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Microtine rodents in the Frick Collection from Yushe Basin, Shanxi Province, China

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ABSTRACT

Charles A. Repenning probably examined every fossil microtine collection in the United States and most of them across the globe. The American Museum of Natural History, New York, holds significant specimens that attracted his attention. The Frick Collection of the American Museum is well known for its carnivoran and ungulate samples, but Frick collectors also managed to "squirrel" micromammals into the crates that came back from the field. Two interesting microtines accompanied diverse fossils from the Pliocene age deposits of Nan Zhuang Gou, Yushe Basin, Shanxi Province, China, and came to be recognized in the collection in the 1980s. As study of the American Museum specimens progressed under the direction of Richard H. Tedford, Rep and I determined that they represent two distinct taxa. Subsequent field work in Yushe Basin showed that one species, *Mimomys gansunicus*, is well represented in late Pliocene fluvio-lacustrine deposits. The other, *Mimomys orientalis*, is clearly older but not yet duplicated in modern collections of fossils from Yushe. Its affinity lies with *Mimomys* recovered from Yushe localities of about 3.3 Ma. The assemblage from Nan Zhuang Gou is a composite of material spanning at least one million years and probably acquired over a large part of the local subbasin.

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KEY WORDS: China; Yushe Basin; microtines; Pliocene; *Mimomys*; *Cromeromys*

INTRODUCTION

Charles A. Repenning preferred to be known as Rep to everyone. Rep was always kind and encouraging about research in the geosciences, especially to students, and this is the way I met him. He introduced the fascinating world of microtine evolution and diversity to the students of Everett Lindsay at the University of Arizona, Tucson, where I was part of the graduate program. Rep was profoundly interested in microtines – those muroid rodents with prismatic molars, which radiated during the later Neogene. He was particularly interested in the patterns of intercontinental dispersal of microtines, as evidenced in his subdivision of the late Cenozoic of North America (Repenning

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1987; Repenning et al. 1990) and subsequent analyses tracing the biogeography of diverse subgroups (Repenning 1998, 2003). Repenning (1988, 1992) well knew that the prismatic structure of the cheek teeth was likely independently derived in various microtine lineages (for example Arvicolinae versus Ondatrinae versus Lemminae [voles-muskrats-lemmings]), and he consistently used the term "microtine" as a convenient label for all of them, without implying close systematic relationship. Here, it is important to note that, while the microtine radiation covers perhaps no more than the last 7 m.y., the various microtines may well have a genetic coalescence that is deeper in time and monophyletic *with respect to most other extant* muroids.

Rep documented the evolution of detailed dental, cranial, and mandibular structures in microtines. He explored subtle changes in dentine tracts, expansion of the anterior cap of m1 and posterior expansion of M3, addition of triangles, spacing of triangles and thickness of their enamel, and development of cementum. He illustrated biogeographic dispersal routes through North America, coupled with an unsurpassed familiarity of the natural history of the western part of the continent, including its changes over time. This introduction to the world of voles, bog lemmings, muskrats, and their kin left an indelible imprint, such that years later, when I had fossil microtines at my disposal, I naturally turned to Rep as an authority and potential coauthor.

FRICK MICROTINES FROM CHINA

Fossils described here are conserved at the American Museum of Natural History (AMNH), New York, as part of the Frick Collection. Childs Frick was famous for amassing a large collection of fossil vertebrates mainly from Cenozoic deposits of the western United States. In the 1930s he also paid collectors to work in the late Tertiary sedimentary basins of Shanxi Province and elsewhere in the People's Republic of China. Kan Chuanpo ("Buckshot" of the earlier Central Asiatic Expeditions of the AMNH) was engaged to acquire material representative of the later Cenozoic of China in central to southern Shanxi, including Yushe Basin. Fifty years later, Richard H. Tedford and Qiu Zhanxiang led another expedition to Yushe Basin, of which I was a member.

