

Dating vertebrate microfaunas in the late Neogene record of Northern China

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Abstract

Chinese paleontologists have ordered Neogene strata in time on the basis of their contained fossils, small mammals in particular, but biochronology alone attains limited accuracy in a biogeographically restricted system. The chronology of terrestrial sediments can be refined when sound systematics of the contained fossils is combined with paleomagnetic data. The geomagnetic polarity time scale has proven to be a useful independent reference system for dating the biochronology of continental deposits in North China. Long composites of successive microfaunas, with faunal correlation at times of low endemism, and age estimation through paleomagnetic correlation, yield robust biochronologies that are well constrained in time. The Yushe Basin (Shanxi Province) sequence, which has magnetostratigraphic control, provides a key reference for the late Neogene of North China.

Data from Yushe Basin identify the microfauna characteristic at the time of the Miocene/Pliocene boundary in northern China. The assemblage from near the village of Jiayucun strongly resembles the rich microfauna of Ertemte, Inner Mongolia, and occurs at the base of a reversed magnetozone correlated with Chron C3r (early Gilbert Chron), latest Miocene. Successive Pliocene age assemblages from Yushe Basin resemble the Jingle and Youhe local faunas, which were formerly used as reference faunas for North China. Nihewan-like assemblages are correlated with the Matuyama Chron, some being pre-Olduvai Subchron, and therefore Pliocene in age by current definition. Later Pleistocene time is represented in Yushe Basin by fossil sites in loam deposits. The well-known loess sequence of central China, and other Plio/Pleistocene reference faunas yield a date of ca. 1 Ma for a reddish loam microfauna from Yushe Basin. © 1997 Elsevier Science B.V.

1. Introduction

In China, terrestrial deposits are widespread, assemblages span long intervals yielding a fairly dense fossil record but with high endemism, and few instances of independent dating are now available. The endemism and lack of absolute dates pose a difficult problem in precise dating of the biochronology, however well it is refined by a dense fossil record. Methods of dating that are

independent of the terrestrial vertebrates, be they radioisotopic, paleomagnetic, or by superpositional constraints from marine deposits, are essential checks on the local chronology, and when employed in tandem with fossils, can offer a scale of precision that the vertebrates alone cannot. In China, marine deposits are few and radioisotopic dates are rare, exceptions being the early Miocene localities Shanwang and Sihong (Xiacowan). Paleomagnetic characteristics of fossiliferous rocks

are useful when sufficiently well constrained through biochronology. Magnetic data offer one line of independent dating, when related fossils render them unambiguous.

Before dating, a biochronology can be built by seriation; i.e., arranging faunas in time, based on their contained taxa. Confidence in the seriation increases when phylogeny is well understood and multiple taxa are employed (see discussion in Flynn et al., 1995). The paucity of elements, especially species, shared by China and areas to the west through most of the Cenozoic has led to great difficulty in applying the biochronology of Europe in China. Chinese paleontologists have proceeded to seriate Neogene faunas and recognize biochrons based on them (Chiu et al., 1979; Li et al., 1984; Qiu, 1990; Qiu and Qiu, 1995; Tong et al., 1995), independent of other biochronologic schemes. Within the framework of Chinese biochronology, it is then possible to equate local biochrons with those from other biogeographic regions, for example MN zones. Herein, we prefer to refine the biochronology for North China without reference to MN zonation.

Biochrons remain poorly dated without reference to an external system. One means of dating is by widespread exotic taxa. A classical example is immigration from North America of the horses *Hipparion* and *Equus*, which appear dramatically in the late Miocene and late Pliocene, respectively. Immigrants appearing at times of decreased endemism offer more precise biochronologic dating. Given biochronologic constraints on the ages of rocks, precise dating can be achieved through magnetostratigraphy. For northern Asia, the most fruitful approach to dating terrestrial deposits is a marriage of biostratigraphic and paleomagnetic data. The magnetic time scale used herein is that of Cande and Kent (1995).

2. Chinese late Neogene faunas

China has a wealth of long stratigraphic sections, many of which are under study and a few of which are being sampled for magnetic stratigraphy. In combination with biochronology, magnetic reversal stratigraphy has the potential to resolve

dating within a biogeographic province on the scale of 10^5 yr (see Flynn et al., 1990, for discussion of magnetostratigraphic resolution of the Siwalik Group of the Indian subcontinent).

Qiu (1990) summarizes the biostratigraphic work undertaken in China this century and presents the rationale behind the development of local Neogene biochrons. At least for later Neogene history, it is clear that North China and South China represent different biotic provinces (Chiu et al., 1979; Qiu, 1996) and that the province including North China extends through Mongolia and southern Siberia to eastern Kazakhstan (Tedford et al., 1991). North China contains a rich Miocene record of vertebrate evolution (see Fig. 1), but the chronology of Miocene faunas remains imprecise.

The history of terrestrial faunas in northeastern Asia was incompletely known well into the second half of this century. Other than the *Hipparion* faunas and Pleistocene assemblages, the roots of the modern fauna seemed enigmatic. Work by Teilhard and Piveteau (1930) in northern Hebei Province suggested that their Nihewan fauna likely was intermediate in age to *Hipparion* and Pleistocene faunas, but this could not be resolved for lack of superposition of assemblages. Licent and Trassaert (1935) saw Yushe Basin in southeastern Shanxi Province as a sort of “Rosetta Stone,” because they recognized demonstrably superposed faunas of “*Hipparion* red clay” type, intervening assemblages, and overlying Nihewan type (their Zones 1, 2 and 3). These faunas were thought to have chronostratigraphic value (explicitly so in Teilhard and Trassaert, 1937, under the rubric Zones I, II, III). The general temporal relationships perceived for the Yushe zones were accurate, although their contained faunas were incompletely known and poorly constrained in time.

The many late Miocene localities in China record high faunal diversity and long term faunal stability. These include Yushe assemblages considered Zone I, but are typified by a set of local faunas around Baode in northwestern Shanxi Province, which characterize the Baodean age and represent most of late Miocene time. In building a mammal biochronology for China, Li et al.

