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The Late Cenozoic Mammal Record in North China and the Neogene Mammal Zonation of Europe

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ABSTRACT – *The focus of modern biostratigraphic studies on later Cenozoic deposits of China is multifaceted. Recent efforts have established a well-resolved biostratigraphy and have advanced alpha taxonomy of new faunal elements. From this basis, researchers have begun to analyze faunal patterns through time, recognizing turnover, relative faunal stability, and appearance of exotic elements. Events intrinsic to the depositional systems and contained fossils of China are the foundation for eastern Asian biochronologic units whose utility in other depositional systems, indeed beyond China, is readily testable. Such research is rather advanced for the late Neogene represented in Yushe Basin, Shanxi Province. The robust regional biochronology can be correlated with the MN zonation of Europe at a finer degree of precision than hitherto possible. As previously acknowledged, the oldest Yushe deposits correlate to MN 13. Successive assemblages represent equivalents of MN 14-17 and terminate with a middle Pleistocene microfauna. Closest correlation is with MN 13 and MN 17. Few species are shared, however, and a number of genera show different temporal ranges in Europe and China, attesting to different dispersal patterns of certain elements.*

RIASSUNTO – [Il record fossile a mammiferi del tardo Cenozoico in Cina e la zonazione a mammiferi del Neogene dell'Europa] – *Gli studi in corso sulla biostratigrafia dei depositi del Cenozoico superiore della Cina sono focalizzati su diversi obiettivi. Negli ultimi anni è stato possibile realizzare un quadro biostratigrafico ad alta risoluzione, ed è stato definito lo stato tassonomico di nuovi elementi faunistici. Su questa base i ricercatori hanno potuto analizzare la dinamica dei cambiamenti nelle associazioni faunistiche nel tempo, individuare i periodi di rinnovamento e di stabilità delle associazioni faunistiche ed i momenti di dispersione che hanno portato all'ingresso di elementi esotici (Flynn et al., 1991). La successione degli eventi sedimentari e delle associazioni a mammiferi fossili in alcuni bacini sedimentari, sono la base della costruzione di una scala biocronologica per l'Asia, la cui applicabilità in altre successioni sedimentarie della Cina è già stata verificata. Questo tipo di ricerche è ormai ad uno stadio molto avanzato per la successione neogenica affiorante nel bacino di Yushe, nella provincia di Shanxi (Qiu et al., 1987; Tedford et al., 1991). La solida scala biocronologica sviluppata in questa successione, può essere correlata, con una risoluzione sino ad oggi impensabile, con la zonazione MN dell'Europa. Le associazioni faunistiche provenienti dai depositi più antichi di Yushe sono correlate con l'unità MN 13. Le associazioni successive rappresentano equivalenti delle unità MN 14-17 e terminano con una associazione a micromammiferi del Pleistocene medio. Le correlazioni più evidenti sono con le unità MN 13 e MN 17. Poche sono tuttavia le specie in comune e molti generi hanno distribuzioni temporali diverse in Europa e Cina, a dimostrazione che molti taxa hanno tempi e modi di dispersione differenti.*

INTRODUCTION

Through the middle part of the last century, the science of vertebrate paleontology in China advanced by the efforts of scientists surveying the fossil wealth of that vast region. Earlier researchers, who explored important fossil beds and brought to light famous localities, had only discovered the tip of the iceberg. In many ways, the Chinese fossil record is unsurpassed because it is so complete when taken as a whole. A number of fossil basins have emerged, which contain thick deposits that yield multiple fossil horizons. This is crucial for basing a refined level of biostratigraphy on single depositional settings. The best of these basins contain many fossil horizons that allow resolution of the local history of change on a scale of 10^5 years.