The specimens collected by Buckshot came to be housed in the Frick Wing at the AMNH in the late 1970s. For the first time, Frick collections became available for general study. Typically, Frick had favored dramatic fossil representatives of carnivores and ungulates. Interesting rarer taxa inevitably were also found. Despite a bias against small mammals, several were inserted into the crates of fossils returning from the field, from both the western United States and China. Shanxi Province produced a number of excellent leporid and ochotonid specimens (see Erbajeva et al. 2006) and a rich microfauna from Pai Tao Tsun (as it was known in the 1930s). Few but diverse small mammals also came from Yushe Basin (Table 1) and many of these were attributed to the general collecting area Nan Zhuang Gou. Two microtines in the Nan Zhuang Gou assemblage attracted my attention, and I enlisted the help of Charles Repenning in their description and interpretation.

Our research led to the conclusion that the museum collection from Nan Zhuang Gou was a composite of material coming probably from a large area and held until buyers (typically dragon bone drug dealers) came to purchase them. Realizing that the collection in itself would not advance understanding of microtine biogeography and biochronology, by 1989 we abandoned a manuscript on their significance. However, Rep had prepared a beautiful drawing of the two specimens, and his description remains sound. Subsequent field work has made a return to analysis of these specimens relevant to fuller knowledge of the fossil record of Yushe Basin. In the following, I borrow from our fragmentary manuscript and add new data.

Abbreviations:

AMNH – American Museum of Natural History, New York

F:AM – Frick Collection of the American Museum of Natural History

IVPP – Institute of Vertebrate Paleontology and Paleoanthropology, Beijing

YS – YS followed by a number is a site number in the "Yuhse Site" system employed by the Sino-American field team, 1987-1991.

SYSTEMATICS

Genus *Mimomys* Forsyth Major, 1902[1]

Arvicoline rodent with rooted molars and anteroconid complex on m1 having a cap that is skewed lingually and with prominent wings, a "*Mimomys* Kante[2]" and an islet derived from a buccal reentrant in early stages of wear; M3 with one triangle and a basined posterior loop (islet with wear) or two triangles and hooked posterior loop.

Cementum and dentine tract development are trends within the genus.

Mimomys (Mimomys) orientalis Young, 1935

Holotype and Type Locality: complete right m1 of a young individual, little worn, now lost according to Zheng and Li (1986); from locality 34, lower level (sands) at Pinglu, southern Shanxi, more than 300 km south southwest of Yushe.

Distribution and Age: The type locality is considered "Youhean" in age, now late Yushean (Late Pliocene, pre-Nihewanian), and a referred specimen is from Weinanliuhe, Youhe, Shanxi Province. Zheng and Li (1986) reported Yushe specimens purported to come from around Haiyan and Jizi Gou, which is middle to late Pliocene.

Diagnosis: Length of m1 ranges from 2.8 to 3.1 mm, cement absent from reentrant angles (traces of cement in one specimen according to Young 1935), islet present in the anteroconid complex until about half worn, dentine tracts moderately developed (as in *M. hajnackensis*).

Referred specimen from Nan Zhuang Gou: F:AM 116247, a left dentary with incisor, m1 and m2, and with m3 alveolus but lacking the posterior part of the jaw (Figure 1). Cheek teeth are half worn, so that the enamel islet of m1 is nearly removed by wear. A dense area in the dentine with a minute remnant of enamel still shows the position of the islet. The m1 is 2.9 mm long. There is no cement in the reentrants of F:AM 116247. The full extent of dentine tracts is not known due to wear, but on the buccal posterior salient angle, the tract is comparable to the modest tract of unworn specimens (see the buccal views of specimens described by Zheng and Li (1986), fig. 3).

The matrix found in crevices of F:AM 116247 appears to indicate a rather dark gray to brownish gray poorly sorted mudstone with fine sand and abundant black grains. The bone is dark brown with light brown highlights where thinner. The occlusal surface of the tooth enamel is medium gray, while the dentine is orange-brown. These contrast in the second specimen.