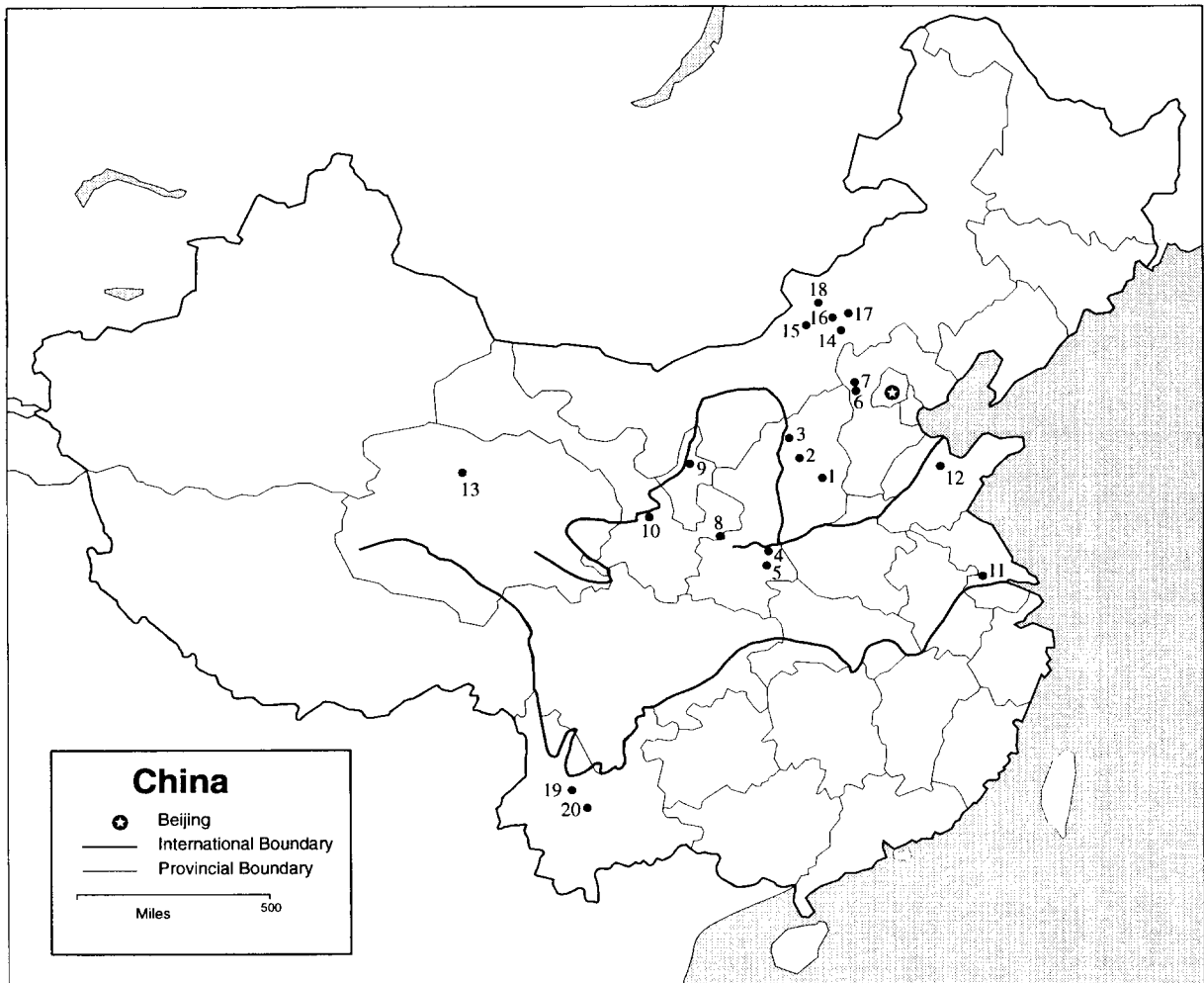


Fig. 1. Location map for Neogene localities discussed in the text. 1 Yushe; 2 Jingle; 3 Baode; 4 Youhe; 5 Bahe; 6 Daodi; 7 Xiashagou; 8 Lingtai; 9 Wuzhong; 10 Lanzhou; 11 Sihong; 12 Shanwang; 13 Qaidam; 14 Ertemte; 15 Harr Obo; 16 Tunggur; 17 Bilike; 18 Amuwusu; 19 Yuanmou; 20 Lufeng. As references in the interior of China, the Yellow River to the north and Yangtze River to the south are shown.

(1984; our Fig. 2) recognized two Pliocene biochrons, an older Jinglean and younger Youhean. The earliest Pleistocene was thought to be represented by the fauna collected near Nihewan in Hebei Province. Qiu (1990) agreed generally, but recognized a Miocene fauna that was stable over a very long time (his Mammal Unit IV). He considered the faunal succession around Gaozhuang (Yushe Basin) to represent early Pliocene time (Mammal Unit V) better than the isolated locality of Jingle, and he associated Youhe with Nihewan

(Xiashagou, *sensu stricto*) in his Mammal Unit VI. Qiu and Qiu (1995) utilize reference faunas, rather than the more abstract Mammal Units. They designate Baodean, Yushean and Nihewanian biochrons that correspond in most essentials to Mammal Units IV–VI, but their Nihewanian straddles the Pliocene/Pleistocene boundary and includes part of what previously was included in a Youhean biochron.

Such ordering of faunas is robust because faunal differences are strong and correlated mainly with

A

EPOCH	MAMMAL AGE	
	Li, Wu, & Qiu 1984	Qiu & Qiu, 1995
Pleist.	Nihewanian	Nihewanian
Pliocene	Youhean	Yushean
	Jinglean	
Miocene	Baodean	Baodean

B

EPOCH	TEILHARD TRASSAERT ZONES	FORMATION
Pleist.		Loess
Pliocene	Zone III	Haiyan
	Zone II	Mazegou
Miocene		Gaozhuang
	Zone I	Mahui

Fig. 2. Relationships of (A) mammal age biochrons and (B) Yushe Basin stratigraphic units to epoch boundaries. The biostratigraphic zonation of Teilhard and Trassaert (1937) was based on Yushe stratigraphy. These provide the basis for revision of the late Neogene biochronology of Li et al. (1984). In (B) dashes indicate imprecision in zone boundaries; wavy lines indicate unconformities.

the passage of time. The reference faunas are widely scattered over the last 7 m.y. As other assemblages are interpolated into this seriation

(e.g., Zheng and Li, 1990; Zheng, 1994), the ordering becomes less robust, because the assemblages are closer in age with fewer faunal differences. The rich and classic Ertemte microfauna of Inner Mongolia illustrates this point. It is generally considered late Miocene Epoch, but apparently postdates the local faunas around Baode. How much younger Ertemte may be has been unclear (Fahlbusch et al., 1983; Qiu, 1990; Repenning et al., 1990).

The Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) recognized Yushe Basin, Shanxi Province, as the best area to develop a precise, datable, late Neogene biostratigraphy for North China. Over a series of field seasons, and later with American colleagues, especially Profs. Richard H. Tedford and Neil D. Opdyke, a refined biostratigraphy was tied to a paleomagnetic section, which significantly modified the perceived biochronology of North China.

2.1. Yushe basin biostratigraphy

Qiu et al. (1987) and Qiu (1987) presented the fruits of the initial phases of research by IVPP in the Yuncu subbasin, one of the components of the complex Yushe Basin, including its rich fauna and local stratigraphy. The adopted lithostratigraphic nomenclature differs from that of Cao et al. (1985) for the neighboring Zhangcun subbasin to the south, because the different sedimentary sequence of that area originated under independent depositional conditions. This work also laid much of the paleobiological systematic foundation for general biochronologic correlations. The Yushe large mammal fauna was dominated by deer, antelopes and gazelles, by hipparionine horses and elephant-like proboscideans, and by hyaenid and felid carnivores. Small mammals included shrews and moles, the pika *Ochotona* and at least one hare, flying and ground squirrels, gerbils, hamsters, mice, voles, and the ubiquitous gopher-like zokors (myspalacines such as *Prosiphneus*). The small mammals are under study, and published in part in Wu and Flynn (1982), Flynn (1983), Flynn et al. (1991), Flynn and Wu (1994), Xu (1994), Zheng (1994) and Daxner-Höck et al. (1996).

