens are referred to the genus *Parasminthus*, two species of which can be readily distinguished by size and morphology. The larger species (n=11) is identical with *P. tangingoli.* A mandible fragment with m1 and m2, and 4 isolated teeth can be comparable to that of *P. parvulus*, which show some similarities to *Plesiosminthus vegrandis* in size, but differ in being less lophodont. Both *P. tangingoli* and *P. parvulus* are known from Oligocene localities such as Taben-buluk, Gansu and Ulantatal, western Nei Mongol (Bohlin, 1946; Huang, 1992). It is noteworthy that *Parasminthus* is considered to survive in Central Asia into Early Miocene before becoming extinct, and no remain of the genus has been found in the Neogene of central Nei Mongol until now. Therefore, we consider the occurrence of *Parasminthus* in Halajin Hushu as another case of reworked fossils from older strata. Thirteen molars can be referred to *Eozapus major* based on their relatively simple molar structure and developed lophs, lack of mesocone(id), presence of strong mesoloph(id) and posteroloph(id)s, single protoloph on upper molars and metalophid on lower molars. They are similar to those of *E. similis* from Ertemte and Harr Obo, but larger in size with less strong lophs. The M2s in the assemblage correspond in all features with the type specimen of the species from Balunhalagen (Fig. 4). These materials afford a good understanding of the species *E. major*, which was named based on limited specimens (Qiu and Li, 2016). A mandible fragment with m1, and 263 isolated teeth are referred to *Sinozapus parvus*. In size and morphology, they are close to those from Balunhalagen, Amuwusu, Shala and Huitenghe, but smaller than those of *S. volkeri* from Bilike. Two hundred and fifty-seven molars are referred to *Sicista* sp. The indeterminate species of birch mice is larger than *S. prima* from Aoerban and Gashunyinadege, but smaller than *S. bilikeensis* from Bilike. It appears to represent a population morphologically

intermediate between the Early Miocene and the Pliocene taxa with moderately developed accessory spurs on molars, moderate amount of protoloph joining protocone or anterocone on M1, and transitional characters in the direction of hypolophid on m1 and the development of secondary ridges in posterosinusid on m1–2. *Heterosminthus orientalis* and *Lophocricetus xianensis* are recognized in the sample, by 931 and 1119 specimens, respectively. These two frequently co-occurring taxa are similar in general dental morphology. Those molars possessing the following features are here assigned to *H. orientalis*: smaller dimension, relatively long and narrow occlusal outline, weakly developed cusps, protostyle lacking or present as a posterolingual rib of protocone and long mesoloph on M1, frequent double anteroloph on M2, long-triangular M3, metaconid usually connecting to mesoconid on m1, double rooted m2 with poorly developed ectocingulid and distinct posterior arm of protoconid, otherwise to *L. xianensis* (Fig. 4). Twenty-four molars are referred to two indeterminate genus and species of Zapodidae by size and morphology. The smaller one, represented by 17 specimens, possesses features highly similar to *Parasminthus*: buno-lophodont molars with well-developed mesoloph(id)s, asymmetric sinus(id)s, single protoloph in M1, and single metolophid in m2–3, but can be easily distinguished from all known species of the genus by its small size. The larger one shares some characters with *Eozapus major*, but larger in size and relatively shorter and wider in occlusal outline. Further study may show these specimens to represent new taxa of Zapodidae.

Remains of Dipodidae are rather scarce, and only two genera and species, representing Allactaginae, are represented in the assemblage. Four cheek teeth are identified as *Protalactaga lantianensis* known from the early Late Miocene of Bahe in Shaanxi and Balunhalagen in Nei Mongol, based on its smaller size, uncompressed cusps anteroposteriorly, protoloph and metaloph joining respectively entoloph and posteroloph on M2, and hypolophid connecting with the middle of mesolophid on m2. Three P4s and one M1 are referred to *Paralactaga shalaensis* from Shala, representing another jerboa with large size, high crown, strong lophs and protoloph connected to the middle of mesoloph on M1.

