Recent Advances in the Small Mammal Biochronology and Magnetostratigraphy of Lanzhou Basin

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Abstract The consensus view among geologists is that the Lanzhou Basin sequence of sediments contains the Oligocene/Miocene boundary, but where this occurs is unknown. Indeed, this is the crux of the issues concerning mid-Tertiary paleontology in Asia: what fauna corresponds with this time? What turnover events or distinctive taxa signal the beginning of the Miocene epoch? Once known, this will be of broad usefulness because vertebrate-bearing deposits are widespread in Asia and can be used to date basin sediments.Lanzhou and other basins permit a means of correlating to the time scale by using fauna and paleomagnetic data locally, and ultimately radiometric data from distant localities, to develop a precise biochronology. Herein, we summarize faunal constraints, primarily those of small mammal taxa, on correlation of the Lanzhou magnetozone sequence to the magnetic time scale. We conclude that the lower part of the Xianshuihe Formation contains the Oligocene/Miocene boundary, and that the top of the formation, both in the south and north parts of the basin, is middle Miocene in age. Rodents from lower white sand units of the Xianshuihe Formation, correlate to the Xiejia assemblage of the Xining Basin, Qinghai Province, and are early, but not earliest, Miocene age. The implication for rodent faunas of the epoch boundary is that they retained a mainly "Oligocene" composition, and that other presumed late Oligocene assemblages may be, in fact, early Miocene in age. The Lanzhou appearance of Proboscidea is 19 - 18 Ma, as expected.

Keywords: Oligocene, Miocene, Gansu, China, biostratigraphy, biochronology, paleomagnetsim

1. Introduction

The fossil resources of Gansu Province, central China, are diverse and include excellent mid-Tertiary [1-2] and late Cenozoic localities [3]. Early investigators found important small mammal remains in the area north of Lanzhou, now known as Lanzhou Basin [4]. The Lanzhou Basin Chuantougou (Quantougou) assemblage of small mammals came to be understood as similar to the famous Tunggur, Inner Mongolia, fossils and therefore middle Miocene in age [5]. In the 1960's the Gansu Geologic Brigade found gomphotheres and the suid *Kubanochoerus* near there, consistent with that age. Xie [6] summarized the salient results of work on Gansu paleontology published up to the late 1980's.

Renewed interest in the fossil record of Lanzhou Basin starting in the later 1980's greatly increased knowledge of the potential for a good vertebrate record spanning the Oligocene/Miocene boundary and extending into the middle Miocene in that part of Gansu Province. The Lanzhou local fauna [7] comes from a big hill just south of the Lanzhou train station and yields a small mammal fauna that is advanced over the Oligocene Hsanda Gol faunas, and is comparable to, but likely older than, the Xiejia fauna [8]. It is therefore presumably very early Miocene. North of Lanzhou, the Zhangjiaping local fauna of Lanzhou Basin, discovered in 1987, produces forms that seem to be somewhat younger. Together with the Jiaozigou fauna of Linxia Basin, the fossils speak to a diverse early Miocene fauna with Oligocene holdovers, e.g., *Paraentelodon* [1].

Since about 1988, teams from the Gansu Provincial Museum and the Institute of Vertebrate Paleontology and Paleoanthropology, and more recently with foreign collaborators, have revisited Lanzhou basin to study it in greater detail. Lanzhou Basin is an elongate syncline with north northwest axis, now structurally separated from the larger Longzhong Basin to the southeast. Our groups focused at first on the Duitinggou area on the eastern limb of the syncline (Fig. 1). This area is characterized by