The Yuncu subbasin includes over 800 m of

mainly fluvial deposits filling a large river valley cut in non-marine Triassic sediments. Fossil vertebrate horizons are numerous but vary in richness. Colluvial debris is succeeded by fluvial deposits consisting of loosely consolidated sands and silts with gravel units. The clay component increases upward and the 200 m sequence is capped by a resistant lacustrine mud. This basal cycle in the Yuncu subbasin constitutes the Mahui Formation. It is only moderately fossiliferous, with the coarse basal 50 m being virtually barren. Its large mammal assemblages include the last records in North China of the browsing horse *Sinohippus*, the hyaena *Acerocuta*, and the bear *Indarctos*, the first North China elephantine mastodont, *Stegodon*, and diverse pigs, giraffes and deer. The common Mahui gazelle is *Gazella gaudryi*. Small mammals include a pika and hare, squirrels, dipodoids, the gerbil *Pseudomeriones*, the hamster *Neocricetodon*, the zokor *Prosiphneus murinus*, and the first record in North China of true mice (see table in Flynn et al., 1991).

In the Yuncu subbasin, the Yushe sequence continues with the superposed Gaozhuang Formation, 400 m thick and with a disconformable (locally unconformable) basal contact. This formation includes three fining upward units that we designate the Taoyang, Nanzhuanggou and Culiugou Members. The thick (240 m) Taoyang Member is poorly fossiliferous; the others are productive throughout. Large mammal fossils include advanced hipparionine horses, various new deer and antelope, the appearance of *Pliohyaena*, and early Eurasian records of camelids and canids. Small mammals are well represented higher in the formation. There are shrews and moles, and probably two hares, *Alilepus* and a form like *Hypolagus* that we have referred previously to *Trischizolagus*. The microfauna is characterized by different species of genera present in the Mahui Formation and first records of the bamboo rat *Rhizomys shansius* and the murine *Chardinomys* and, higher in the sequence, two voles. Because the Yuncu record is poor in microfauna low in the Gaozhuang Formation, we failed, until recently, to identify a local assemblage that closely resembled the well known Ertemte microfauna.

The succeeding 200 m thick Mazegou Formation

is lithologically distinctive in its greater amounts of clays and thinner fining-upward sequences. The Mazegou Formation appears to rest conformably on the Gaozhuang Formation, but a hiatus is implied at the basal contact by magnetic data. The fauna of this unit resembles that of the upper part of the Gaozhuang Formation, but contrasts at the species level. Notable first appearances are *Felis*, *Lynx*, *Homotherium*, *Vulpes*, *Canis*, *Dama*, *Rusa*, several bovids and the mammoth *Archidiskodon*. Small mammals are diverse, including the first record of *Ochotonoides*, several squirrels, the last local record of *Rhizomys*, advanced hamsters and zokors, several murines and a derived *Mimomys*. The latter taxon, a vole, was compared with *M. orientalis* by Flynn et al. (1991), but larger samples now available show the Mazegou species to be *Mimomys (Cromeromys) irtyshensis*.

There is an angular unconformity between the horizontal Haiyan Formation and the underlying Mazegou Formation. The fauna of this 80 m thick, partly lacustrine unit differs greatly from that of the Mazegou Formation (see Flynn et al., 1991, for a discussion of relative faunal change in the Yushe sequence). Zokors with ever-growing cheek teeth, modern hamsters (*Cricetulus* and *Phodopus*), *Marmota*, the vole *Borsodia chinensis*, and advanced species of Mazegou genera (e.g., *Mimomys (Cromeromys) gansunicus*, *Chardinomys nihowanicus*) distinguish the small mammals. The modern horse *Equus* and carnivores *Cuon* and *Megantereon* are notable. Giant deer and large bovids (*Bison* and the takin *Budorcas*), appear in the Haiyan Formation.

Reddish deposits blanketing the Yushe Group and termed variously as loess or loam, yield small mammals of dominantly modern aspect, including the shrew *Crocidura*, the advanced zokor *Youngia epitingi*, the vole *Microtus brandtioides*, the living hamster *Cricetulus barabensis*, and an extant mouse *Apodemus* sp. A late record of the murine *Chardinomys nihowanicus* represents an interesting archaic element in this assemblage.

2.2. Magnetostratigraphy and correlations

Being dominantly normally magnetized, the Mahui Formation is considered to have been

deposited during later chron C3A (formerly Chron V). The upper part of the formation is richest in fossils, which places most of them, including *Stegodon* and *Prosiphneus murinus*, at about 6 Ma. The overlying Taoyang Member of the Gaozhuang Formation is mainly reversed, which corresponds to Chron C3r (the older portion of the Gilbert Chron). Fossils are not abundant, but important latest Miocene first occurrences are the camel *Paracamelus* and two lineages of Canidae from North America, and the bamboo rat *Rhizomys* from southern Asia. In Yushe Basin, the time of the Miocene/Pliocene boundary corresponds to moderate faunal turnover (Flynn et al., 1991), including replacement of *Gazella gaudryi* by *G. blacki*.

The early Pliocene Nanzhuanggou and Culiugou Members of the Gaozhuang Formation are much more fossiliferous than underlying strata and include first occurrences of the hare *Hypolagus* from North America, the modern bear *Ursus*, and rodents *Germanomys* and *Mimomys*, from western or northern Asia. The reversed Chron C2Ar (later portion of Gilbert Chron) is not recorded in our interpretation, which is part of the rationale for recognizing a significant hiatus at the disconformable contact with the overlying deposits.

In our interpretation, the dominantly normally magnetized Mazegou Formation is correlated with Chron C2An (Gauss chron), except that most of its younger normal magnetozones is missing. The pika *Ochotonoides* appears at circa 3.5 Ma and the mammoth *Archidiskodon* at circa 3 Ma on the Cande and Kent (1995) time scale. The succeeding Haiyan Formation is mostly reversely magnetized. Its correlation to the magnetic time scale is Chron C2r (early Matuyama), late Pliocene, which is consistent with records of the local zokor *Youngia tingi* and of the immigrant pre-Pleistocene large mammals *Equus* and *Bison*.

The composite Yushe Basin polarity sequence contains enough character in relative lengths of magnetozones to suggest correlation, assuming relatively constant depositional rates. The basal normal couplet is Chron C3A, the dominantly reversed portion with short normals equals Gilbert, the dominantly normal Mazegou Formation is Gauss, and the reversed Haiyan is Matuyama. The

superposed magnetozones constrain each other in possible correlations, but it is reasonable to query why the ends of the sequence are correlated as they are. Faunal data limit the possible correlations.