TABLE 1. Composite list of mammals from Nan Zhuang Gou in the AMNH Frick collection (recent collections excluded). Asterisk denotes mid-Pliocene (Mazegou Fm.) or younger elements; double asterisk signifies later (Haiyan Fm. or loess) components of the assemblage; other taxa could be derived from the Gaozhuang Fm.

Erinaceidae

*Erinaceus olgai**

Ochotonidae

Ochotona sp.

*Ochotonoides complicidens***

Leporidae

*Lepus wongi***

Sciuridae

Speromphilus sp.

Cricetinae

Genus undetermined

Myospalacinae

*Mesosiphneus praetingi**

Arvicolinae

*Mimomys (Mimomys) orientalis**

*Mimomys (Cromeromys) gansunicus***

Canidae

Nyctereutes sinensis

Hyaenidae

Genus undetermined

Elephantidae

Genus undetermined

Suidae

Sus sp.

Cervidae

*Axis shansius**

*Cervus elaphus***

Subgenus *Cromeromys* Zazhigin, 1980

Enamel islets in m1 and M3 not present, cement present in all species and well developed in later forms, "*Mimomys* Kante" present on the buccal primary wing in older forms and progressively migrates anteriorly as a distinct triangle of the cap of the anteroconid complex, dentine tracts

1. Repenning loved footnotes. He would drive editors crazy, inserting comments copiously. I follow his example in this and in his usage of *Mimomys* subgenera. Later *Mimomys* (*Cromeromys*) has many derived features that make its diagnosis easy. *Mimomys* (*Mimomys*), on the other hand, is a cluster of primitive *Mimomys* species that show the generic characters but with little else uniting them. They tend to be larger species, so his rule of thumb was that average length of m1 is 3 mm or more – but this is an average, and individuals, like the one described here, can be less than 3 mm.

2. Diagnoses and terminology follow Repenning (2003, for example). *Mimomys* Kante is an extra structure at the anterior end of the first lower molar (m1), a vertical ridge on the buccal primary wing of the anteroconid complex.