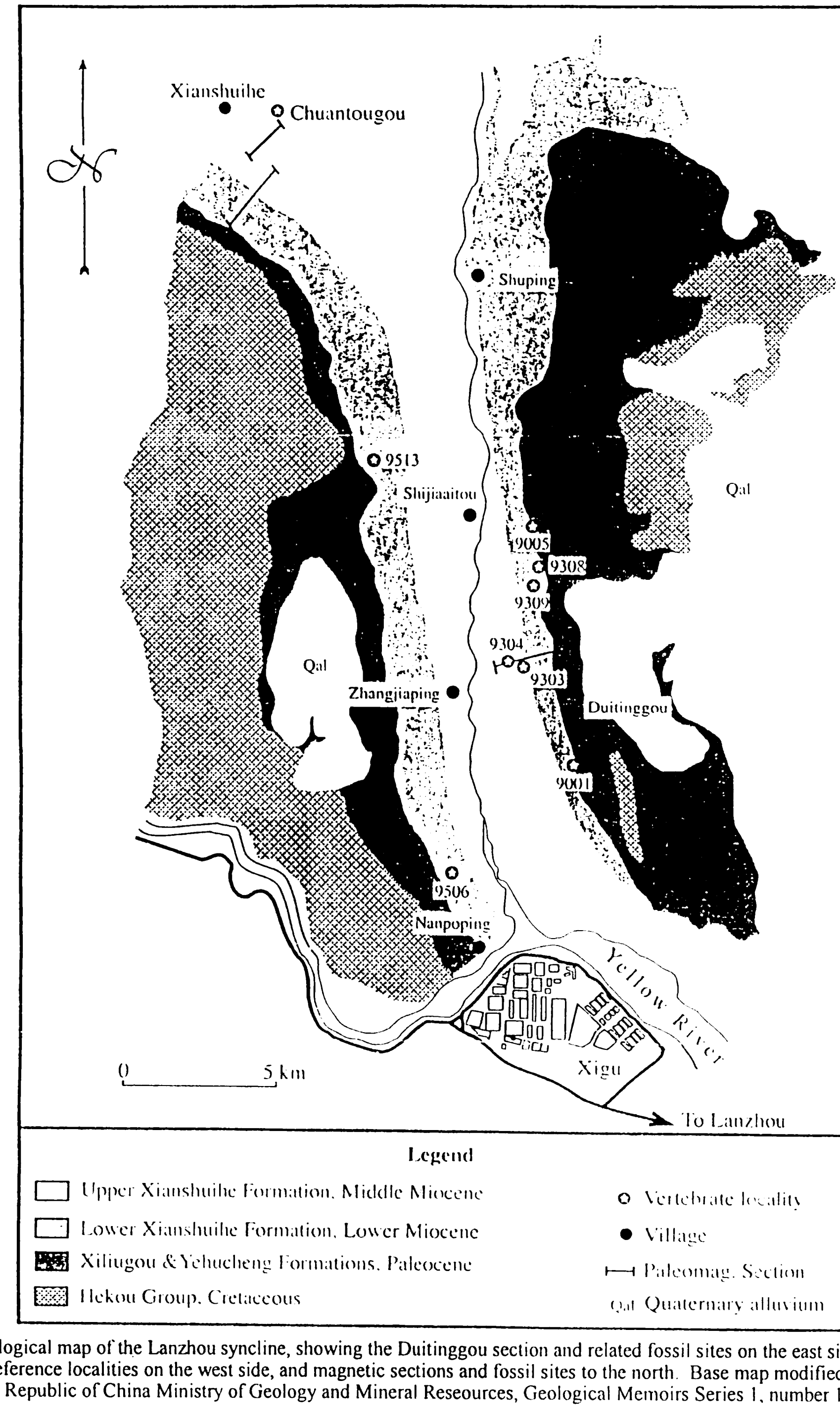

Figure 1. Geological map of the Lanzhou syncline, showing the Duitinggou section and related fossil sites on the east side of the syncline, as well as reference localities on the west side, and magnetic sections and fossil sites to the north. Base map modified from People's Republic of China Ministry of Geology and Mineral Reseources, Geological Memoirs Series 1, number 19.

well exposed, continuous stratigraphy, which we sampled for magnetic properties of the sediment. Zhangjiaping, a few kilometers to the west, but on the opposite limb of the syncline, is difficult to interpolate into our section without independent magnetostratigraphy. Chuantougou, nearly 20 km northwest of the Duitinggou section, depends on careful tracing of beds to correlate its own magnetostratigraphic sections to Duitinggou. For Duitinggou, our international team has begun to compile the Lanzhou biostratigraphy, which is complemented by the other important localities of Lanzhou Basin.

2. Lanzhou Basin Stratigraphy

The Lanzhou syncline extends 25 km north northwest from the Yellow River and Lanzhou itself, flattening out near the town of Xianshuihe, near which occurs the Chuantougou quarry [4]. The thickness of the stratigraphic section increases to the north, indicating both a higher rate of deposition and inclusion of somewhat younger rocks there. There are stratigraphic differences in number of sand units on west and east limbs of the syncline. Consequently, correlation of distant localities requires careful bed tracing and multiple paleomagnetic sections.

The Tertiary stratigraphy unconformably overlies the Hekou Group [9], presumed to be Cretaceous in age. Early Tertiary units are the relatively thin Xiliugou Formation (about 200 m) and the thick Eocene to Oligocene Yehucheng Formation, which has yielded rare amynodontid rhinos. In the vicinity of the Duitinggou section, the overlying Xianshuihe Formation is about 300 m thick. To the north, it is over 400 m thick. In 1993, our Chinese-American team sampled the Duitinggou section for paleomagnetic determination. Our section (Fig. 2) commences in the Yehucheng Formation and continues through the highest local erosional remnant of the Xianshuihe Formation. A distinctive unit known as the Yellow Sandstone marks the base of the Xianshuihe Formation. It is readily followed over more than ten kilometers on the eastern limb of the syncline. It can be recognized on the western limb and followed to the north toward the town of Xianshuihe, where a Chinese-Swiss team constructed the Dahonggou and Xia Jie paleomagnetic sections (see [10] and our Fig. 1). Other sedimentary bodies are too discontinuous to be useful as tracers over this distance. Future work remains to correlate the magnetostratigraphy of these sections in detail, and to construct complementary sections to the south, on the western limb of the syncline.

In the Duitinggou area, the Yehucheng Formation is distinctive in the dark red monotony of its gypsiferous clay, silt, and sand units. The prominent Yellow Sandstone breaks this sedimentary regime, without apparent regional unconformity, although Zhai and Cai [9] note a hiatus, and we have found it locally. The Yellow Sandstone is about 10 m thick, composed of multiple crossbedded to thinly bedded sheets of sand distinguished by a predominance of small, yellow, calcareous, pedogenic nodules and near absence of metamorphic minerals. This constrasts distinctly from higher white sand complexes, which are predominantly quartz arkoses showing abundant minerals of metamorphic origin. Sedimentological comparison of these sands would complement tectonic interpretations. Fossils are locally numerous, including at some localities 5 to 10 rhino jaws (*Aprotodon*). At many places along the exposed yellow sand we find concentrations of micromammals. Screening techniques have produced quite large samples. Our colleague Wang Banyue has developed a faunal list of 14 small mammals for this unit (see [11] and Table 1), which demonstrates Oligocene age [10, 12]

Above the Yellow Sandstone is a thick unit of red mudstone. Being monotonous, it is reminiscent of the underlying Yehucheng Formation, except that it contains less gypsum. Interestingly, the red mudstone, 60 m thick and barren in the Duitinggou section, becomes a bit coarser and more orange in color to the north. This is interesting because the change in lithology coincides with occurrence of fossils near Xiagou, about 7 km northwest of Duitinggou. Locality 9513 was found by Qiu Zhanxiang in 1995, and is a rare producer of vertebrates for this unit. Surface finds include *Parasminthus parvulus*, *Tataromys* sp., and *Yindertemys grangeri* among rodents, and the archaic "carnivore" *Didymoconus* cf. *D. berkeyi* [12] At present, this seems consistent with a late Oligocene age, but early Miocene is possible, pending analysis of screened rodents.