After an interval of collecting, assaying, and description, scientists have increasingly turned to synthetic studies for China. Chiu *et al.* (1979), refined by Li *et al.* (1984), proposed a series of biochrons for the Neogene of China, which have proven durable and useful. Some notable alterations have accommodated new data (Qiu, 1990; Qiu & Qiu, 1995), so

that at the beginning of the 21st century the major biochrons based on mammal zonation are stable. Qiu *et al.* (1999) formalize successive Miocene time units based on fauna by naming Neogene Mammal Units (NMU) for that epoch; NMU 11, the youngest, is roughly equivalent to MN 13.

The next challenge is heightened precision of biochronology by densely sampling biostratigraphy in fossiliferous basins. Yushe Basin in Shanxi Province provides one of the better examples for realizing this potential for the late Neogene of China. The biostratigraphy of Yushe Basin has been built by the efforts of a collaborative team (Qiu *et al.*, 1987; Tedford *et al.*, 1991), with special attention to carnivores (Qiu, 1987; Qiu & Tedford, 1990; Tedford & Qiu, 1991, 1996), artiodactyls (Chen, 1991; Dong & Hu, 1994) and rodents (Flynn, 1993; Flynn *et al.*, 1991, 1997; Wu & Flynn, 1992). Like many basins, Yushe Basin lacks suitable rocks for radiometric dating, but Yushe Basin has a long section, whose composite magnetostratigraphy can be correlated unambiguously to the Magnetic Polarity Time Scale (Flynn *et al.*, 1995; Tedford *et al.*, 1991).

Many interesting questions in paleobiology require ever greater resolution of the fossil record. Precision in correlation of the developing paleobiotic record of China to the mammalian zonation of Europe demands precision in the biochronology of the Chinese record and continued testing of the MN zonation of Europe. Given an independent biochronology built on north-east Asian biostratigraphies, it is possible to establish correlations to European biochronology based in part on index fossils, and by reference to paleomagnetic data. This paper highlights relevant fossil appearances and the paleomagnetic composite record for northeastern Asia, specifically the Yushe Basin of China, to test a correlation to the MN zonation of Europe.

PREVIOUS WORK

The French Jesuits E. Licent and M. Trassaert (1935) recognized that the Yushe Basin of Shanxi Province, North China, contained a key sequence of faunas in one place. They demonstrated superposition of faunas of "*Hipparion* red clay" type, intervening assemblages, and overlying Nihewan type (their Zones 1, 2, and 3). These faunas were thought to have temporal significance (explicitly in Teilhard & Trassaert, 1937, who utilized Roman Numeral Zones I, II, III), and thus span Pliocene time. We now know the faunas to date to late Miocene through late Pliocene time. Representatives of the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Beijing, continued such studies. Qiu (1987) and Qiu *et al.* (1987) summarized work known up to that time, and identified Yushe as the best place to build a reference biostratigraphy for the late Neogene. Parallel to this work, Cao *et al.* (1985) investigated the Zhangcun area to the south of the town of Yushe. This area differs from Yushe lithostratigraphically, but yields consistent biostratigraphic and magnetostratigraphic results. Qiu (1987) concluded his study of hyaenids with the first preliminary correlation of the Yushe Basin sequence to the European MN zonation.

Subsequent work by Qiu Zhanxiang and colleague Dick Tedford (American Museum of Natural History, New York) led to refined biostratigraphic study and recognition that the contained biostratigraphic units represented biochrons applicable to a large part of northeastern Asia (Mongolia and southern Siberia to eastern Kazakhstan) (Tedford *et al.*, 1991). Flynn *et al.* (1991) examined the pattern of faunal change and saw major events near the Miocene/Pliocene boundary and in the late Pliocene. Later, Flynn (1997) examined key dispersal events as recorded especially in the rock record of Yushe Basin.

The Yushe biochronology tested the pre-existing biochrons of North China that had been proposed (e.g., Li *et al.*, 1984). This led to adjustments by Qiu (1990) and Qiu & Qiu (1995), which validated the earlier analysis, except that much of Pliocene time was found to reflect a little-changing fauna. These

authors recognized a Yushean mammal age, replaced by early Nihewanian in the late Pliocene. The Yushe record documents change from stable late Miocene faunas (late Baodean age), through Yushean, to early Nihewanian assemblages. As data accumulate, the Yushean may be divided into subages in the future, as suggested by Qiu (1990).