Cricetidae are the most diverse rodent family in the sample, and at least 10 genera and 15 species including cricetids with buno-lophodont type and lophodont (microtoid) type cheek-teeth are represented in the assemblage. Three M2s are referred to an indeterminate species of *Alloeumyarion*, which are similar in morphology to the corresponding tooth of *A. sihongensis* from the Early Miocene Xiacaowan Formation of Jiangsu in having low crown and square occlusal outline, more prominent cusps than crests, slightly anterolingually-directed protoloph and transverse metaloph, short mesoloph, and straight entoloph connected with protoloph and hypocone, but smaller in size (Qiu, 2010). Eight molars are identical with *Democricetodon lindsayi*, a commonly known taxon from Early Miocene to early Late Miocene in Nei Mongol, in M1 and m1 having wide and simple anterocone(id) and medium or long mesoloph(id), M1–2 having metaloph connected with posteroloph, m1–2 lacking metalophid II, hypolophid joining with ectolophid. They fall within the range exhibited by the early Late Miocene populations
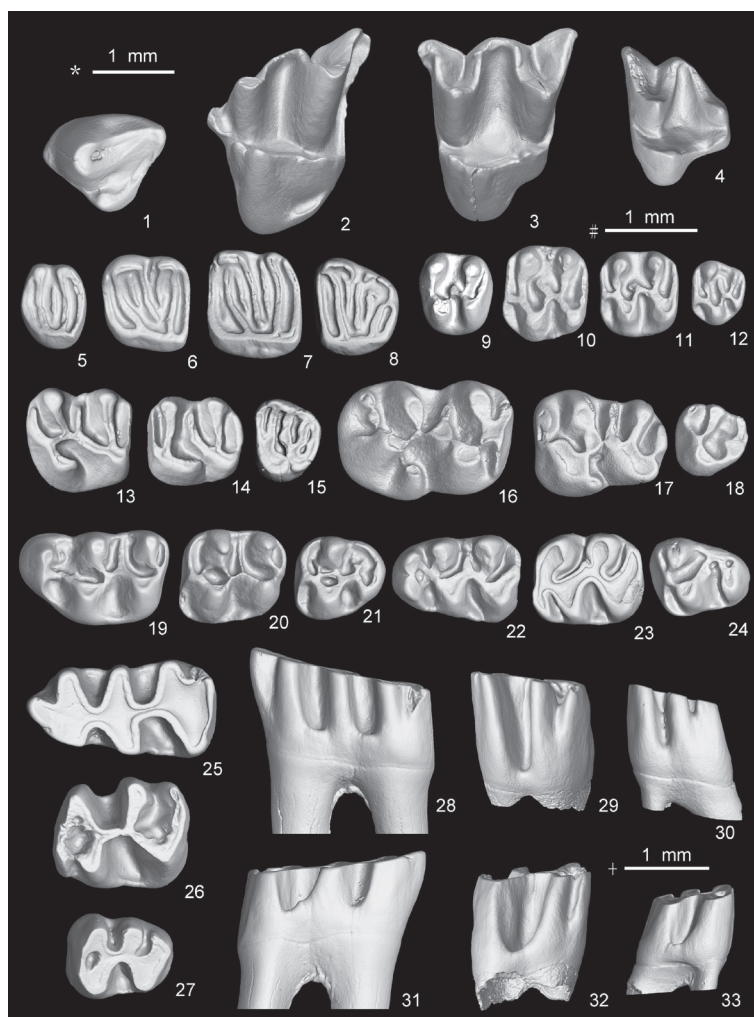
Fig. 4   Selected specimens of small mammals from Halajin Hushu
Yanshuella cf. *Y. primaeva* (1–4), left P4–M3; *Orientiglis wuae* (5–8), left P4–M3;
Leptodontomys gansus (9–12), left P4–M3; *Eozapus major* (13–15), right M1–M2 (reversed) and left M3;
Lophocricetus xianensis (16–18), left M1–M3; *Kowalskia shalaensis* (19–21), left M1–M3;
Colloides sp. nov. (22–24), left m1–m3; *Epimeriones* sp. nov. (25–33), left m1–m3;
1–27. occlusal view, 28–30. lingual view, 31–33. buccal view; scales: * for 1–4, # for 5–24, + for 25–33

from Amuwusu, Balunhalagen and Huitenghe as to size and morphology. Twenty-one molars
are referred to the genus *Plesiodipus* based on the absence of mesoloph(id), cusps and crests
aligned in three rows, and the presence of pronounced "medial diagonal ridge". Three taxa
of the genus can be readily distinguished by size and morphology. The smaller species
represented by 10 molars is identified as *P. leei*, which are frequent in the Middle Miocene
of central Nei Mongol, Xinjiang and Gansu (Qiu, 2001a; Wu et al., 2009; Qiu and Li, 2016).
All 10 teeth in the collection distinctly show signs of water erosions and we suspect that they
have been reworked. The medium-sized one (n=7) is similar to *P. progressus* from Tamuqin,
Balunhalagen and Bilutu (Qiu, 1996; Qiu and Li, 2016), in having more elongated cheek teeth