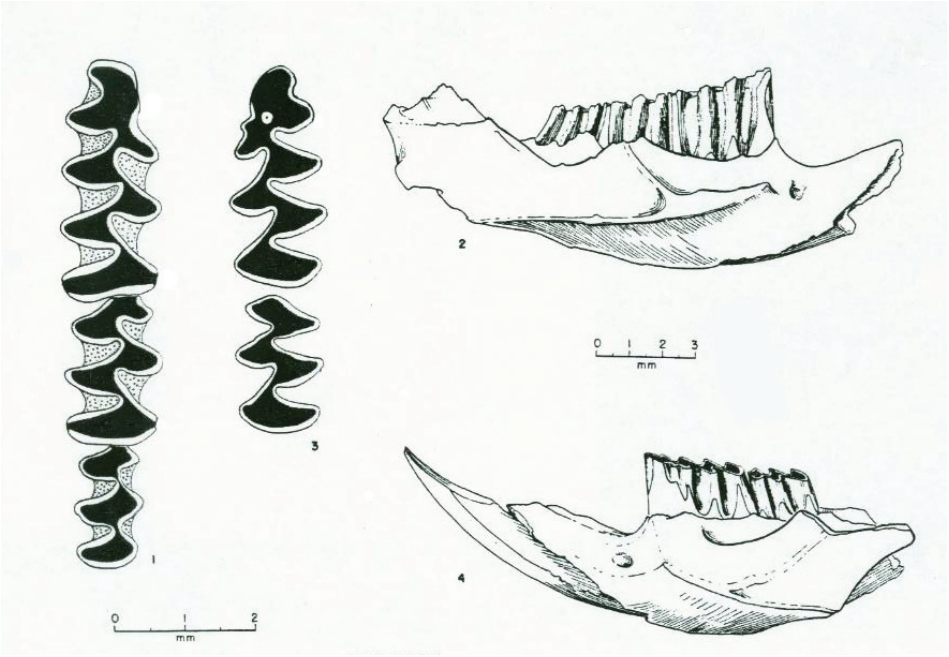

FIGURE 1. Occlusal and lateral views of Frick collection microtines from Nan Zhuang Gou. Right dentary F:AM 116248, *Mimomys (Cromeromys) gansunicus* (1, 2). Left dentary F:AM 116247, *Mimomys (Mimomys) orientalis* (3, 4). Separate millimeter scales for the occlusal views and lateral views (drawings by Charles Repenning).

progressively more developed with time, M3 short, with completely confluent central triangles and wide posterior loop not extended posteriorly.

Mimomys (Cromeromys) gansunicus Zheng, 1976

Holotype and Type Locality: IVPP V-4765, a right m1 from an adult with incomplete root development from Jingou, Heshui, Gansu Province.

Distribution and Age: The few Chinese specimens known to Repenning in the 1980s are from early Nihewanian age deposits, early Matuyama Chron equivalent, late Pliocene. Repenning considered this species to be very close to *Mimomys tornensis* of Europe and to *Mimomys* populations from Siberia incorrectly called *M. intermedius* by Zazhigin (1980), both of which range from late Pliocene into early Pleistocene. Field work in Yushe Basin in 1988 produced abundant *M. gansunicus* from the Haiyan Formation, early Matuyama Chron (Flynn et al. 1997).

Diagnosis: Length of m1 ranges from 2.9 to 3.1 mm, "*Mimomys* Kante" absent or weakly developed on the posterior part of the cap of the anteroconid complex, cement well developed, dentine tract on the posterior buccal salient angle very long and breaking the enamel pattern of the occlusal surface at a slightly earlier stage of wear than does the tract on the buccal face of the anteroconid complex.

Referred specimen from Nan Zhuang Gou: F:AM 116248, a right dentary with all cheek teeth and part of the posterior portion of the jaw. The specimen is an adult, with roots fully formed on all molars, but wear is only about one quarter on the molars with the dentine tract of the anteroconid complex not quite reaching the surface. The dentine tracts are slightly less extensive than those of *M. tornensis*, suggesting somewhat greater geological age, consistent with early Matuyama Chron equivalence in China.

The matrix found in crevices of F:AM 116248 appears to indicate a light reddish tan well sorted sandstone composed of very fine to fine sand with almost no black grains. The bone is white with tan stains, and on the occlusal surface of the teeth the enamel is light gray but is mottled dark gray low on the sides of the teeth. The dentine and cement are white. The bone and possibly the enamel have been bleached by exposure, and the bone is gray (not dark brown) beneath its surface.

MIMOMYS PRODUCED BY YUSHE FIELD WORK

The Sino-American team assembled by Richard Tedford and Qiu Zhanxiang in the late 1980s

1

EPOCH		MAMMAL AGE	
		Li, Wu, Qiu, 1984	Qiu and Qiu, 1995
PLEIST		NIHEWANIAN	NIHEWANIAN
PLIOCENE		YOUHEAN JINGLEAN	YUSHEAN
MIOCENE		BAODEAN	BAODEAN

2

EPOCH	TEILHARD - TRASSAERT ZONE	FORMATION
PLIOCENE	ZONE III	HAIYAN
	ZONE II	MAZEGOU
		GAOZHUANG
MIOCENE	ZONE I	MAHUI

FIGURE 2. North China biochronology (1, above) and the stratigraphy and general biozonation applied to Yushe Basin, Shanxi Province (2, below). The Yushean mammal age supplants the Pliocene Jinglean and Youhean; Nihewanian is shown to be late Pliocene, in part. The classic biozones of Teilhard de Chardin and Trassaert (1937) have lithostratigraphic correlates. In the Nan Zhuang Gou area, the Gaozhuang and Mazegou formations, separated by a short hiatus, correspond to their Zone II. Gaozhuang and Mazegou assemblages differ at the species and generic levels. Wavy lines indicate depositional hiatuses. Figure modified from Flynn et al. (1997). Outcrop in middle of upper photo 0.5 km long.