The fauna of the Mahui Formation includes advanced hipparionine horses and other elements that demonstrate faunal similarity with Baode and general correlation to the late Miocene Turolian faunas of western Asia and Europe. For example, late Miocene Palaeartic index fossils found at Yushe include the hyaenas *Adcrocuta* and *Ichtherium*. Furthermore, Mahui and overlying sediments yield *Stegodon*, bamboo rats and murines, which are not recorded at Baode and which we interpret as evidence consistent with an age younger than that of typical Baode assemblages. The correlation to Chron C3A is corroborated strongly by the Taoyang Member records of Canidae and Camelidae. It is unreasonable to assign an age older than basal Gilbert Chron to the Taoyang Member, and unreasonable to assign an age in excess of Chron C3A for the Mahui Formation, given the strong faunal similarity between the two units (see Flynn et al., 1991).

Correlations of short magnetozones may be suspect in individual cases, but these are not likely to cause gross misalignment of the composite, due to the relatively great thickness of the Yushe sequence. We see lithological evidence for breaks in deposition, which we interpret to truncate some magnetozones. Toward the top of the sequence, in the reversely magnetized Haiyan Formation, the index fossil *Equus* appears, which nowhere in Eurasia is known in excess of circa 2.6 Ma (see Lindsay et al., 1980), meaning that the Haiyan Formation could not be pre-Matuyama. It is reasonable to postulate and test a correlation of the Haiyan Formation to post-Olduvai Matuyama, especially because some workers (e.g., Zheng and Cai, 1991) consider Nihewan faunas to be Olduvai or younger equivalents. Presently, we rule this correlation out based on absence in the Haiyan Formation of *Allophaiomys*, a small mammal indicator of Pleistocene (Olduvai and younger) age (Repenning, 1992), and on faunal correlation to Danangou in the Nihewan area, where an assem-

blage like that from Haiyan is correlated with the earlier Matuyama subchron (Du et al., 1995).

2.3. The end of Miocene time

Continued work in the region south of the town of Yushe (Tancun subbasin) yielded two rich microfaunas in the early Gilbert Chron, at just the time when our Yuncu record suffered from poor sampling. The greatest concentration of fossils in the area we studied was high in the section, particularly around the village of Jiayucun, a locality known to Young (1927). Magnetic polarity data (Fig. 3) show the lower half of the section to be normally magnetized, the upper half reversed. Coupling this observation with the fauna, we consider the lower strata to have been deposited during Chron C3A and coeval with the Mahui Formation. At Jiayucun, where the rocks are reversed, there is no apparent depositional hiatus. We thus interpret these strata as earliest Gilbert Chron (latest Miocene), equivalent to basal Gaozhuang Formation. The area around the small

village Dengyucun, ca. 7 km south of Jiayucun, also yields a good microfauna, and occurs just above an angular unconformity that could equal the Mahui–Gaozhuang contact to the west in the Yuncu subbasin. There are no paleomagnetic data from Dengyucun.

Faunal similarity combined with magnetic information, renders a robust intrabasin correlation. The Jiayucun and Dengyucun faunas represent a part of the fossil record that is poorly sampled to the west in the Yuncu subbasin. The terminal Miocene small mammal faunal list for Yushe Basin (Table 1) is expanded, demonstrating a number of species shared with the classic (Schlosser, 1924) localities of Ertemte and Harr Obo, Inner Mongolia, including *Yanshuella primaeva*, *Ochotona lagrelli*, *Pliopetaurista rugosa*, *Karnimata hipparionum*, *Apodemus orientalis*, and *Micromys chalceus*. Interestingly, key Ertemte elements such as *Microtoposcoptes*, *Microtodon* and “*Prosiphneus*” *eriksoni* are missing from Yushe. Different zokors and rhizomyines characterize Yushe, and in the place of *Orientalomys*, *Chardinomys* is the Yushe

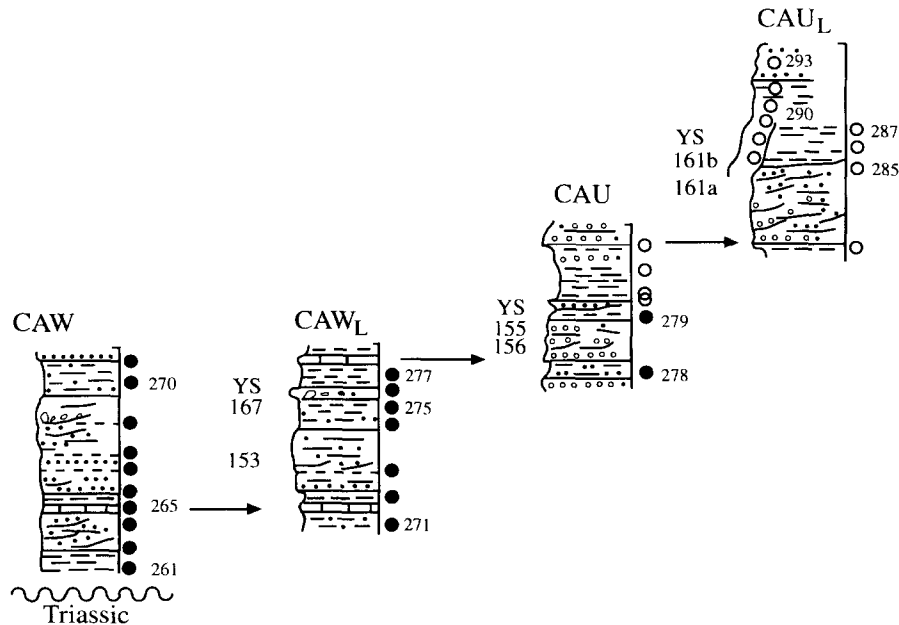


Fig. 3. Tancun subbasin magnetostratigraphy indicating normal polarity (solid circles) superposed by reversed polarity (circles), which represents the C3A–C3r (Chron V–Gilbert) boundary. Site numbers are indicated to the right of subsections; selected fossil localities (YS prefix) are indicated on the left. YS 161 at Jiayucun yields fossils which are early Gilbert in age and include Ertemte faunal elements. For reference, subsection CAW is 50 m thick; subsections are located 1 to 2 km to the south and to the east of Jiayucun.

Table 1

Selected late Miocene small mammal assemblages from North China. Data for Ertemte updated from Fahlbusch et al. (1983), for Youhe from Xue (1981), for Daodi from Cai (1987), Cai (1989) and for other assemblages on this and other tables from our ongoing research, Xu (1994), Zheng (1994), and Qiu Zhuding (pers. commun.)