with more compressed cusps, more reduced protosinus of M1, narrower and shallower buccal valleys of lower molars. In respect of reduction of valleys, it is closer to those populations from Late Miocene than to the Middle Miocene. The largest one (n=4) is referred to *P. robustus* based on the large size, heavily built and lophodont molars with high crown and strong ridges, M1 with completely reduced protosinus and roughly "ε"-like ridges, m1 with single and thick anterolophulid. *P. robustus* is also known from the Late Miocene localities, Balunhalagen, Huitenghe and Bilutu. Eight molars are assigned to *Gobicricetodon* by their large size and buno-lophodonty, M1 and M2 with oppositely arranged main cusps, single protoloph and metaloph, and slightly anteriorly-directed sinus, M1 and m1 with simple anterocone(id) and short mesoloph(id). Two species of the genus are recognized, with the larger species *G. robustus* by five molars, and the smaller one *Gobicricetodon* aff. *G. flynni* by three m1s with weakly or undeveloped metalophid and mesolophid. Both are also known from Amuwusu, Balunhalagen and Bilutu. Seventy-two specimens, including two maxillary fragments with M1 and M2, represent the genus *Khanomys*. In morphology, they are roughly similar to *K. baii* from Amuwusu and Balunhalagen, and *K. cheni* from Shala, Huitenghe and Bilutu, but more similar to the former in less frequent presence of a circular lake-like posterosinus on M1–2, in having curved or smooth anterior wall on M1 and absence of protosinus on M2. Forty-three isolated molars are characterized by their relatively hypsodont cheek teeth with deep and narrow valleys, short or absent mesoloph(id)s, and undivided anterocone on M1, single and posteriorly-directed protolophs and metalophs on M1–2, slightly split anteroconid, single anterolophulid, metalophid and hypolophid on m1, lack of lingual anterolophid on m2–3, which correspond to the diagnosis of *Colloides* given by Qiu and Li in 2016. Eight molars can be referred to *C. xiaomingi*, the larger species from Amuwusu, Balunhalagen, Huitenghe and Shala by its more distinctly split anteroconid on m1, and the other thirty-five molars to a smaller form, probably representing a new species of *Colloides* (Fig. 4). *Kowalskia* is represented by 233 specimens, including 4 maxillary and mandibular fragments, on the basis of their smaller-sized cheek teeth with relatively long mesoloph(id)s, M1 having narrow and weakly divided anterocone, protoloph I and metaloph II present in the majority of the three-rooted M1–2, m1 having nearly undivided anteroconid and occasionally the ectomesolophid. The dental features in the specimens completely correspond to the diagnosis of *K. shalaensis* from Shala, except for the presence of a single anterolophulid in most of m1s (Fig. 4). *Microtoscoptes* is a genus possessing hypsodont molars with prismatic structure, which occurs in the Late Miocene of Eurasia. A lower m3 identified as an indeterminate species of the genus is comparable in size and in reduction of the posterior lobe to that of *M. fahlbuschi* from Balunhalagen, Bilutu and Baogeda Ula or the indeterminate species from Shala. On the basis of relatively large size, hypsodont prismatic and cementless, undifferentiated enamel walls, slightly alternating synclines/anticlines with tendency to form a rhombic dentine area in the middle of the occlusal surface, a mandibular fragment with m1–2, and an m3 are identified as an indeterminate species of *Ischymomys*. This genus is a rare microtoid rodent distributed

in the Late Miocene of Kazakhstan and Ukraine, as well as in Nei Mongol (Topachevsky et al., 1978; Qiu and Li, 2016). Two hundred and fourteen specimens represent two taxa of microtoid cricetids with semihypsodont molars and trilophodont M1. The first form, based on 116 molars, are referred to a new species of *Epimeriones*, representing the first record of the genus in Asia (Fig. 4). The taxon is similar to the type species *E. austriacus* from Eichkogel, Austria (MN 11) in possessing two lobes on M2–3 and m2–3, additional lingual distal sincline on m1, but differs in having narrower longitudinal enamel connected dentine areas on molars and more distinct additional lingual sinclines on lower molars, characters that may be indicative of a more primitive status. *Epimeriones* was originally treated as a gerbil and later as a "Muridae" incertae sedis (Daxner-Höck, 1972; Daxner-Höck and Höck, 2015). The possible assignment to Gerbillinae or "Muridae" incertae sedis is still under discussion (Fejfar, 1999; McKenna and Bell, 1997). It is likely that *Epimeriones* shows relatively hypsodont prismatic molars lacking cement in synclines, with flat chewing surface, dentine areas connected by longitudinal enamel or very narrow dentine bands, which demonstrates some *Microtoscoptes*-like characters. Further study may lead to the recognition of affinities of the microtoid cricetids to Microtoscoptinae. The second form, based on 98 molars, is assigned to Baranomyinae gen. et sp. indet. The taxon is somewhat larger than the *Epimeriones*, slightly lower crowned molars with two lingual and buccal synclines on M1, and three lingual synclines and two buccal synclines on m1. Morphologically, it is more or less similar to *Microtodon* from Asia, and "*Celadensis*" from Europe, but much larger in size, and in having distinctly narrower dentine bands connected dentine areas, and shallower posterosinusids on m1–2. All of these specimens probably represent a new species of *Microtodon* or new genus of microtoid cricetids, but generic assignment must await a further study.