launched a comprehensive investigation of the deposits near the town of Yushe, Shanxi Province, especially the local Yuncu and Yushe subbasins. Qiu Zhanxiang (1987) had worked out the local lithostratigraphic sequence, which we measured and sampled for its paleomagnetic zonation (Tedford et al. 1991). Yushe is the site of classic studies of the late Cenozoic faunas of East Asia. Teilhard de Chardin and Trassaert (1937) recognized three zones, which we were able to correlate to the observed succession (Figure 2). Zone I corresponds to our late Miocene Mahui Formation. Much of the Yushe sequence is Zone II, early to mid-Pliocene, and we recognized two units, the Gaozhuang and Mazegou formations. These Pliocene units and their faunas were employed by Qiu and Qiu (1995) to typify the Yushean Mammal Age, which supplants the Jinglean-Youhean usage of Li et al. (1984). Zone III corresponds to a thin fluviolacustrine unit, the Haiyan Formation, reversely magnetized and considered pre-Olduvai Matuyama. It is correlated as early Nihewanian Mammal Age. As part of the loess plateau, Yushe contains overlying red and yellow loess, the oldest units of which probably date to about 1 Ma.

The Mahui Formation produces no microtines. Rep was keenly interested in *Microtoscoptes* Schaub (1934), known from abundant material from Ertemte, Inner Mongolia (Fahlbusch 1987). This genus does not occur in Yushe, but Yushe sediments equivalent in age to Ertemte would be uppermost Mahui or lower Gaozhuang Fm. *Germanomys*, a later prometheomyine relative of *Microtoscoptes*, does occur higher in the Gaozhuang and Mazegou formations.

The oldest Yushe *Mimomys* is from upper levels of the Gaozhuang Fm., which Flynn et al. (1997) placed in excess of 4 Ma. The material is indeterminate, but with low dentine tracts. The Mazegou Formation, in the range of about 3.4 to 2.9 Ma produces a nice sample of *Mimomys*. The best locality, toward the older part of the range, is YS5, found by Richard Tedford. In consultation with Zheng Shaohua, Rep and I studied a suite of jaws from YS5 and developed the opinion that it represents *Mimomys (Cromeromys) irtyshensis*, the type species of the subgenus. It differs from *C. gansunicus* in having considerably less cement. It is not a member of the subgenus *Mimomys* and lacks evidence of an islet or primitive "*Mimomys* Kante".

3. Kormos (1934) named *Mimomys chinensis* for material from a locality in Hebei Province. This species is derived and has been referred to *Villanyia* (for example, Zheng and Li 1990). However, Rep followed current European workers who see *Villanyia* as endemic to Europe and utilized *Borsodia* as the appropriate generic name.

FIGURE 3. Exposures of the Gaozhuang Formation of the Nan Zhuang Gou area. Image above: sediments dip gently to the northwest. Image below: Will Downs prospects marl horizon, with outcrops of overlying red and yellow loess in the distance. Kodachrome slides by L. Flynn 1987-1988.

The Haiyan Formation produces a distinctive mammal fauna. For the microtines, it contains derived species, abundant *Cromeromys gansunicus* and *Borsodia chinensis*[3]. Thus our field work determined the likely stratigraphic origin of the F:AM *Cromeromys gansunicus* specimen. It probably came from young, late Pliocene, or possibly early Pleistocene deposits in Yushe Basin, likely not from the same time range as that producing the F:AM *Mimomys orientalis*. Our conclusion is based on different matrix and preservation in the fossils.

The overlying loess is a possible source for some of the old collections attributed to Nan Zhuang Gou, but the only microtine we found in the older loess was referable to the extant genus *Microtus*, probably identifiable as the Gongwanglingian *M. brandtioides*.