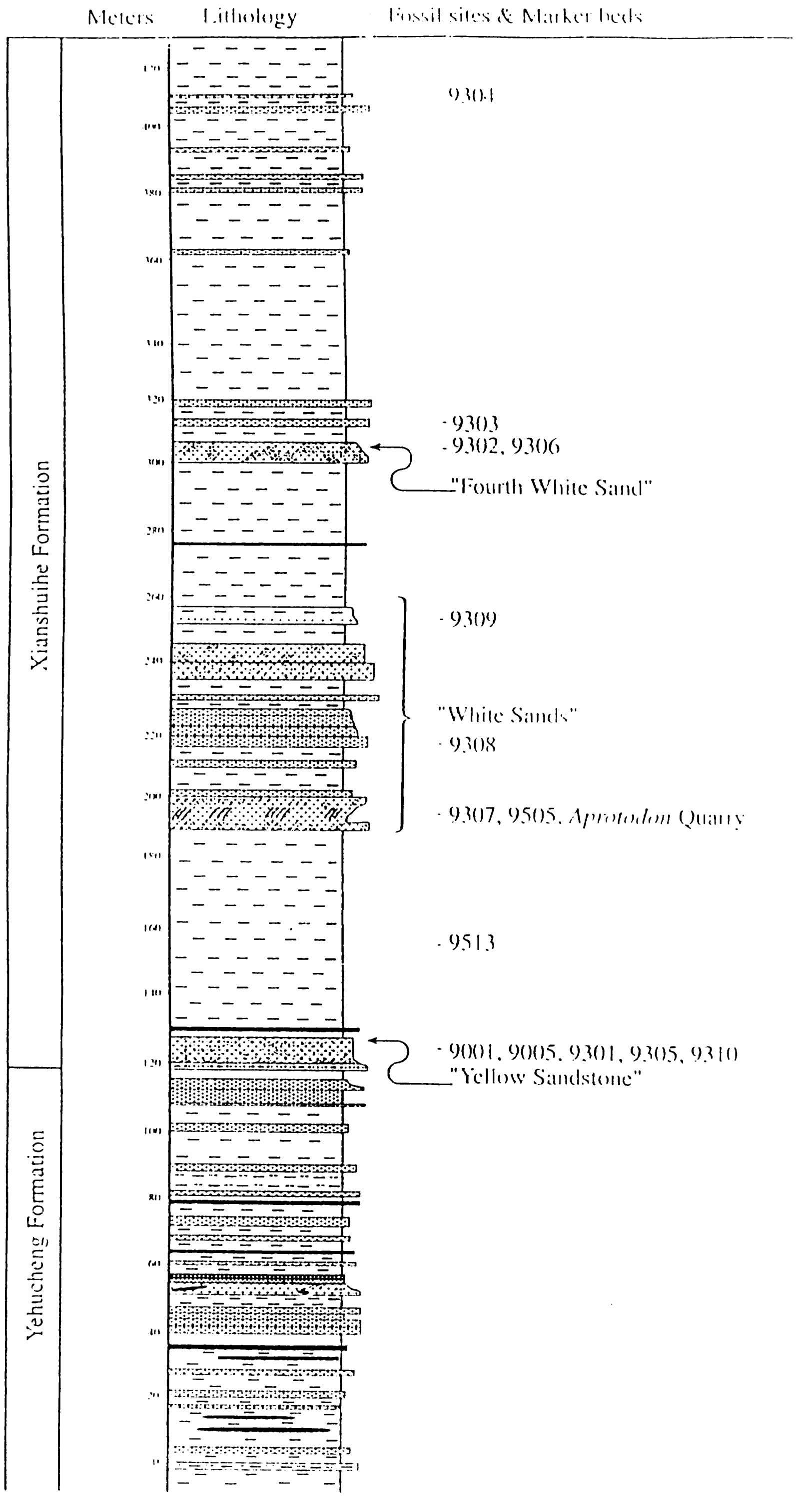

Figure 2. Duitinggou stratigraphic section, showing the formation boundary, thickness in meters, lithology, and superposition of localities and marker beds. This is the section on which the Duitinggou magnetostratigraphy is plotted (Fig. 5).

Table 1. Small Mammals from the Yellow Sands and Lower White Sands.

YELLOW SANDS/NANPOPING FAUNA	ZHANGJIAPING/9308
	Erinaceidae indet.
Desmatolagus pusillus	*Sinolagomys* sp. small
Ordolagus teilhardi	*Sinolagomys pachygnathus* (9509)
Anomoemys lohiculus	cf. *Ansomys* sp.
Tataromys plicidens	*Tataromys* sp.
Tataromys sigmodon	*Yindertemys gobiensis* (Qiu et al., 1997)
Tataromys minor	*Yindertemys xiningensis*
Bounomys bohlini	*Bounomys* sp.
Bounomys ulantatalensis	Tiny zapodid
Karakoromys sp.	cf. *Plesiosminthus xiningensis*
Parasminthus tangingoli	cf. *Protalactaga grabaui*
Parasminthus parvulus	*Parasminthus* sp.
Eucricetodon asiaticus	*Eucricetodon* sp.
Tsaganomys altaicus	*Tachyoryctoides kokonorensis*
Steneofiber sp.	Large rodent, cf. *Tachyoryctoides* sp.

The Xianshuihe Formation continues with prominent white sand bodies, most of which are discontinuous laterally. In the Duitinggou area, two thick basal sandstones stand out, but they are really composed of several smaller units and include thin siltstones. Locally, above this is a "third" sand. For this sequence we measured 50 m of sediment. Another 40 m of mainly reddish mudstones is capped by a prominent sand unit that we dubbed the "Fourth Sand" (of course, not literally sand number four). The distinctive feature of this unit is its lateral continuity as a prominent ledge-former that can be traced for kilometers. It has a light blue-green hue, contains bivalves all along its strike, and is locally crossbedded.

To distinguish vertebrate fossils found in these higher strata from those of the Yellow Sandstone, previous collectors have applied the informal provenance of "White Sands" to them. Given the >100 m of rock between the first and "fourth" sands (not to mention fossils from still higher stratigraphic levels), this is imprecise. Present field work by Gansu Provincial Museum and IVPP has established stratigraphic sections that enable notation of exact horizons for new localities.

Throughout the sequence of white sands, there are important fossil localities. Low in the thick basal sand are several quarries, including the *Aprotodon* Quarry excavated in the later 1980's. In 1993 at site 9307, we discovered a partial skull of *Paraentelodon* (under study at IVPP). The basal white sand on the west limb of the Lanzhou syncline also produces fossils, e.g. sites 9505 and 9506. Near these our team recovered a large astragalus (9508) and teeth representing a proboscidean, and a jaw of the chalicothere *Phyllotillon*. Rodent sites occur throughout the sequence and, with study, hold the key to more precise correlations to other sequences in Asia.

The top 120 m of Xianshuihe Formation above the "4th sand" in the Duitinggou section consist of red to brown siltstones with a few thin local sand units. The sediments become browner upward with paleosols becoming more evident. Two key rodent sites constrain the age of this sequence. Locality 9303, at the 310 m level in the section, has taxa advanced with respect to both the rich Yellow Sandstone fauna and the early Miocene Lanzhou local fauna [11]. The species are demonstrably less derived than those from the 410 m locality 9304 (Table 2). In turn, the 9304 fauna is antecedent to the Chuantougou assemblage, thus confirming that more stratigraphic section is preserved in the northern part of the basin. Since the 9304 fauna shares many genera with Chuantougou and Tunggur, the top of the Duitinggou section may be considered as "early Tunggurian" or early middle Miocene in age.