Spalacidae are represented by only three isolated molars, belonging to the genus *Pararhizomys*. The taxon is characterized by its small size, lower crown, uprightly W-shaped occlusal surface of M1 and two-lobed M3 and m3. It is smaller than *P. hipparionum* from Baogeda Ula (Li, 2010), and all the species of *Pararhizomys* and *Pseudorhizomys* from Linxia Basin, Gansu (Wang and Qiu, 2018), but closely identical to *P. qinensis* from the Late Miocene Bahe Formation, in Lantian, Shaanxi (Zhang et al., 2005).

Three M1s showing wear by water are referred to an indeterminate species of *Myocricetodon*, which is more similar to *M. plebius* from the Quantougou Formation of Middle Miocene in Gansu than to *M. lantianensis* from the Bahe Formation of early Late Miocene in having single anterocone, less closer cusp-pairs and presence of an initial "new" longitudinal crest (Qiu, 2001b). These specimens represent the first record of *Myocricetodon* in central Nei Mongol.

Myospalacidae are recognized based on 199 specimens. These molars are similar to those of *Khanomys*, but larger in size, having very short or remnant mesoloph(id)s in early wear, and less developed protosinusid on m2–3. They are identical in size and morphology to *Prosiphneus qiu*, a primitive zokor commonly known from Amuwusu and Balunhalagen.

Lagomorpha   Lagomorphs are abundant small mammals in this sample, but only two genera, *Desmatolagus* and *Ochotona* of the family Ochotonidae can be recognized. *Desmatolagus* are mainly distributed in the Oligocene and Early Miocene of Central Asia. Twenty-three rooted cheek teeth may be represented the last record of the genus in central Nei Mongol, characterized by the unilateral upper P3–M3, P3 having anteroloph crossing about two-thirds width of the tooth and crescentic valley connecting to anteroexternal wall, P4 having developed anterobuccal and middle buccal elements, and P4–M2 having hypostria crossing more than one-third occlusal width. Three hundred and sixty-four cheek teeth are referred to an indeterminate species of *Ochotona* on the basis of their smaller size, rootless teeth, deep hypostria on upper molariform teeth, presence of a posteriorly directed process from the posteroloph on M2, nearly equal width of trigonid and talonid on lower molariform teeth, having two external and one internal cement-filled folds on p3. These specimens seem to be quite homogenous, but there is distinct variation in size and morphology. *Ochotona* are frequent in the Late Miocene faunas in central Nei Mongol. The taxon from Halajin Hushu, as well as those from Shala and Huitenghe of early Late Miocene age appears to be smaller than *O. lagreli* from the Ertemte Fauna of late Late Miocene in size.

Artiodactyla   Because of the limited exposures, the Halajin Hushu site produced only one identifiable large mammal, mostly through screening efforts. A species of musk deer (Moschidae) is represented by two complete and one partial upper molar, one complete and one partial lower molar, and 10 complete or partial lower premolars (Fig. 5). The upper molars show some resemblance to *Hispanomeryx*, but its short and compact p4 seems consistent with *Micromeryx*. Halajin Hushu moschid may represent an undescribed species (Israel M. Sánchez pers. comm.) and until a detailed analysis is performed, we conservatively treat it as Moschidae indet. The Halajin Hushu materials also appear to be different from that in Amuwusu (see below).

Three genera of moschids are commonly recognized: the extinct *Micromeryx* and *Hispanomeryx*, and the extant *Moschus*. All three have been recorded in the Neogene of Nei Mongol, although generic status of these records is evolving. Schlosser (1924) first named a species of *Moschus*, *M. grandaevus* from Ertemte, Harr Obo, and Olan Chorea, which is perhaps closest to the living musk deer clade (Sánchez et al., 2010). Shortly after, Teilhard de Chardin (1926) erected another species, *Moschus primaevus* (he also spelled it *M. primigenius* in the captions of his figures in plate V), from Huitenghe (Chiton-gol), which was reassigned to *Micromeryx* (Mennecart et al., 2019). Recently, Sánchez et al. (2011) established a third species, *Hispanomeryx andrewsi*, from Wolf Camp. Other, largely undescribed, moschids from Nei Mongol include *Micromeryx* throughout the Damiao section (Kaakinen et al., 2015; Sukselainen et al., 2017; Zhang et al., 2011) and *Micromeryx* sp. from Amuwusu (Wang et al., 2015), the latter being first mentioned in an unpublished master's thesis (Zhou, 1984). Although knowledge about Chinese moschids generally lacks behind its European counterparts, known records seem to indicate a comparable diversity and age range across