Up to now, we have focused on establishing the paleobiotic succession of northern China, exploring its paleogeographic limits, and studying paleobiotic trends in that part of Asia. Now that the biochronology is better established, it becomes more instructive to explore precise correlations with Europe. Toward that end, we attempt a correlation to the MN zonation of the continental deposits to the west.

THE BIOSTRATIGRAPHIC SUCCESSION OF YUSHE BASIN

Yushe large mammal faunas are dominated by deer, antelopes, and gazelles, by hipparionine horses and elephant-like proboscideans, and by hyaenid and felid carnivores. Small mammals include shrews and moles, the pika *Ochotona* and several hares, flying and ground squirrels, gerbils, hamsters, mice, voles, and the ubiquitous gopher-like zokors (myospalacines such as *Prosiphneus*). Yushe lithostratigraphy around the town of Yushe is a set of fluviolacustrine deposits including fining-upward sequences. The local Mahui Formation lies on Triassic bedrock and includes many Baodean late Miocene elements plus murids and *Stegodon*. It is truncated by a slight angular unconformity, apparently representing little time (based on faunal similarity and thickness of magnetozones). The succeeding Gaozhuang Formation yields Pliocene elements, such as early camels and canids, *Pliohyaena*, *Sus*, high crowned gazelles, *Muntiacus*, *Axis*, and *Proboscideipparion*. New rodents are advanced zokors and, later, arvicolines. As Flynn (1997) showed, new appearances continue during the Pliocene, as with *Ursus* prior to 4 Ma. The successive Mazegou Formation contains similar fauna indicating general community stability. However, species composition differs, with rodent lineages characterized by higher crowned species. Notable appearances in the Mazegou Formation are *Ochotonoides*, *Antilospira*, *Lynx*, and *Felis*, followed later, about 3 Ma, by *Archidiskodon*, *Canis*, and *Vulpes*.

An unconformity occurs between the Mazegou and overlying Haiyan Formation. The Haiyan fauna differs greatly from underlying assemblages and is latest Pliocene. It contains advanced arvicolines (*Borsodia* and *Cromeromys*) and zokors (*Youngia*), as well as *Marmota*, *Trogontherium*, *Equus*, *Elaphurus*, *Bison*, and *Megalovius*. A blanket of loess yields small mammals spottily. The oldest "loess" (deep red loam) assemblages correlate to faunas of about 1 Ma or somewhat younger, and contain *Microtus*, *Cricetulus barabensis*, and endemic Pleistocene species (see Flynn *et al.*, 1997).

EVIDENCE FOR MN ZONE CORRELATION IN YUSHE BASIN

The preceding section briefly outlines Yushe biostratigraphy. We mean "biostratigraphy" literally, because we discuss faunas with respect to successive lithostratigraphic units. Lithostratigraphy is discussed at length elsewhere (e.g., Tedford *et al.*, 1991; Flynn, 1997). Our purpose here is to improve the basis for correlation to MN zonation (Text-fig. 1), which of course depends on fauna.

The Mahui Formation yields a large mammal fauna considered comparable to but younger than the famous Baode beds to the north (see Kurtén, 1952). Classic MN 13 components are the hyaenids *Adcrocuta eximia*, *Ictitherium*, plus *Chasmaporthetes*, the last records of the felid *Machairodus* and bear *Indarctos*, several horse species, the suid *Microstonyx*, low crowned *Gazella*, the porcupine *Hystrix*, the beavers *Dipoides* and *Castor*, and the mammutid *Stegodon*. Upper levels of the Mahui Formation contain abundant fossils, including several small mammals with stratigraphic ranges extending into the lower part of the Taoyang Member of the Gaozhuang Formation (see Flynn *et al.*, 1997). Taoyang deposits add *Paracamelus* and *Nyctereutes* to the list of MN 13 index fossils. Flynn *et al.* (1997) correlated the Ertemte local fauna of Inner Mongolia to basal Taoyang levels, about 5.5 Ma. Consensus (most

recently Qiu & Storch, 2000) relates Ertemte to late MN 13, which is supported by its records of *Eozapus*, *Microtoscopes*, *Micromys*, *Apodemus* and *Pseudomeryx*. Consequently, we see evidence for MN 13 correlation to Mahui Formation faunal levels as well as basal Gaozhuang Formation.