Yushe Mahui	Jiayucun/Dengyucun	Ertemte
Insectivora	Insectivora	Insectivora
Soricidae indet.	Soricidae indet.	Soricidae, spp.
Talpidae indet.	<i>Yanshuella primaeva</i>	<i>Yanshuella primaeva</i>
Lagomorpha	Lagomorpha	<i>Quyania chowi</i>
<i>Ochotona lagrelli</i>	<i>Ochotona lagrelli</i>	Erinaceidae
Leporidae indet.	Leporidae indet.	Lagomorpha
Rodentia	Rodentia	<i>Ochotona lagrelli</i>
<i>Eutamias ertemtensis</i>	<i>Pliopetaurista rugosa</i>	<i>Alilepus annectens</i>
<i>Sciurus</i> n. sp.	<i>Prosiphneus murinus</i>	<i>Hypolagus</i> sp.
? <i>Petinomys</i> sp.	<i>Neocricetodon grangeri</i>	Rodentia
<i>Pliopetaurista rugosa</i>	<i>Karnimata hipparionum</i>	<i>Pseudapladon asiaticus</i>
<i>Hystrix</i> sp.	<i>Apodemus orientalis</i>	<i>Eutamias ertemtensis</i>
<i>Dipoides anatolicus</i>	<i>Huaxiamys downsii</i>	<i>Sciurus</i> sp.
<i>Castor anderssoni</i>	<i>Micromys chalceus</i>	<i>Sinotamias gravis</i>
<i>Sicista</i> sp.	<i>Chardinomys</i> sp.	<i>Spermophilus orientalis</i>
<i>Lophocricetus</i> sp.		<i>Pliopetaurista rugosa</i>
<i>Pseudomeriones abbreviatus</i>		<i>Petinomys auctor</i>
<i>Prosiphneus murinus</i>		<i>Dipoides anatolicus</i>
<i>Neocricetodon grangeri</i>		<i>Castor anderssoni</i>
<i>Karnimata hipparionum</i>		<i>Leptodontomys gansus</i>
<i>Apodemus orientalis</i>		<i>Myomimus sinensis</i>
<i>Huaxiamys primitivus</i>		<i>Sicista</i> sp.
		<i>Eozapus</i> sp.
		<i>Lophocricetus pusillus</i>
		<i>Lophocricetus grabaui</i>
		<i>Paralactaga anderssoni</i>
		<i>Brachyscirtetes wimani</i>
		<i>Sminthoides fraudator</i>
		<i>Sinocricetus zdanskyi</i>
		<i>Nannocricetus mongolicus</i>
		<i>Kowalskia similis</i>
		<i>Kowalskia neimengensis</i>
		<i>Microtodon atavus</i>
		<i>Anatolomys teilhardi</i>
		<i>Microscoptes praetermissus</i>
		<i>Pseudomeriones abbreviatus</i>
		<i>Prosiphneus eriksoni</i>
		<i>Karnimata hipparionum</i>
		<i>Micromys chalceus</i>
		<i>Apodemus orientalis</i>
		<i>Orientalomys</i> sp.
		<i>Rhagapodemus</i> sp.
		<i>Occitanomys pusillus</i>
Yushe Taoyang		
Lagomorpha		
<i>Ochotona lagrelli</i>		
<i>Hypolagus</i> sp.		
Rodentia		
<i>Pliopetaurista rugosa</i>		
<i>Castor anderssoni</i>		
<i>Dipoides</i> sp.		
<i>Hystrix</i> sp.		
<i>Pseudomeriones abbreviatus</i>		
<i>Prosiphneus murinus</i>		
<i>Neocricetodon grangeri</i>		
<i>Karnimata hipparionum</i>		
<i>Micromys chalceus</i>		
<i>Huaxiamys primitivus</i>		
<i>Chardinomys</i> sp.		
<i>Rhizomys shansius</i>		

large murine. We take this to indicate different environmental preferences for these rodents, and possibly to reflect biotic subprovince differences.

In any case, Ertemte, which previously seemed

to defy correlation to the Yushe sequence, can now be determined as terminal Miocene age and equivalent to basal Gaozhuang strata. In our correlation, Ertemte is younger than Chron C3A, but

pre-Thvera event, probably older than 5.5 Ma. Information from Yushe and other magnetostratigraphic sections (as at Lingtai, Gansu Province; see Huang et al., 1993) suggest that Ertemte-like faunas can be found in rock correlated as young as Sidufjal Subchron, circa 4.8 Ma at youngest. That Ertemte-like faunas spanned a range of time of about 0.5–1 m.y. agrees in general with the conclusions of Fahlbusch et al. (1983) and Repenning et al. (1990) who recognized an Ertemtean age. As at Yushe, the Lingtai microfauna lacks the high crowned *Microscoptes* that characterizes the coeval Ertemte assemblage in Inner Mongolia.

Mongolian and Russian colleagues have developed the biostratigraphy and magnetostratigraphy for similar composites in western Mongolia and adjacent Siberia. Repenning et al. (1990) use fauna to correlate these successions with the Yushe sequence. For western Mongolia Pevzner et al. (1982) correlate Ertemte-like faunas that include *Microscoptes* to late Chron C3A and to early Gilbert. These correlations are robust overall, despite some details we query, partly because they are based on thick stratigraphic sequences.

2.4. The Pliocene epoch in North China

The reference fauna of Jingle, once taken as representative for the early Pliocene fauna of North China (Li et al., 1984), contains many micromammals that we encounter in the Mazegou Formation and consider correlative with Gauss Chron. Other than the Gaozhuang Formation of the Yushe Basin and the Bilike fauna of Inner Mongolia, there are few known early Pliocene sites in China. Chen (1994) presents the paleomagnetic data from the Hefeng section at Jingle, which shows normal polarity at the base where the Jingle fauna is found. In the overlying Wucheng Loess, *Equus* occurs in the early Matuyama beneath the Olduvai Subchron (Chron C2An); above the Olduvai, the advanced vole *Allophaiomys* is recorded.

The late Cenozoic fluvial and lacustrine deposits exposed in the vicinity of Nihewan in northern Hebei Province provided the first substantial evidence of the nature of the mammalian

fauna contemporaneous with the early phase of loess deposition in the terminal Pliocene (Barbour et al., 1926). These complex deposits in adjacent basins did not have fully comparable histories and are difficult to correlate. Outcrops in the eastern Yangyuan Basin around Nihewan village comprise the type area for the Nihewan Formation; the rich fauna from the vicinity of nearby Xiashagou Village (Teilhard and Piveteau, 1930) constituted the “Nihewan fauna”. Recollecting and subsequent magnetostratigraphy and biochronology (Wang, 1988; Du et al., 1995) date the fossiliferous beds to late Gauss and Matuyama chrons.

Recently the focus of study has shifted to the outcrops in the Yuxian Basin along the lower Hulihe River southwest of Nihewan. The local sequence begins with dipping “Pontian Red Clays” that contain Pliocene assemblages correlated with late Gilbert and early Gauss Chron. These rocks are unconformably overlain by flat-lying fluvial and lacustrine deposits formerly considered the Nihewan Formation, but are now subdivided. The lower of these units, the Daodi Formation, lies totally within the late part of the Gauss Chron and contains a microfauna resembling the Mazegou and Jingle assemblages (see Table 2; Cai, 1987, 1989). The overlying Dongyaozitou Formation is a widely traceable set of cross-bedded sands and gravels that appears to represent the early Matuyama. A vole, cf. *Mimomys youhenicus* from the lower Dongyaozitou, supports Li et al. (1984) placement of the Youhe Local Fauna from southern Shaanxi in the late Pliocene.