Eurasia (Aiglstorfer et al., 2018; Mennecart et al., 2019; Sánchez and Morales, 2006; Wang et al., 2015), but Europe lacks the latest records of "*Moschus*" in the latest Miocene to Pliocene of East Asia (Vislobokova and Lavrov, 2009).

Fig. 5   Selected specimens of moschids, Moschidae indet. from Halajin Hushu
Left upper molar (1–3), right upper molar (4–6), left m1/2 (7–9), right p4 (10–12), partial right p3 (13–15), and right p2 (16–18); 1, 4, 7, 12, 15, 18. buccal views; 2, 5, 8, 11, 14, 17. occlusal views; 3, 6, 9, 10, 13, 16. lingual views

4   Composition of micromammalian fauna

The Halajin Hushu sample is one of the most diverse and abundant Neogene fauna in China. Compared to well-documented faunas in central Nei Mongol and other part of northern China, the assemblage seems to consist of a relatively complete fauna of small mammals, and may be considered as a rather representative association for Nei Mongol and the time of its origin. Nevertheless, it is reasonable to suspect that the sample is a mixed assemblage containing elements that appears to "not belong" to Late Miocene. There seem to be two grounds for this conjecture. The first is because of dominant genera commonly known from the Late Miocene localities of central Nei Mongol (Amuwusu, Balunhalagen, Huitenghe, Shala, Baogeda Ula, Bilutu and Ertemte), and quite a number of genera recorded for the first time in Late Miocene, such as *Castor*, *Eozapus*, *Sinozapus*, *Lophocricetus*, *Paralactaga*, *Khanomys*, *Kowalskia*, *Microtoscoptes*, *Epimeriones*, *Pararhizomys*, *Prosiphneus* and *Ochotona*, etc. (Daxner-Höck, 1972; Qiu and Li, 2016). This seems to suggest that the real association (fauna) should be younger than Middle Miocene in age. However, the assemblage contains a few specimens of archaic genera which are considered to have become extinct by Early Miocene,

for example, *Tataromys* and *Parasminthus*. It is unlikely that the two genera lived through much of the Middle Miocene and survived into the Late Miocene without being detected in those strata in Nei Mongol. The second reason is that distinct traces of erosion or transportation are seen in some specimens (e.g. *Plesiodipus leei* and *Myocricetodon* sp.) recovered from the channel deposits, which are frequently known genera or species in the Middle Miocene localities (Tairum Nur, 346 RM, Moergen, Tamuqin), but unknown in the Late Miocene. This seems to indicate that the assemblage contains specimens reworked by water from underlying strata. Out of 62 taxa in the Halajin Hushu small mammal assemblage, we recognize the following 6 species of mixed age (reworked form older strata): *Tataromys* sp., *Parasminthus tangingoli*, *P. parvulus*, *Alloeumyarion* sp., *Plesiodipus leei*, and *Myocricetodon* sp., or about 10% of the total. Most of these taxa are represented by less than 10 specimens.

Reworked elements in an assemblage are easy to disturb consideration and age assessment of a fauna. Only those newcomers and prosperous taxa should serve as the true indicators of the depositional age. Thus, it is necessary to recognize contemporaries and tease out reworked elements. We prefer to consider taxa in this assemblage with the following characters as contemporaries: 1) forms only occurred or commonly known in the Late Miocene localities of central Nei Mongol, such as *Yanshuella*, *Quyania*, *Paranourosorex*, *Ansomys*, *Tamias ertemtensis*, *Orientiglis*, *Leptodontomys*, *Castor*, *Eozapus*, *Sinozapus*, *Sicista*, *Lophocricetus*, *Paralactaga*, *Plesiodipus progressus, Gobicricetodon robustus*, *Khanomys*, *Kowalskia*, *Ochotona*, etc; 2) new comers of Late Miocene, Zapodidae indet. 1 and 2, *Colloides* sp. nov., *Epimeriones*, Baranomyinae indet., for example. They are presumed to be true elements of the Halajin Hushu Fauna. However, those thriving in Oligocene and becoming extinct by Middle Miocene in the Asian Palearctic, i.e. *Tataromys*, *Parasminthus* and *Alloeumyarion*, and those predominant in the Middle Miocene faunas, but disappeared in the Late Miocene, such as *Plesiodipus leei* and *Myocricetodon* (specimens usually scarce and with traces of erosion or transportation) are here arbitrated to be elements from reworking of earlier strata, which should be rejected from the fauna (Table 1).
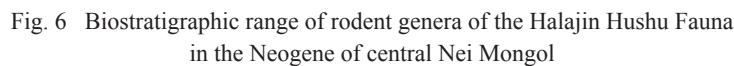
5   Biochronology