3. Lower White Sands Rodents

Given the importance of the proboscidean record as arguing for early Miocene age of the lower white sands of the Xianshuihe Formation, ca. 200 m on our section, rodent fossils should shed considerable light on correlations, at least to other parts of China and contiguous areas. Are the proboscideans older than expected, demonstrating early emigration from Africa, or are the white sand

Table 2. tunggur taxa and lanzhou localities (left to right, youngest to oldest)

Tunggur [after 14]	Chuantougou	9304	9303
Chiroptera indet.			
Soricidae indet.		Indet.	
Mongolosorex qiui			
Talpidae: *Quyania* sp.		Indet.	Indet.
Yanshuella sp.			
Proscapanus sp.			
Erinaceidae	Erinaccid indet.	Diff. Genus	?Tiny sp.
Mioechinus (?) gobiensis	aff. *M. gobiensis*		aff. *M. gobiensis*
Mioechinus (?) larger sp.			
Large erinaceid	Same large sp. ?	?*Metexallerix* sp.	LikeChuantougou
Ochotonidae	Ochotonidae		
Alloptox gobiensis	spp.	*Alloptox minor*	*Alloptox* sp.
Bellatona forsythmajori		cf. *B. forsythmajori*	Same
Desmatolagus (?) moergenensis		cf. *Sinolagomys*	Same
Sciuridae		Large indet.	? Same
aff. *Eutamias ertemtensis*			
Sinotamias primitivus		cf. *S. primitivus*	
Atlantoxerus orientalis		*A. orientalis*	
Aplodontidae: *Ansomys* (?) sp.			
Eomyidae: *Keramidomys fahlbuschi*			
Dipodoidea			
Heterosminthus orientalis	*H. orientalis*	*Hetero.* n.sp.	*Plesio. xiningensis*
Protalactaga grabaui	*P. grabaui*	*Prot. grabaui*	cf..*Prot.grabaui*
Protalactaga major	Big (like *P. major*)		?*Parasminthus* sp.
Muroidea			
Plesiodipus leei	aff. *P. leei*		*Tachyoryctoides* sp
Gobicricetodon flynni			?*Gobicricetodon* sp.
Democricetodon tongi	cf. *D. tongi*		*Democricetodon* sp.
Democricetodon lindsayi		Robust *Democricet.*	
Megacricetodon pusillus			
Megacricetodon sinensis	Large *Megacricetodon*	Large *Megacricet.*	Large*Megacricet.*
Ctenodactylidae (none)	none	Indet. sp.	*Yindertemys*
		Prodystylomys sp.	*xiningensis*
Gliridae: *Miodyromys* sp.			
Microdyromys wui			
Castoridae: *Hystricops* (?) sp.			
Steneofiber tungurensis			
Anchitheriomys tungurensis			
Hystricops sp.			

units rather young and not even earliest Miocene? Are there significant disconformities in the sequence, associated with the Yellow Sandstone or the base of the white sands? Crucial evidence lies among the emerging microfauna and in establishing supplementary paleomagnetic sections to improve correlation.

We have only begun analysis of the microfauna from several localities, but certain observations at this point are helpful. In the late 1980's a team from IVPP recovered a few small mammals from the Zhangjiaping area. Taxa include *Sinolagomys*, an ochotonid advanced over the Yellow Sandstone *Desmatolagus*, the ctenodactylid rodent *Tataromys* and the primitive muroid *Tachyoryctoides* [2]. We believe that the Zhangjiaping fauna, fossils from our 9506 and nearby localities, and other low white sands sites from the Duitinggou area are about the same age.

The Duitinggou area has produced a few surface finds from the basal white sands of the 190 to 240 m interval, including ochotonids and *Tachyoryctoides*. At ca. 220 m we have one productive microsite for which we screened a small sample (about 200 kg of silty fine-grained sand). This matrix from locality 9308 yielded over 40 small mammal teeth identifiable to genus.

Among Lagomorpha, only a small ochotonid has been recovered from 9308, but two or more species are found in other localities. The material is not diagnostic, but the asymmetry of the lobes of the upper molars suggests *Desmatolagus* or *Sinolagomys*. We attribute the fragments to the latter due to the true hypsodonty of the material. *Sinolagomys pachygnathus* is known from a locality of about the same level from the western limb of the syncline [12].

Aplodontidae are represented by a single upper third molar. We consider it an aplodontid due to appropriate size, protocone elongated antero-posteriorly with thin connection to the protoloph, long posterior arm of the protocone, and anterior arm of the protocone joining the anterior cingulum and isolating an extra small fossette. The specimen is lower crowned than *Anomoemys* and more like *Ansomys* although it appears simpler than illustrated specimens.

Ctenodactylidae are relatively diverse. Qiu and Qiu [2] noted *Tataromys* sp. from Zhanjiaping, and Qiu et al. [12] identified both *Tataromys* sp. and *Yindertemys gobiensis* among surface finds from 9308. Most screened specimens indicate the presence of *Yindertemys xiningensis*, the type locality of which is from the Xiejia Formation [13]. One other tooth fragment suggests *Bounomys* sp.

Muroids are represented by fragmentary *Eucricetodon*, a primitive cricetid, and by *Tachyoryctoides*, which represents a group of early muroid derivation. Qiu [1] noted an extremely large rodent represented by a jaw without molars, and which is larger than known *Tachyoryctoides*. Our group recovered several *Tachyoryctoides* specimens, including a jaw with very worn molars found by Downs at 9505, and isolated teeth at 9308 and 9506. All of the molars from this set of deposits are completely consistent with *Tachyoryctoides kokonorensis*, known from Xiejia, Xining Basin, Qinghai.

Dipodoidea are the most abundant and diverse group at 9308. Several specimens are large, including one well preserved lower first molar that matches the Tunggur sample of *Protalactaga grabaui* [14]. The bulk of the sample resembles *Heterosminthus*, but lacks diagnostic, advanced features like a developed entostyle, and is significantly smaller than *H. orientalis* from Tunggur. Morphological and metric features are consistent with *Plesiosminthus xiningensis* from the Xiejia Formation [8]. A few teeth distinguished by narrow, transverse crests indicate the presence of *Parasminthus* as well.