The Olduvai Subchron apparently lies within the lower part of the restricted Nihewan Formation, overlying the Dongyaozitou Formation in the Yuxian Basin. The large mammal fauna resembles the typical Nihewan at Xiashagou, including the horses *Equus sanmeniensis* and *Proboscoidipparion sinense*. The rich micromammal fauna includes *Chardinomys nihewanicus*, *Borsodia chinensis* and another vole near *Allophaiomys pliocenicus*, a widespread taxon whose earliest Eurasian occurrence is at or just below the Olduvai Subchron (Repenning, 1992). The restricted Nihewan Formation of the Yuxian and Yangyuan basins, spans the late Matuyama Chron, from the Olduvai to Brunhes. Fossil mammals from the

Table 2
Selected Pliocene small mammal assemblages from North China

Yushe Upper Gaozhuang	Yushe Mazegou	Daodi
Insectivora	Insectivora	Insectivora
<i>Desmana kowalskae</i>	cf. <i>Erinaceus</i> sp.	Talpidae indet.
<i>Soriculus praecursor</i>	<i>Peisorex pliocaenicus</i>	cf. <i>Peisorex</i> sp.
Blarinini indet.	cf. <i>Blarinoides</i> sp.	Soricidae indet.
<i>Yanshuella primaeva</i>	<i>Yanshuella primaeva</i>	
<i>Scaptochirus</i> sp.	<i>Scaptochirus</i> sp.	
Lagomorpha	Lagomorpha	Lagomorpha
<i>Ochotona lagrelli</i>	<i>Ochotona lagrelli</i>	<i>Ochotona erythrotis</i>
<i>Altilepus annectens</i>	<i>Altilepus annectens</i>	cf. <i>Ochotona lagrelli</i>
<i>Hypolagus</i> sp.	<i>Hypolagus schreuderi</i>	<i>Ochotona minor</i>
	<i>Ochotonoides complicidens</i>	<i>Pliopentalagus nihewanensis</i>
		<i>Hypolagus schreuderi</i>
Rodentia	Rodentia	Rodentia
cf. <i>Eutamias ertemtensis</i>	<i>Sciurus</i> n. sp.	<i>Eucastor</i> sp.
<i>Sciurus</i> n. sp.	<i>Sciurus</i> sp.	<i>Paralactaga</i> sp.
<i>Sinotamias</i> sp.	<i>Pliopetaurista rugosa</i>	<i>Sminthoides</i> sp.
<i>Pliopetaurista rugosa</i>	<i>Castor anderssoni</i>	<i>Mesosiphneus paratingi</i>
<i>Castor anderssoni</i>	<i>Dipoides majori</i>	cf. <i>Namocricetus</i> sp.
<i>Dipoides majori</i>	<i>Eucastor youngi</i>	cf. <i>Allocricetus</i> sp.
<i>Hystrix</i> sp.	<i>Hystrix</i> sp.	<i>Germanomys</i> sp.
<i>Myomimus</i> sp.	<i>Sminthoides fraudator</i>	cf. <i>Mimomys irtyschensis</i>
<i>Sminthoides fraudator</i>	<i>Rhizomys shansius</i>	<i>Chardinomys louisii</i>
<i>Cricetinus</i> n. sp.	<i>Cricetinus</i> n. sp.	cf. <i>Micromys</i> sp.
<i>Allocricetus</i> n. sp.	cf. <i>Allocricetus bursae</i>	cf. <i>Leopolodomys</i> sp.
<i>Neocricetodon grangeri</i>	cf. <i>Allocricetus chiki</i>	
<i>Chardina truncatus</i>	<i>Cricetulus</i> sp.	
<i>Mesosiphneus praetingi</i>	<i>Mesosiphneus paratingi</i>	
<i>Germanomys A</i>	<i>Germanomys B</i>	
<i>Mimomys</i> sp.	<i>Mimomys (Cromeromys) irtyschensis</i>	
<i>Chardinomys yusheensis</i>		
<i>Apodemus qui</i>	<i>Chardinomys louisii</i>	
<i>Micromys tedfordi</i>	<i>Apodemus zhangwagouensis</i>	
<i>Huaxiamys downsi</i>	<i>Micromys tedfordi</i>	

higher part of the section (ca. 1 Ma; see Zheng and Cai, 1991) include the advanced voles *Microtus* and *Lasiopodomys*.

The large mammal fauna from the Haiyan Formation of Yushe Basin closely resembles at the species level those from the Nihewan and Dongyaozitou formations. The small mammals also agree, particularly with the Dongyaozitou assemblage, which includes the moderately advanced zokor *Youngia tingi* but not the derived vole *Allophaiomys*. This is consistent with assignment of the Haiyan Formation to Chron C2r (early Matuyama).

2.5. The Pleistocene record and Yushe basin

The work at Nihewan has been synthesized in a paper by Du et al. (1995), which develops the biochronologic record against the magnetic time scale. The Nihewan fossil record is of good quality, if patched together, and serves to bridge the Pliocene and Pleistocene, especially the large mammal record. Still for microfauna, the richest and most continuous record of Plio/Pleistocene evolution is in the loess sequence developed by Liu (1985) and colleagues therein. Certainly this is the case for middle Pleistocene biostratigraphy,

which is quite discontinuous at Nihewan. Zheng Shaohua (see especially Zheng and Cai, 1991 and Zheng, 1994) has developed the small mammal biostratigraphy for the loess sequence and many other Plio/Pleistocene strata in China. His cumulative work forms the basis for assessing the age of the microfauna from the Pleistocene reddish loam blanketing Yushe basin.

The Yushe red “loess” is widespread, but evidently young and evidently of complex depositional history. These deposits contain some stratified sediments that are obviously fluvial in origin. There are many soils within the red “loess”, and some of the deposits are likely of subaerial origin. Because they are not strictly loess, we use the term loam herein. While deposition of the Wucheng Loess commenced elsewhere on the Loess Plateau, the Yushe Basin saw fluvio-lacustrine conditions including deposition of the Haiyan Formation. After a period of erosion, the red loam began to accumulate in Yushe Basin, which in turn was blanketed by yellowish sediment that is more classically eolian in nature. Many scientists have found fossils in Yushe “loess”, and we made an effort to collect fauna, especially from the oldest red loam. In addition to various horizons that yielded several specimens of zokors, we discovered a fossiliferous concentration, YS 83, in basal dark red loam. Sediments at this locality are poorly sorted, include fine sand, and cut deeply into Yushe Group deposits; these probably correspond to the oldest “R Loess” of Di et al. (1984).

Site YS 83 produced a microfaunal assemblage of fragmentary white bone and teeth representing mostly modern taxa. The shrew *Crocidura* is widespread in North China today and present at this site, but is absent from older horizons. Much of a zokor skull representing the advanced (but extinct) *Youngia epitingi* is preserved. There is a modern vole *Microtus brandtioides*, an extant hamster *Cricetulus barabensis*, and the murines *Chardinomys nihowanicus* and *Apodemus* sp.