Among the 63 forms of mammals in the Halajin Hushu assemblage, 57 are considered as contemporary association derived from central Nei Mongol (Table 1). Although the list is a preliminary determination of the fauna, some tentative ideas on the aspects of biochronology, paleoecology and biogeography may be given.

The Halajin Hushu Fauna contains 43 genera, 56 species of contemporary small mammals, belonging to 15 families. The majority of the families and quite a number of genera are already present in the Middle Miocene and are distributed over Eurasia, but the age of the fauna cannot be Middle Miocene because of the appearance of the family Myospalacidae, as well as some genera first appeared in the Late Miocene, such as *Sorex* and *Paranourosorex*

in Insectivora, *Castor*, *Colloides*, and *Kowalskia* in Rodentia, and *Ochotona* in Lagomorpha. All the genera of the fauna, except *Epimeriones* are recorded in the Neogene of central Nei Mongol. Fig. 6 shows the generic occurrence of rodents of the fauna in the Neogene of this area. Among the 30 genera of rodents, half made their first appearance in Late Miocene, i.e. *Pseudaplodon*, *Prospermophilus*, *Hylopetes*, *Eozapus*, *Sinozapus*, *Lophocricetus*, *Khanomys*, *Colloides*, *Microtoscoptes*, *Pararhizomys* etc. The presence of these genera indicates an age of later than Middle Miocene for the fauna. Nevertheless, it is unlikely to be later than Late Miocene, because the families Arvicolidae, Muridae and Leporidae commonly known in Pliocene are absent from the fauna, and the Myospalacidae in this fauna are less diverse than those in Pliocene. This suggests that the age of the Halajin Hushu Fauna is younger than Middle Miocene but older than Pliocene.

Generally, the Halajin Hushu Fauna is characterized by the frequent retention of Middle Miocene holdovers, i.e. *Ansomys lophodens*, *Orientiglis wuae*, *Leptodontomys lii*, *Keramidomys fahlbuschi*, *Monosaulax tungurensis*, *Heterosminthus orientalis*, *Democricetodon lindsayi*, *Gobicricetodon robustus*, and highly specialized Middle Miocene survivors, e.g. *Plesiodipus robustus*, by the high diversity of Zapodidae, and the absence of Muridae, Leporidae, and some modern genera in Cricetidae, such as *Nannocricetus*, *Sinocricetus*, *Microtodon*, etc. The more retention of Middle Miocene holdovers, the high diversity of zapodids and the lacking of murids, leporids and modern hamsters in this fauna are indicative of an earlier age of the fauna in the Late Miocene.

According to the Chinese Neogene Land Mammal Stage/Age (LMS/A) proposed, the Late Miocene includes Bahean age and Baodean age (Qiu et al., 2013). In central Nei Mongol, the localities Amuwusu, Balunhalagen, Huitenghe and Shala are subordinated to the Bahean, while Baogeda Ula, Bilutu, Ertemte and probably Harr Obo to the Baodean (Qiu and Li, 2016). The following comparison of faunas may further demonstrate that the Halajin Hushu Fauna is closer to the Bahean faunas rather than the Baodean faunas. Although it shares quite a number of taxa with the Baodean Ertemte and Harr Obo faunas, such as *Yanshuella*, *Quyania*, *Sorex*, *Paranourosorex*, *Pseudaplodon*, *Tamias ertemtensis*, *Prospermophilus orientalis*, *Hylopetes*, *Leptodontomys gansus*, *Castor*, *Eozapus*, *Sinozapus*, *Sicista*, *Lophocricetus*, *Paralactaga*, *Kowalskia*, *Microtoscoptes*, *Prosiphneus*, and *Ochotona*, the Halajin Hushu Fauna lacks many Baodean newcomers that are very prosperous in the two faunas, such as *Myomimus*, *Dipoides*, *Paralophocricetus*, *Brachyscirtetes*, *Dipus*, *Nannocricetus*, *Sinocricetus*, *Microtodon*, *Anatolomys*, *Pseudomeriones*, and *Alilepus*. In addition, both the Ertemte Fauna and Harr Obo Fauna possess Muridae and Leporidae, and some genera, *Paralophocricetus*, *Microtodon* and *Micromys* for example, are rather dominant in the assemblages. This indicates that the Halajin Hushu Fauna is much older than the two faunas of Late Baodean age. The assemblage of Bilutu obviously contains elements reworked from earlier deposits. The presence of a relatively higher diversity of murids, and of more advanced genera and species, such as *Pliopetaurista*, *Lophocricetus grabaui*, *Dipus*, *Nannocricetus*, *Sinocricetus*, *Microtodon*,