4. Lanzhou Chronology

In the volume dedicated to the work of C.C. Young, who of course initiated research on Lanzhou small mammals, Qiu et al. [12] reviewed the paleontological perspective on age range of the deposits in the basin. Additional information from our ongoing study of the emerging microfaunas agrees with their correlations and adds to the basis for them. In addition, we frame our discussion in terms of the necessity of determining the *ages* of those correlations and the composition of the fauna characteristic of the Oligocene/Miocene boundary.

Up to now, scientists have used a working hypothesis on early Miocene biochronology, which still requires confirmation from independent dating. Li et al. [5] considered the Taben-buluk series to represent the end of the Oligocene epoch and proposed Xiejiaan, Shanwangian, and Tunggurian as successive "land mammal stages" representing early to middle Miocene time. No data have emerged that would dispute this general scheme, but later work [1-2] has elaborated on it, recognizing the Xiejia fauna as typical early Miocene, with two Lanzhou assemblages interpolated into the sequence: the Lanzhou local fauna [7] as older than Xiejia, and the Zhangjiaping fauna as younger. The Lanzhou local fauna contains Oligocene holdovers, including *Tsaganomys*, along side advanced species of *Tataromys* and the brachyericine hedgehog *Metexallerix*.

4.1. Duitinggou microfauna age constraints

The Duitinggou section includes, as noted above, a rich Oligocene assemblage from the Yellow Sandstone, which includes *Tsaganomys*, but no *Tachyoryctoides*. The Xiagou 9513 assemblage is considered late Oligocene by Qiu et al. [12], but we note that future study of screened material and definition of biotic indices for the epoch boundary could demonstrate early Miocene age.

Fossil sites from lower white sands horizons, 200 to 220 m in Duitinggou and equivalent to the Zhangjiaping fauna, yield Proboscidea, *Paraentelodon*, and a microfauna that are consistent with early Miocene correlation. One characteristic is lack of *Tsaganomys*, but common *Tachyoryctoides*. *Sinolagomys pachygnathus*, *Yindertemys xiningensis*, cf. *Plesiosminthus xiningensis*, cf. *Parasminthus*, and *Tachyoryctoides kokonorensis* argue for correlation to Xiejia - solidly early Miocene according to present understanding of biochronology. The possible *Ansomys* and dipodoid close to *Protalactaga grabaui* do suggest an age younger than Xiejia.

The 310 m locality 9303 retains archaic taxa, such as *Sinolagomys*, *Tachyoryctoides*, *Plesiosminthus xiningensis*, and *Yindertemys xiningensis*, but is characterized by advanced forms such as *Alloptox*, *Democricetodon,* and *Megacricetodon.* This level is probably Shanwangian equivalent. The younger horizon at 410 m, locality 9304, shares a significant number of taxa with Chuantougou and Tunggur (Table 2). We consider it as early Tunggurian, early middle Miocene.

Zhangjiaping and other lower white sands assemblages, and by correlation inference Xiejia, appear to be Miocene, if Proboscidea did not invade northern Asia much earlier than supposed. Qiu et al. [12] use large mammals to argue that these faunas correlate to the early Miocene of Bugti, Baluchistan. Accepting a constraint of early Miocene, just where in the early Miocene do these faunas fit? Important insight could be supplied by construction of an uninterrupted paleomagnetic section at Xiejia, which would show correlation of that reference section to the magnetic time scale. The results of the faunal analysis offer robust observations of correlation: lower white sands assemblages correlate with Xiejia, while site 9304 is nearly as young as Chuantougou. Still, we endeavor to determine the *ages* of these faunas and the small mammal assemblage characteristic of the Oligocene/Miocene boundary. This is why we sampled the paleomagnetic properties of the Duitinggou section.

4.2. Duitinggou magnetostratigraphy

In 1993 oriented hand samples were taken from the Duitinggou section using a brunton compass, at one to five meter intervals over the 400 m section (Fig. 2). Each sampled horizon consisted of three independently oriented samples taken from a single horizon. The samples were taken from fine-grained mudstones and siltstones. The Duitinggou section is in the eastern limb of the Lanzhou syncline, with beds dipping up to 35° to the west (see Fig. 2 in ref. [12]). The base of the measured section is 120 m below the prominent Yellow Sandstone, which marks the contact of the lower Yehucheng Formation and superposed Xianshuihe Formation. It extends through the entire 280 m of Xianshuihe Formation exposed there.

Laboratory work. The samples were fashioned into 2 cm cubes and were processed in the paleomagnetic laboratory at the University of Florida. The direction of magnetization was measured on a 3 axis cryogenic magnetometer housed inside a steel room which reduces the ambient field to under 400 milliteslas. All samples were demagnetized to destruction, using incremental thermal demagnetization in 14 or more steps. Typical results of thermal demagnetization are given in Fig. 3. The demagnetograms reveal two components of magnetization, a low temperature component that is removed by 300°C (A component) and a high temperature component that unblocks at 680°C (B component).

The directions of magnetization at each site are determined by line fitting to the characteristic component of magnetization [15]. Data are excellent and the MAD value for each specimen is usually under 10°. Site mean directions were then calculated using Fisherian statistics [16] The site mean directions for the B component are shown in Fig. 4. The mean direction of magnetization $D=8.4^{\circ}$; $I=37.8$ appears to be slightly rotated in a clockwise direction, however, this apparent rotation may be caused by an insufficient number of bedding attitudes being taken at the time of sampling, since correction for bedding tilt (right side of Fig. 4) causes a counter-clockwise rotation of the site mean directions. It should be noted that the mean inclination is shallower than expected.

Magnetic stratigraphy. Virtual Geomagnetic Poles were calculated for each site and polarity was plotted for relative stratigraphic position as shown in Fig. 5. Eighteen magnetozones are each delineated by two or more consecutive sites of the same polarity. Five other changes of polarity are defined by single sites. However, since three oriented samples were available for study from these sites, it is probable that the observed polarity changes represent changes in the earth's field, and are so defined.

We attempted to reconcile probable ages of Duitinggou fossil horizons with the magnetic polarity time scale. Hidden disconformities probably associated with the sandstones will undoubtedly distort the pattern match of the magnetostratigraphic record. The most probable position of a major unconformity would be the base of the Yellow Sandstone or at the base of the white sands.