Oldest Mahui Formation fossils are about 6.5 Ma, and we see no evidence for MN 12 correlation here, although some forms such as *Hystrix* and *Pliopetaurista* appear earlier in Europe (Sen, 1999). On the other hand, it is important to note certain Mahui/Taoyang faunal elements considered as indicators of MN 14 in Europe. These include *Castor*, *Sus*, and *Anancus*.

Higher Gaozhuang Formation assemblages of about 5 Ma correlate to the younger MN 14 zone. The distinctive deer *Paracervulus* has its last record. Key appearances supporting MN 14 correlation are *Ursus*, *Eucyon*, *Meles*, and increased horse diversity. Small mammals include the shrew *Soriculus* and mole *Desmana* (see Flynn & Wu, 1994), the leporid *Hypolagus*, and the hamster *Allocricetus*. *Ursus* appears toward the top of the section, probably after 4.5 Ma (Qiu, in press). By 4.3 Ma primitive forms of *Miomys* and *Germanomys* can be taken to signal beginning of MN 15. The pattern for China appears to be that *Ursus* enters China after its first appearance in Europe, about the time of arrival of arvicolines that indicate the later biochron MN 15. We accept uppermost parts of the Gaozhuang Formation as MN 15 equivalent.

In Yushe Basin, the superposed Mazegou Formation is bounded above and below by stratigraphic hiatuses. The contact with the Gaozhuang Formation is a disconformity; the upper contact with the Haiyan Formation is a slight angular unconformity. Both breaks represent perhaps a half million years. The Mazegou fauna is distinguished from the Gaozhuang fauna based on key appearances and species replacements (see, e.g. Flynn, 1997; Flynn *et al.*, 1997). Correlation with the MN zonation is not clear, but elements mainly of MN 16 equivalence are present. The relevant forms are: *Crocuta*, *Lynx*, *Felis*, *Vulpes*, *Canis* (as restricted by Tedford & Qiu, 1996), cervids *Dama* and *Rusa*, the bovid *Antilocapra*, the muskox *Megalovis*, and in the upper part of the formation, *Archidiskodon*. Small mammals include *Blarinoides*, *Scaptochirus*, primitive *Ochotonoides*, advanced *Germanomys* and *Miomys irtyshensis*, a species showing cementum. *Equus* is not present.

The Haiyan fauna differs markedly, and we correlate it to MN 17. Appearances include the carnivores *Megantereon* and *Cuon*, the cervids *Eucladoceras* and *Elaphurus*, the bovines *Bison* and *Budorcas*, and the horse *Equus*. Small mammals include *Marmota*, *Trogontherium*, *Borsodia chinensis*, *Cromeromys gan-sunicus* and of cf. *Micromys minutus*.

Trogontherium, of course, appears much earlier in Europe, but it is an element of faunal change in

MA	EPOCH	Yushe Basin Teilhard/Trassaert zonation	Formation	MN Units
2	Pliocene	Zone III	Hayan	17
3		Zone II	Mazegou	16
3.5			-----	-----
4.3				15
5	Miocene	Zone I	Gaozhuang	14
5.5				13
6		Zone I	Mahui	13
6.5				

Text-fig 1 - Relationships to time scale and epoch boundaries of Yushe Basin stratigraphic units, with MN zone correlation. Mahui Formation and basal Gaozhuang Formation fauna contain MN 13 elements. Correlations of higher strata to MN 14 - MN 16 are not as clear. The Haiyan fauna is distinctive and more readily correlated with MN 17.