Fig. 6   Biostratigraphic range of rodent genera of the Halajin Hushu Fauna
in the Neogene of central Nei Mongol

Anatolomys and *Pseudomeriones*, distinctly indicates that it is younger than the Halajin Hushu Fauna. Although the Halajin Hushu Fauna has *Sicista*, *Lophocricetus xianensis*, *Paralactaga*, *Kowalskia shalaensis*, *Microtoscoptes*, *Prosiphneus*, *Pararhizomys*, and *Ochotona* in common with the Baogeda Ula Fauna, the absence of Muridae and Leporidae, and the lack of some forms that also occur at Ertemte, i.e., *Myomimus*, *Dipoides*, *Brachyscirtetes*, *Dipus*,

Nannocricetus, *Sinocricetus*, *Microtodon*, etc., imply that the Halajin Hushu fauna is still older than these Baodean faunas. In general, the Halajin Hushu Fauna shows a close community structure and taxonomic composition with the Bahean faunas, containing relatively more genera frequently seen in Middle Miocene and fewer taxa in Late Miocene. Among the small mammals, 17 genera and 15 species occur in the Amuwusu Fauna, 21 genera and 21 species in the Balunhalagen Fauna, 14 genera and 11 species in the Huitenghe Fauna, and 15 genera and 11 species in the Shala Fauna, respectively (Qiu and Li, 2016). This seems to present a substantial evidence for the Bahean age of the Halajin Hushu Fauna. As far as the lacking of Muridae and the advanced genera of Cricetidae is concerned, the fauna is closely similar to the Amuwusu Fauna, but the presence of more derived species, i.e., *Protalactaga lantianensis* and *Paralactaga shalaensis*, and the absence of *Pentabuneomys* and *Hystricops* appear to suggest that the Halajin Hushu Fauna may be slightly younger than the latter. On the other hand, the occurrence of *Sinotamias gravis*, *Paralactaga parvidens*, *Salpingothus*, *Cardiocranius*, *Khanomys cheni*, *Microtocricetus*, and *Progonomys* in the Shala Fauna may be indicative of a younger age than the Halajin Hushu Fauna. Thus, the fauna is considered to represent a stage of faunal evolution intermediate between the Shala Fauna and the Amuwusu Fauna in central Nei Mongol.

Outside Nei Mongol, the Halajin Hushu Fauna has in common with the early Late Miocene Bahe Fauna in Shaanxi Province the genera *Pseudaplodon*, *Tamias*, *Protalactaga*, *Paralactaga*, *Lophocricetus*, *Kowalskia* and *Pararhizomys*, but contains more survivors from the Middle Miocene and lacks Muridae and some genera frequently occurred in higher horizons, e.g. *Sciurotamias* in Sciuridae, *Salpingothus* and *Cardiocranius* in Dipodidae, *Nannocricetus* in Cricetidae, and *Abudhabia* in Gerbillidae (Qiu et al., 2004a, b). This testifies to an older age of the Halajin Hushu Fauna than the Bahe Fauna. The Shengou Fauna from Qinghai Province is considered to be another early Late Miocene fauna in China, which was thought to be close to but slightly younger than the Bahe Fauna in age due to the content of co-genera and the presence of more derived murid *Huerzelerimys* (Qiu and Li, 2008). Thus, the Nei Mongol fauna is even earlier in age than the Qinghai fauna. Other Late Miocene faunas in China, such as the Lingtai Fauna in Gansu, and the Lufeng and Yuanmou faunas in Yunnan, share few congeners with the Halajin Hushu Fauna (Ni and Qiu, 2002; Zheng and Zhang, 2000). These faunas contain abundant murids and leporids, which should be younger than the Nei Mongol fauna. The Halajin Hushu Fauna has at least 11 genera, *Tamias*, *Spermophilinus*, *Keramidomys*, *Leptodontomys*, *Castor*, *Eozapus*, *Democricetodon*, *Kowalskia*, *Ischymomys*, *Epimeriones*, and *Ochotona*, in common with European Late Miocene faunas, among which *Democricetodon* made its last occurrence in the MN 9 in Europe.