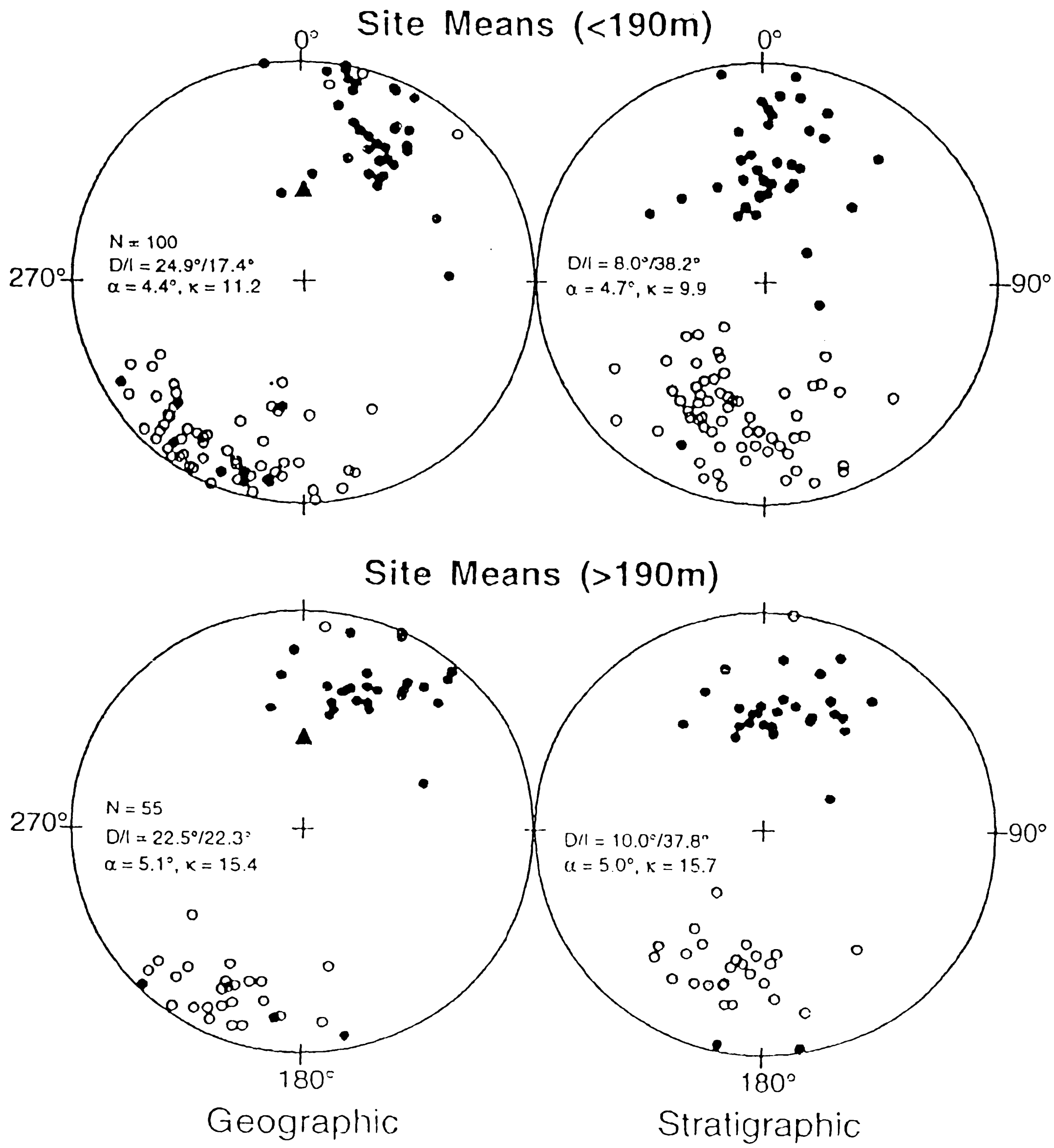

Figure 4. Site mean directions for Duitinggou samples grouped according to occurrence below and above the 190 m level, and showing correction for dip (right side of each pair).

Faunal tests of this hypothetical correlation are provided by localities 9303 and 9304. Site 9303 at 310 m includes the important index taxa *Democricetodon* and *Megacricetodon*. Qiu et al. [12] have already noted that the appearance of these rodents in Europe is taken as an event indicative of MN zone 4, with a maximum age of about 18 Ma [17], and this is also the age of appearance of these genera in Pakistan [18]. Given advanced ochotonids and other taxa (Table 2), the site likely is not that old. The correlation of its level to late chron C5Br, ca. 15.5 Ma is reasonable. Locality 9304, 100 m higher and showing taxonomic change, would correlate to the young end of chron as C5ADn, with a date in excess of 14 Ma. The Chuantougou quarry of the northern part of the basin is younger on stratigraphic and stage-of-evolution grounds. The previous correlation of Chuantougou with MN zone 7 in Europe [12], which is presumably less than 13 Ma, is consistent with our assessment.