Where would *Mimomys orientalis* have occurred in Yushe Basin? Unfortunately, this species has not been recovered in modern collections from Yushe. *M. orientalis* represents a different clade than the *Cromeromys* lineage. Zheng and Li (1986) postulated that *M. orientalis* is a member of the Youhean Mammal Age, which would correlate with uppermost levels of the Mazegou Fm., ca. 3 Ma. That hypothesis is consistent with the provenance data for the old Yushe specimens they referred to *M. orientalis*: one is from the Zhaozhuang area, which is Mazegou Fm., and one is attributed to Haiyan (which is up section, but near Zhaozhuang). Zheng and Cai (1991) confirmed this conclusion by noting that *M. orientalis* occurs at Daodi with the derived myospalacine *Mesosiphneus paratingi*, an upper Mazegou Fm. element.

NAN ZHUANG GOU

Our field crew visited Nan Zhuang Gou ("gou" meaning wash) in 1987 and 1988. Located about 11 km west of the town of Yushe, it was known to the French Jesuit E. Licent (his locality 24, Licent and Trassaert 1935). A village there now bears the name Nan Zhuang Cun ("cun" meaning village). Buckshot acquired the two microtine specimens from the area in 1935, but provenance data only allude to the town where they were purchased. Richard Tedford's research in the 1980s on AMNH specimens from Yushe Basin had already indicated that Buckshot's Nan Zhuang Gou collection came from at least two sources characterized by different modes of preservation. Many specimens preserved in a sandy matrix are stained and partially mineralized; others are little altered by fossilization, have fine grained matrix, and likely came from silty to sandy nodules in the base of loess overlying the local basin fill.

Nan Zhuang Gou is located in the Yuncu subbasin of Yushe Basin, where the Sino-American team under Tedford and Qiu primarily conducted its field work (Figure 3). The stratigraphy there is local and applies only broadly to other subbasins. Sediments exposed near Nan Zhuang Gou occur in the top half of the unit named the Gaozhuang Formation and the overlying loess. The local Gaozhuang strata correlate to Chrons C3n1r and C3n2n, about 4.4 to 4.6 Ma. We found squirrels, hamsters, murines, early *Germanomys,* and primitive myospalacines there, but no *Mimomys*. There are many exposures of the overlying red and yellow loess at Nan Zhuang Gou, so it is quite possible that some fossils might come from those Pleistocene deposits.

The general strike of the nearly flat Yushe sediments is northeast-southwest, age decreasing to the northwest. Immediately east and southeast of Nan Zhuang Gou are older Gaozhuang deposits assigned to Chron C3n2r, about 4.7 Ma. East of Nan Zhuang Gou (Figures 4 and 5) are our productive site YS50 (within about 0.5 km), and 2 km

FIGURE 4. Gaozhuang Formation at YS50, 0.6 km east of Nan Zhuang Gou. Will Downs stands at fossiliferous sand unit. Kodachrome slide by L. Flynn 1987.

away, the Yaergou Quarry (=YS57) that had produced the type specimen of the murine *Chardinomys yusheensis* Jacobs and Li (1982). It is quite conceivable that specimens from these older deposits could have made their way to Nan Zhuang Gou dragon bone dealers.

Younger strata occur in the opposite direction. Near Nan Zhuang Gou deposits of about 4.2 Ma produce more advanced rodents plus early *Mimomys*. We place a hiatus in the section about 0.5 km to the northwest, where the rock becomes dominantly normally magnetized ("Gauss" age). This is the type area of the Mazegou Formation, which contains mid-Pliocene faunas, including *Mimomys (Cromeromys) irtyshensis*, a derived species of *Chardinomys*, and the myospalacine *Mesosiphneus paratingi* (Flynn et al. 1997).