Yushe. The arvicolines (following Fejfar & Heinrich, 1990) and large mammals support the MN 17 correlation rather well, in contrast to some difficulty of correlating the preceding interval. We consider the reversely magnetized rock of the Haiyan Formation to represent pre-Olduvai Matuyama chron.

The oldest red loam produces small mammals dated biochronologically (Flynn *et al.*, 1997) to somewhat less than 1 Ma. Taxa found by modern field parties include: *Crociodura*, the advanced zokor *Youngia epitingi*, the vole *Microtus brandtioides*, the living hamster *Cricetulus barabensis*, a living mouse *Apodemus* sp. and a late record of the murine *Chardinomys nihowanicus*. This assemblage loosely represents the *Microtus-Mimomys* superzone of Fejfar and Heinrich (1990), but low level taxa are not shared with Europe. Future study could show a more precise comparison with the Tologoi faunal complex of Transbaikalia (see Erbaeva *et al.*, 2001).

CONCLUSIONS

The coordinated use of magnetic and faunal data has increased the resolution of characteristic, successive assemblages preserved in the fossil record of Yushe Basin. We have already established observed temporal ranges for key taxa and identified index fossil immigrants. Now we evaluate the evidence for correlation of the Yushe sequence to the European mammalian zonation.

The late Miocene assemblages of Yushe Basin span approximately the last million years of that epoch, and contain enough characteristic elements, especially among carnivores, to demonstrate equivalence with MN 13. Many of the elements of the faunas of Yushe Basin's Mahui Formation (NMU 11 of Qiu *et al.*, 1999) extend into the overlying Gaozhuang Formation. Thus we feel that the lower part of the Taoyang Member of the Gaozhuang Formation, which is latest Miocene in age, is also equivalent to MN 13. The correlation to MN 13 is qualified by some elements of the fauna that suggest variously MN 12 and MN 14 correlation. For example, the Mahui hyaenid *Thalassictis* is much older in Europe. This ambiguity only illustrates that temporal ranges of certain taxa vary between Europe and Asia.

Higher parts of the Taoyang and overlying members of the Gaozhuang Formation contain a much different fauna that we correlate with MN 14. The correlation is again based largely on carnivores, although certain small mammals give a consistent conclusion. Some key elements appear out of phase, for example *Ursus* appearing rather late, at about the time of arrival of *Mimomys* and *Germanomys*. These rodents indicate correlation of the top of the Gaozhuang Formation with MN 15.

Correlation based on faunas of the Mazegou Formation are ambiguous. There is a hiatus below and above the fauna. Faunal elements are largely

endemic, with few Holarctic additions, but overall faunal composition is consistent with MN 16.

The Haiyan Formation is correlative with the early Matuyama Chron and some early Nihewanian age faunas. *Equus* and large deer immigrants are indicators of MN 17, and advanced arvicolines are consistent. The succeeding red loam fauna compares tentatively with the Tologoi complex of central Asia.

The purpose of this exercise was to test long distance correlation of MN zones to distant east Asia. General correlation can be made, but there are uncertainties, particularly in early to mid-Pliocene age deposits. Accepting the European seriation of biochrons, one can propose correlation, but this is based on a small fraction of the fauna. Few genera and fewer species are shared across this vast expanse. The correlation becomes dependent mainly on calibration of MN zones on the one hand, and of Yushe stratigraphy on the other, both to the geologic time scale. Interesting for future study are the cases of taxa with incongruent temporal ranges. For example, Qiu (in press) sees the later Yushe record of *Ursus* as an indication of dispersal from Europe toward North America, where the appearance is later still. The approach of Qiu *et al.* (1999) seems most productive for distinct biogeographic regions: construct a local succession of biochrons, calibrate it, and then test correlation to other biogeographic realms to examine patterns of appearance and disappearance.

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