At present, the strongest indication of age is the combination of *Microtus brandtioides* and *Chardinomys nihowanicus* with *Youngia epitingi*. The first two taxa occur in the Nihewan assemblage reported by Zheng (1981) and given a post-Olduvai age by Zheng and Cai (1991).

Unfortunately the murine is really too poorly preserved to assess similarity at the species level. Given the difference between Haiyan and YS 83 assemblages, and taking the loam to be not much younger than the restricted Nihewan beds, the superposition of the red loam on the Haiyan Formation would tend to support our assignment of the Haiyan to pre-Olduvai Matuyama. The chart of Zheng (1994; his fig. 12) suggests that *Youngia epitingi* is no older than the Gongwangling reference locality (Hu and Qi, 1978), perhaps as young as Chenjiawo. A Chenjiawo correlation would constitute a rather late record for *Chardinomys*. Using Zheng’s data in conjunction with the Loess sequence biostratigraphy and magnetic dating (Liu, 1985), either Gongwangling or Chenjiawo equivalence seem possible. However, recent evidence (Xu, 1996) indicates that Chenjiawo is a composite fauna and its application to biochronology is in question. At present it is impossible to date YS 83 with precision, but an age somewhat less than 1 Ma is consistent with available evidence. Unfortunately, we have no magnetic data for this loam, but still, information from a single site would be ambiguous.

3. Conclusions

An increase in the time resolution of late Neogene microfaunas of North China has proceeded through coordinated use of magnetic and faunal data. The likely temporal relationships of key fossil assemblages in North China is compared to the Yushe sequence in Fig. 4. The Yuncu Mahui Formation spans relatively little time in the late Miocene. It is close in age to many of the classic Baodean localities, with faunal differences (see Tedford et al., 1991) probably due to younger age for Mahui sites based on records of *Stegodon* and mice, but possibly due to paleoecological differences.

Ertemte correlates with Yushe deposits of the early part of the Gilbert Chron and is terminal Miocene age. If Ertemte is considered late Baodean biochron (presently the faunal evidence is weak for this), then Baodean time must extend up to the Miocene/Pliocene boundary, which lies well up

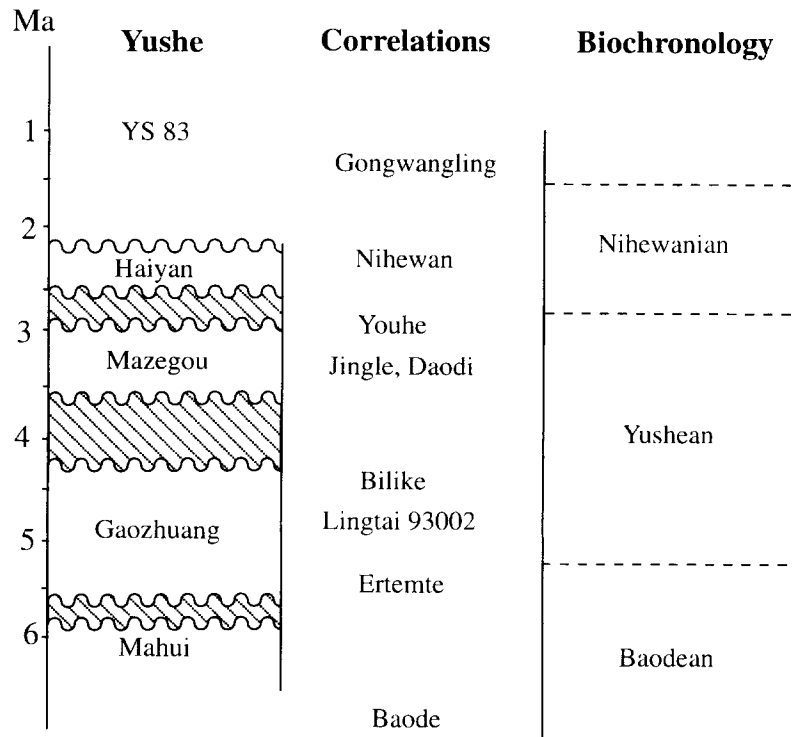


Fig. 4. Yushe Basin stratigraphy applied as a tool in ordering other North China localities, and used to date the corresponding biochronology. The top of the thin Haiyan Formation could be as young as 1.9 Ma, which would imply a larger hiatus at its base. The loess units above it are thin and variable. The fossil site YS 83 is plotted based on faunal comparisons. Biochron limits are dashed, because they depend on more work leading to refined definitions, which will clarify such issues as whether Ertemte should be considered Yushean, whether the Youhe assemblage is early Nihewanian, and what defines the upper limit of the Nihewanian.

in the Gaozhuang Formation. If not, Ertemte would be early Yushean age, and that biochron would commence in the latest Miocene. We favor the latter position.

Jingle, Daodi and similar localities are contemporaneous with the Gauss Chron and correlative with sites in the Mazegou Formation (see Table 2). The Youhe fauna resembles these but, in fact, is not rich. It is distinguished by containing two rare species of *Mimomys* and the elephantid *Archidiskodon* (Xue, 1981). *Archidiskodon* is reported from the upper part of the Mazegou Formation, with which we correlate the Youhe fauna. Thus the Jingle fauna is late Pliocene Epoch and the Youhe fauna is later in age, but not latest Pliocene. It turns out that very few studied sites in China date to early Pliocene Epoch. Likely exceptions other than localities from upper mem-

bers of the Gaozhuang Formation, are in the Lingtai area, Gansu, and Bilike, Inner Mongolia (Qiu, 1988), which produces a fauna comparable to Yushe sites of ca. 4.5 Ma, such as YS 50.

The Pliocene faunas of Yushe are homogeneous, despite some species substitution, from greater than 5 Ma to ca. 3 Ma (Flynn et al., 1991, Fig. 5). For this reason, we argue that a single biochron, the Yushean of Qiu and Qiu (1995), should be recognized for this interval.

The Haiyan Formation is correlative with the early Matuyama Chron and some Nihewanian faunas (Table 3); other Nihewan-like faunas are Olduvai or younger. This would place the Yushean–Nihewanian boundary at least as low as the hiatus between the Mazegou and Haiyan formations, or older than 2.6 Ma. If the Youhe fauna is considered similar to that of Nihewan and