Within about 2 km of Nan Zhuang Gou, up and down section, deposits ranging in age from about 4.7 to 3.4 Ma are encountered, all very accessible to early collectors amassing fossils for sale. It seems quite likely that old assemblages, such as the Frick collection, would include elements from throughout this fossil-rich sequence and from the overlying loess.

CONCLUSIONS

Of the composite fauna in the Frick Collection (Table 1), several taxa quite possibly came from nearby Nan Zhuang Gou (but could be younger elements): *Ochotona, Spermophilus*, *Sus*, and *Nyctereutes*. Others are known from the Mazegou Fm. or younger deposits: *Erinaceus olgai, Mesosiphneus praetingi,* and *Axis shansius.* Modern field work duplicated *M. praetingi* in the base of the Mazegou Fm. Higher in the formation, new collections include *M. paratingi* and *Ochotonoides* close to *O. complicidens*. Possibly *Mimomys orientalis* could come from this interval.

Some Nan Zhuang Gou taxa first appearing in upper levels of the Mazegou Fm., e.g., *Ochotonoides, E. olgai*, and elephantids, range into younger Nihewanian localities of Yushe and elsewhere. Other elements (*Lepus wongi, Cromeromys gansunicus, Cervus elaphus*, and true *Ochotonoides complicidens*) appear to be strictly Nihewanian and would be additions from the overlying loess or from the reversely magnetized Haiyan Formation, about 7 km to the northwest of Nan Zhuang Gou.

FIGURE 5. YS57, Yaergou Quarry, 2 km east of Nan Zhuang Gou. Exposures nearly overgrown and cultivated; Wu Wenyu collecting matrix for washing. Kodachrome slide by L. Flynn 1988.

Previously, Rep and I had the impression that Nan Zhuang Gou fossils collected in the 1930s came from two levels: the local early Pliocene strata and the overlying loess. It was apparent that the two microtines did not belong in the same assemblage, and that certain F:AM taxa were mutually exclusive (e.g., *M. praetingi* and *O. complicidens*). It is now evident that the two-horizon hypothesis does not explain the observed temporal spread. Based on occurrences of taxa determined from field work, my present conclusion is that the Frick fossils would have been acquired from multiple horizons, not all in the vicinity of the local exposures. It is apparent now that Nan Zhuang Gou was a point of sale for material that came from a considerable area of Yushe exposures, encompassing a large span of time.

Although the Nan Zhuang Gou assemblage acquired in the 1930s sheds little light on East Asian biochronology, it nonetheless includes important specimens and is a product of the history of collecting in the area. It also presents a clear example of why precise provenance is important in biostratigraphy. Charles Repenning was a champion of resolved biostratigraphies that are relevant to correlating regions of continental and intercontinental scale. The IVPP-AMNH program in Yushe Basin was designed in that vein – construction of a precise local biostratigraphy that could be extended to a broad region for biogeographic and chronologic analyses. Modern work in Yushe Basin enabled resolution of taxon ranges in time, thereby extending the local biostratigraphy to regional biochronology. Careful fieldwork also specified likely provenance of key fossils collected earlier in the 20th century. Elsewhere in the Holarctic, that level of precision enabled Rep to build a comprehensive interpretation of microtine evolution and dispersal on a global scale.

ACKNOWLEDGMENTS

This contribution must acknowledge Rep, himself, because it began as a coauthored manuscript. We abandoned that effort because it became apparent that the assemblage was a composite, and further, that it was not possible, given data then at hand, to reconstruct the origin of the fossils. The present product differs from our original attempt to advance microtine biochronology. Still, the conclusions drawn here were stimulated by Rep's thinking and publications. Richard Tedford also provided crucial supporting information, and he found the important locality YS5. Zheng Shaohua also kindly supplied information and came to the similar conclusion of multiple origins

for the Nan Zhuang Gou assemblage. I acknowledge the collegial collaboration of IVPP and the Yushe field team, including Qiu Zhanxiang, Wu Wenyu, Will Downs, and Neil Opdyke, and thank the editors for the opportunity to present this tribute.

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