In summary, the age of the Halajin Hushu Fauna is likely of early Late Miocene, and of Bahean Chinese Land Mammal Stage/Age, or roughly equivalent to MN 9–10 of European land mammal zonation (Fig. 6).

6   Biogeography and paleoecology

Among the 15 families of small mammals known from the Halajin Hushu Fauna, most are eurytopic, spreading throughout the Old World and the New World. These are Erinaceidae, Talpidae, Soricidae, Aplodontidae, Sciuridae, Eomyidae, Castoridae, Zapodidae, Cricetidae, and Ochotonidae. Gliridae and Spalacidae are distributed over Eurasia and North Africa. Only Myospalacidae and Dipodidae are endemic to northern Asian Palearctic Region. At the genus level, more than half are confined to the Mongolian highland and its adjacent regions. Few are recorded from the Late Miocene of other areas of Asia (only *Kowalskia* in Yunnan), or from North America (*Monosaulax* and *Castor*) or Africa, but quite a number of genera, *Tamias*, *Spermophilinus*, *Hylopetes*, *Leptodontomys*, *Keramidomys*, *Castor*, *Eozapus*, *Sicista*, *Democricetodon*, *Kowalskia* and *Epimeriones*, occur in Europe, accounting for about one fifth of the total. This suggests dispersal of small mammals to some extent between the two contiguous continents during the Late Miocene, as shown by the other contemporary faunas in central Nei Mongol.

In the mammals known from the Halajin Hushu locality, all the families except Eomyidae are extant. Among the extant families, Erinaceidae, Talpidae, Soricidae, Sciuridae and Cricetidae are eurytopic, others occur today either throughout the Holarctic Region (Castoridae and Zapodidae), or the Palearctic Region (Gliridae, Dipodidae and Myospalacidae), or the Nearctic Region (Aplodontidae), but none of the family is confined to the Oriental Region. The diversity and abundance of zapodids and cricetids, the presence of dipodids, and the flourishing of myospalacids and ochotonids in the fauna are indicative of a predominance of dry and open habitats in central Nei Mongol during the Early Miocene. It is evident that faunal composition of Halajin Hushu shows a temperate, relatively arid steppe environment, similar to the present northern Holarctic Region, as the other Bahean faunas in central Nei Mongol. Nevertheless, remains in this assemblage show that the present-day environment is not completely analogous to the Late Miocene. Relatively permanent water bodies are indicated by fossil fishes and frogs. The presence of beavers fit into such an environment. Judging from their living relatives, *Ansomys*, *Pseudaplodon*, *Hylopetes* and *Eozapus* would require dense thickets of shrubs, even forests. Modern moles also prefer moist shrub habitats and friable soils. The area of deposition of the fossiliferous sediments must have been more diversified in early Late Miocene time than it is today. The climate might be less dry, and the vegetation more dense than today.

It is worth mentioning that the high diversity of Zapodidae and Cricetidae, and the thriving and increasingly high-crowned Cricetidae (e.g. *Epimeriones* sp. nov., Baranomyinae indet.) in the assemblage are distinctive in the faunas of Bahean age. The faunal turnover seems to bear out again an environmental change towards drier and more grassland condition from Middle Miocene to Late Miocene. It is reasonable to infer that with the ecological and environment deterioration happened in early Late Miocene of central Nei Mongol, plant-eating animals rapidly increased and herbivores increased their crown height for adaptation to abrasive diets.

内蒙古哈拉津胡舒晚中新世动物群

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摘要：过去40年，在内蒙古中部地区的陆相新近纪化石地点中应用了筛选技术，采集到大量标本，这些发现迅速填补着晚新生代动物群演替和生物年代学认识的空白。在把孤立的化石组合按时代先后进行排序和建立动物群序列框架中，小哺乳动物的发现和研究发挥了至关重要的作用。报道了另一个产自哈拉津胡舒地点的晚中新世动物群，这个动物群再次展示了蒙古高原上令人"叹为观止"的化石种类和丰度。新地点位于该地区的最北部，并为玄武岩所覆盖，产出的标本计有7000余件，代表大、小哺乳动物达63种。虽然这一动物群混杂了少量下部层位的属种，但它不失为内蒙古中部地区一个较为真实地反映晚中新世小哺乳动物组成和生态环境的动物群。初步分析表明，哈拉津胡舒动物群属中国陆生哺乳动物年代的晚中新世早期的灞河期，可能比阿木乌苏动物群稍晚，但比沙拉动物群略早。

关键词：内蒙古哈拉津胡舒，中新世灞河期，小哺乳动物，岩石地层

中图法分类号：Q915.873   文献标识码：A   文章编号：1000–3118(2021)01–0019–26

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