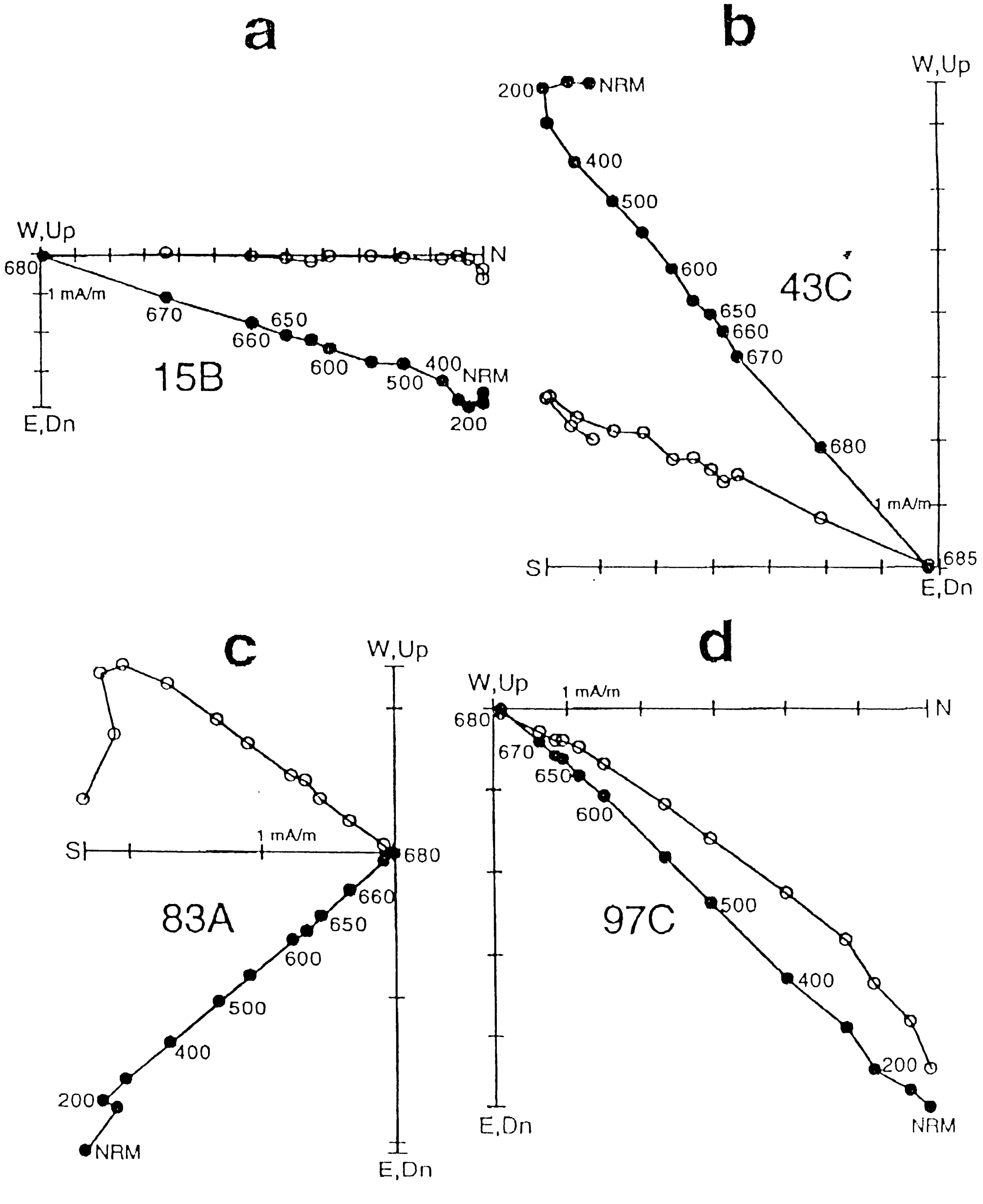

Figure 3 Orthogonal plots for thermal demagnetization of four typical samples from the Duitinngou section Figures 3a-3d show one of three samples (A, B, or C) from numbered paleomagnetic sites

Preceding arguments place the lower white sand units, ca. 200 m (Fig. 5), in the early Miocene. This level is near the top of the longest normal magnetozone in the section. These observations alone suggest identity as chron C6n. In fact, we suspect presence of a small hiatus below the white sands and that the magnetozone represents from 190 m upward, C5En. The succeeding magnetozone match to the GPTS is straightforward: C5Dn at 250 m, C5Cn triplet at 280m, C5Bn couplet at 320 - 350 m. The top long normal magnetozone would be C5ADn.