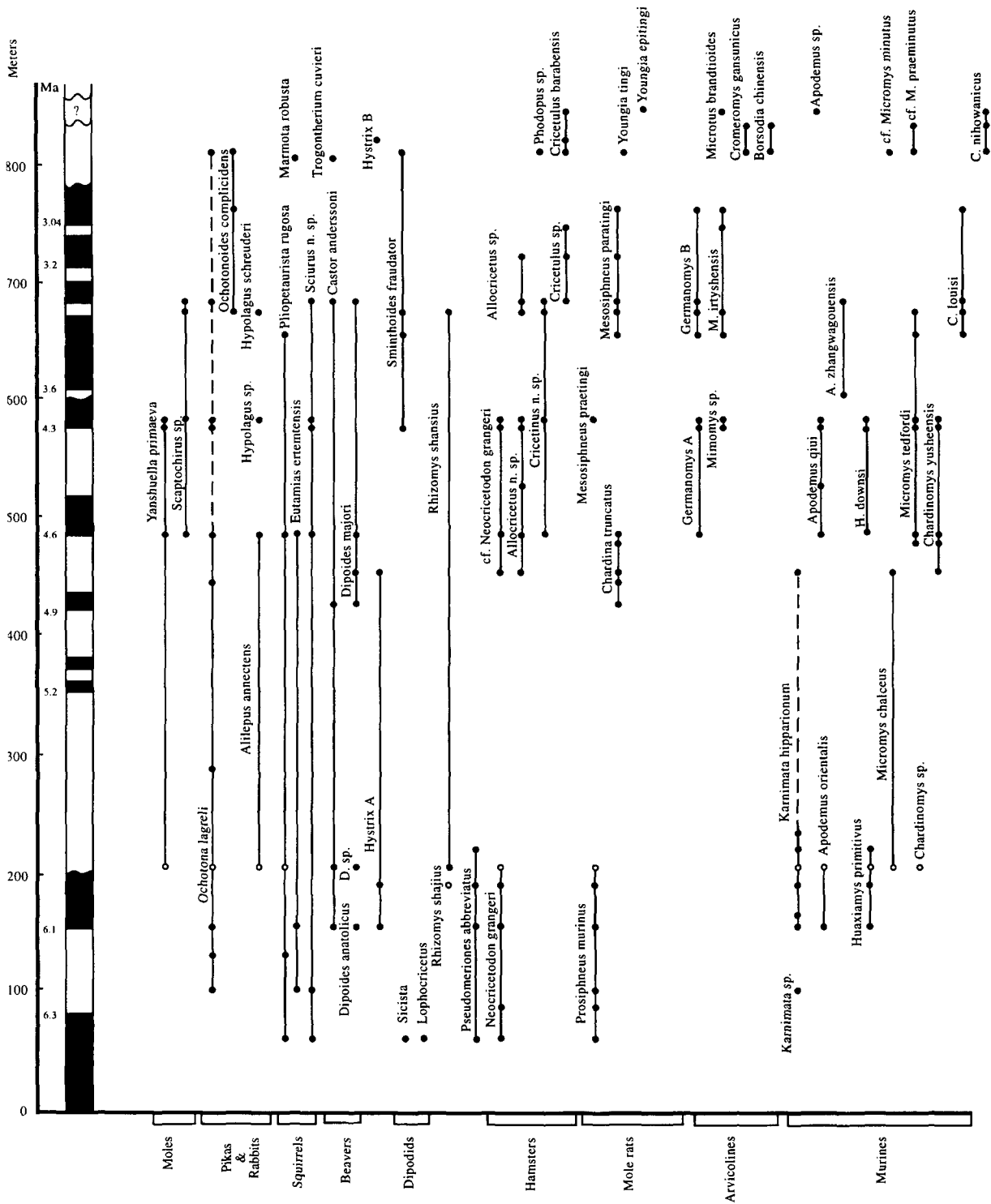


Fig. 5. Biostratigraphic ranges with magnetostratigraphy of selected taxa from Yushe Basin. Fig. 5 is significantly modified from Flynn et al. (1991) by addition of taxa, systematic revision, and interpolation of data from Yushe subbasin (Jiayucun and Dengyucun; shown by circles). Occurrences are dots or circles. Lines connect specimens considered to represent conspecific populations; dashed lines join specimens showing affinity, but not necessarily representing the same species.

Table 3
Selected Plio–Pleistocene small mammal assemblages from North China

Yushe Haiyan	Youhe	Nihewan (restricted)
Insectivora		Insectivora
<i>Sorex</i> sp.		<i>Erinaceus koloshanensis</i>
Lagomorpha	Lagomorpha	Lagomorpha
<i>Ochotona</i> sp.	<i>Ochotonoides complicidens</i>	<i>Ochotona nihewanica</i>
<i>Ochotonoides complicidens</i>		<i>Ochotonoides complicidens</i>
Rodentia	Rodentia	Rodentia
<i>Marmota robusta</i>	<i>Spermophilus</i> sp.	<i>Youngia tingi</i>
<i>Trogotherium cuvieri</i>	<i>Cricetulus</i> sp.	<i>Chardinomys nihowanicus</i>
<i>Hystrix</i> sp. B	cf. <i>Chardinomys nihowanicus</i>	<i>Borsodia chinensis</i>
<i>Sminthoides</i> sp.		
<i>Phodopus</i> sp.	cf. <i>Leopoldomys</i> sp.	
<i>Cricetulus barabensis</i>	<i>Mimomys orientalis</i>	
<i>Youngia tingi</i>	<i>Mimomys youhenicus</i>	
cf. <i>Micromys minutus</i>		
cf. <i>Micromys praeminutus</i>		
<i>Chardinomys nihowanicus</i>		
<i>Borsodia chinensis</i>		
<i>Mimomys orientalis</i>		
<i>Mimomys (Cromeromys) gansunicus</i>		
		Danangou (DO-5 of Zheng and Cai, 1991)
		Lagomorpha
		<i>Ochotonoides complicidens</i>
		<i>Ochotona nihewanica</i>
		Rodentia
		<i>Youngia tingi</i>
		<i>Chardinomys nihowanicus</i>
		<i>Alticola simplicidentata</i>
		<i>Pitimys</i> cf. <i>P. hintoni</i>
		<i>Allophaiomys</i> cf. <i>A. pliocaenicus</i>

therefore placed in the Nihewanian, this would extend the Nihewanian biochron back to 3 Ma. In either case the Nihewanian biochron is late Pliocene to early Pleistocene, and Nihewan-like assemblages are not necessarily indicators of Pleistocene time. The youngest Yushe fauna treated here is likely less than 1 Ma in age, an equivalent of late Gongwangling or Chenjiawo assemblages.

We have demonstrated that the coordinated use of biostratigraphic and magnetic data successfully determines the age of late Neogene deposits of North China. Extending the magnetostratigraphic and faunal record back into earlier late Miocene deposits is important in building the framework for defining the beginning of the Baodean biochron. Whether a distinct Baodean biochron preceding the Baodean can be resolved is not known, but

this possibility can be tested, beginning with analysis of the Baode–Fugu region, northwestern Shanxi and adjacent Shaanxi Province (Fig. 1). The early late Miocene may be spanned in the Lantian area along the Bahe River, in Ningxia at Wuzhong, or in the Qaidam Basin: where better than North China to date the first introduction to Asia of hipparionine horses? The middle Miocene record can best be assembled in Inner Mongolia, as witnessed by localities such as Tunggur and Amuwusu (see Qiu, 1988). The Lanzhou Basin shows great potential for spanning the Oligocene/Miocene boundary and extending well into younger Miocene strata. Finally, the faunal record in South China, e.g. Lufeng and Yuanmou, must be integrated with that to the North. Faunal comparisons should be supplemented with magnetostratigraphic data.

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