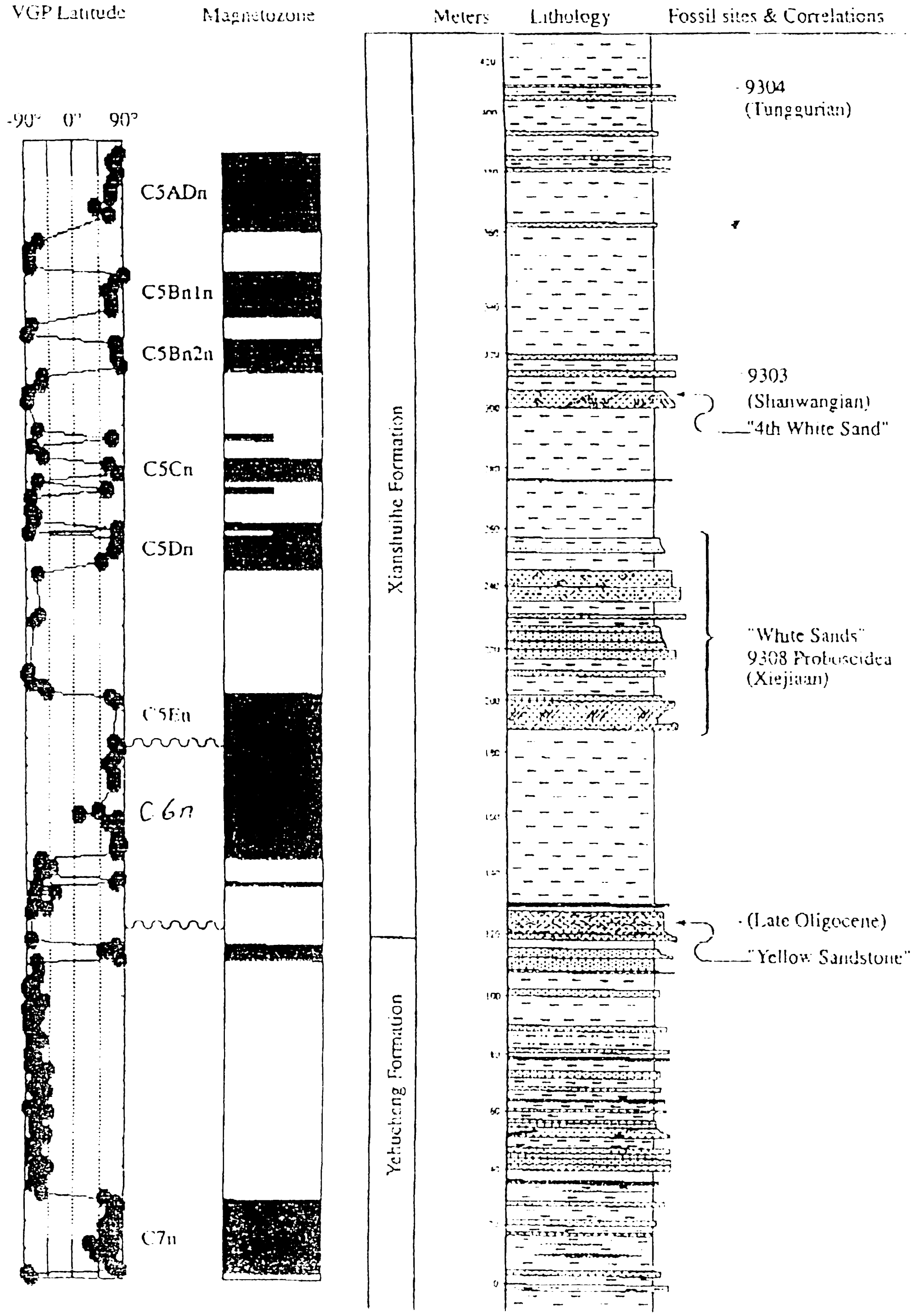

Figure 5. Duitinggou magnetostratigraphy. Observed virtual geomagnetic pole (VGP) latitudes and polarities against the stratigraphic column of Figure 1, with key sites and correlations. Postulated magnetozone correlations and hiatuses (wavy lines) are indicated, as well as mammal stage correlations

The fauna and magnetostratigraphy from 150 m upward can be reconciled to achieve age assessment without hypothesizing excessive breaks in sedimentation or varied rates of deposition. The correlation presents a scenario consistent with biochronologic work in China to date. The lower part of the section is problematic and presents intriguing questions that should stimulate further study.

The normal magnetozone at the base of the Duitinggou section is distinguished by the long reversed zone above it. Originally we considered this as a match to C13n-C12r, and this is still a possibility. However, this would call for a hiatus at the Yellow Sandstone - below it or above it, but not above C6n at 150 m - of about 9 million years, which we do not feel is warranted by field observation. Presently, we think it more likely that the basal normal magnetozone represents chron C7n. Several correlations for the base of the section and the short normal magnetozones are possible. To differentiate which are more likely requires comparison with parallel sections. The Dahonggou section, which seems to be significantly thicker between local Yellow and white sandstone levels, offers important data to test and clarify correlation. Complementary magnetostratigraphy along the Lanzhou syncline might test whether a gradual angular unconformity truncates slightly the section of Duitinggou.

The scenario presented here for magnetic correlation of the base of the Duitinggou section is relatively younger than that being tested [10] to interpret the Dahonggou section. Additional field-work would eliminate much of the ambiguity. For now, we note that our correlation matches well that of Fang, Voo and others (in preparation) who see the formation of Linxia Basin as taking place in the latest Eocene. We would not expect the Lanzhou Basin to have originated at a time greatly different from that of the neighboring Linxia Basin. Their work also notes the local first occurrence of Proboscidea as ca. 19 - 18 Ma.

Proboscidean datum. While correlation of the basal part of the Duitinggou section remains unresolved, the age of its upper half is secure. Using the Cande and Kent [19] time scale, the lower white sands deposited during chron C5En would be less than 19 Ma. Probably site 9308 and the proboscidean remains are all from reversely magnetized rock, and therefore slightly over 18 Ma. For the micromammals of locality 9308, this age is a reasonable estimate, although previously we might have presumed somewhat greater antiquity.

For the record of Proboscidea, this age is very close to that of the base of the Kamlial section in Pakistan, which yields gomphotheres and deinotheres. Interestingly, then, early Proboscidea are consistently recorded in Eurasia in rocks of less than 19 Ma. The only anomaly is the older occurrence of the primitive form *Hemimastodon* in Pakistan [20]. This taxon is known from both Bugti and the Zinda Pir Dome, both estimated to be in excess of 20 Ma. Because the local stratigraphic section at Bugti is quite long, the age of *Hemimastodon* there is unknown. If the Bugti rodent fauna is an indicator, however, then its age is significantly greater than the oldest Siwalik rodent faunas of ca. 18 Ma [21]. The Zinda Pir Dome *Hemimastodon* first occurrence is estimated at ca. 20.5 Ma [22]. Excluding *Hemimastodon*, the Lanzhou proboscidean is consistent with the Proboscidean datum event, as it is known from elsewhere in Eurasia.

5. Conclusion

Small mammal faunal horizons in Lanzhou Basin include a rich Oligocene assemblage from the widespread, traceable Yellow Sandstone, which marks the base of the Xianshuihe Formation. Eighty meters higher at about the 200 m level, lower white sands small mammals and Proboscidea indicate early Miocene age. Thus, the Oligocene/Miocene boundary is contained in the lower part of the Xianshuihe Formation. Deposition of the lower white sands began no more than about 19 Ma, and the fossil sites from this part of the section span 18 to 19 Ma. A superposed assemblage (locality 9303, about 15.5 Ma) is likely a Shanwangian equivalent. A stratigraphically high locality in the southern part of Lanzhou Basin, 9304, is faunally close to but older than Chuantougou from the northern part of the basin. We consider it early Tunggurian biochron, in excess of 14 Ma.

The implication of an age slightly greater than 18 Ma for locality 9308 is that the Xiejia local fauna and the Xiejiaan biochron are early, but not earliest, Miocene in age. Possibly some Chinese faunas, heretofore presumed to be Oligocene in age, are in fact Miocene, and the Yellow Sandstone of Lanzhou

Basin would be late, rather than early, Oligocene. We still have not pinpointed the Oligocene/Miocene boundary in Lanzhou Basin or the assemblage marking that boundary, but fossils from locality 9513 are a candidate. Further work can test these ideas, particularly work targeted on areas that appear to have more complete sections, as in the northern part of Lanzhou Basin. Increasing precision on stratigraphic correlation is a process in which the local paleontology and magnetostratigraphy mature hand-in-hand. The present function for the Lanzhou fossils is to outline general age constraints, which we can now do, so that paleomagnetic work can further delimit a detailed correlation.

Additional work in other basins elsewhere in China (Linxia Basin of Gansu, or the Junggar Basin of Xinjiang) can provide crucial cross checks by verifying homotaxis of the succession of faunas and magnetozones, as illustrated by Tedford [23]. Work in central Asia on similar assemblages could provide ties to radiometric dates (as at Hsanda Gol) in the future. Minimally for now, complementary magnetic sections from Lanzhou Basin can be applied to evaluate missing magnetochrons and extend magnetic sections upward and downward. The refinement and dating of China's early Neogene biochrons is a work in progress that is undergoing important growth and has tremendous potential to continue to do so in Gansu Province.

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