Vertebrate Paleobiology and Paleoanthropology Series

Lawrence J. Flynn
Wen-Yu Wu
Editors

Late Cenozoic Yushe Basin, Shanxi Province, China: Geology and Fossil Mammals

Volume II: Small Mammal Fossils of Yushe Basin

Springer

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Cover Illustration: View of Nan Zhuang Gou area in Yushe Basin with the early Pliocene upper Gaozhuang Formation in the middle ground. The yellow band in the middle ground is a marl marker bed. Younger Red Loess drapes over the outcrops on the upper right. The inset is a skull of the rabbit *Alilepus*, about 5 cm long (see Chapter 4). Background photo, 1988, by L. Flynn.

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Preface

This second volume of the Springer series *Late Cenozoic Yushe Basin, Shanxi Province, China: Geology and Fossil Mammals* focuses on small mammal fossils about 6.5 to 1 million years old from an area of North China that played a role in the emergence of vertebrate paleontology as a modern science. Yushe Basin fossils present a view of changes in Northeast Asian terrestrial faunas during the Late Neogene, and therefore are a key to developing the biochronology for a vast part of the continent. Yushe strata record in one area a succession of faunas that has figured prominently in the definition of land mammal ages in the North Asian biogeographic province. Much of the basis for this system of ages has been the large mammal fauna, and now we can add the small mammals. Field and laboratory work of the last quarter century has added a rich small mammal component to the paleontology of Yushe, which greatly increases the understanding of evolution of its faunas as paleobiological communities. This volume presents the small mammal fossil record of Yushe Basin in the biostratigraphic framework dated by magnetostratigraphy, as developed by Neil Opdyke (University of Florida) and colleagues in Volume I of the Late Cenozoic of Yushe Basin.

The advances in micromammal paleontology presented in Volume II, "Small Mammal Fossils of Yushe Basin" were made possible by a team approach organized around the principle of attention to biostratigraphic detail. A large number of individuals carefully built and dated a stratigraphic framework in which fossil localities were placed relative to their horizons of occurrence. This approach yielded vastly better resolved provenance data for individual finds than were recorded in early historical collections. Secondly, we applied modern wet-screen techniques to process large volumes of sediment from fossiliferous concentrations. This provided improved representation of the micromammal assemblages preserved at individual localities and reduced bias toward representation of "large" small mammals at the expense of species characterized by small body size.

The Yushe teams were inspired by co-leaders Zhan-Xiang Qiu (Institute of Vertebrate Paleontology and Paleoanthropology, IVPP) and Richard H. Tedford (American Museum of Natural History, AMNH), who designed the project to maximize the biostratigraphic potential of Yushe Basin. They established a collegial atmosphere for collaboration by individuals from many institutions of China, the United States, and other countries. Figure 1 shows many of our group from 1987, the first full field season, including visitors S. Mahmood Raza and I.U. Cheema from Pakistan, and an army of paleontologists who made numerous surface finds of small mammal fossils.

Fig. 1 The Yushe Basin Team at the outset of field work, in front of the Yushe County Guest House. Left to right, front row, second from left, De-Fa Yan, fourth to seventh are Wen-Yu Wu, Zhan-Xiang Qiu, Richard Tedford, Will Downs, and at far right, Yi-Zheng Li; back row, left, is Tai-Ming Wang of the Yushe County Museum, fourth from left, Neil Opdyke, S. Mahmood Raza, I.U. Cheema, Xiao-Feng Chen, Jie Ye, and Gen-Zhu Zhu. Photo: September, 1987, by L.J. Flynn

The principal small mammal researchers for the Yushe project were Wen-Yu Wu, Zhu-Ding Qiu, and Lawrence J. Flynn, all of whom would admit that the great success of our work was due to the creativity, drive, and imagination of our colleague William R. Downs. Will, now deceased, prepared numerous fossil finds. Our team developed the succession of small mammal assemblages of Yushe to accompany the large mammal record in a comprehensive biostratigraphy by screening many new fossil localities throughout the succession of strata. The assemblages we developed represent changes in the small mammal community of the Yushe Basin, revealed on a fine scale not previously achieved. Detailed systematic studies on small mammal groups proceeded under the care of specialists, as presented in the chapters of this volume.

Acknowledgments

We express our deep gratitude to all the institutions and individuals, local and more broadly, who warmly supported the Yushe Project in various ways. We thank the people of the town of Yushe for their help and hospitality, and particularly the staff of the Yushe Hotel, who tolerated our screening program in their parking lot. For financial support we thank the National Natural Science Foundation (NSFC, China), the National Science Foundation (NSF, USA), and the Chinese Academy of Sciences. The two NSF grants EAR 8709221 and BSR 9020065 enabled our field work; later synthesis was supported under EAR grants 0716186 and 0958178. We acknowledge the authorities and our colleagues of the Institute of Vertebrate Paleontology and Paleoanthropology, the Tianjin Natural History Museum, and the American Museum of Natural History.

We thank especially our mentors, Zhan-Xiang Qiu and Dick Tedford, who created the atmosphere of scientific inquiry in which our project flourished. Their encouragement and support made our work possible. Sadly, Dick Tedford's health declined in recent years, and he

passed away in 2011, but the inspiration behind the project remained. We also think of Will Downs. Will died prematurely before he could see this volume published, but he steadfastly supported our work. Will found many of the fossils we present and processed most of them from the concentrate produced by screening. His spirit of scientific inquiry and enthusiasm carried us all forward as we developed a series of superposed small mammal horizons that span the entire Late Neogene sequence of Yushe Basin. He is sorely missed. Volume II benefitted from the contributions of many colleagues and associates of IVPP in Beijing and staff members of AMNH in New York, especially Frank Ippolito, Judy Galkin, Susan Bell, Ruth O'Leary, Alejandra Lora, Chester Tarka, and Loraine Meeker. Some of Frank's artwork developed with Dick Tedford for Volume I was adapted for Volume II.

Comparative collections are crucial to realize success in systematic work. For the small mammal fossils studied here, we relied heavily on the comparative collections of IVPP and the Paleontology Division at AMNH, but also on the mammal collections of various institutions. We thank their curators and collection managers. The Department of Mammalogy (currently under the day to day care of Eileen Westwig) at AMNH holds important reference collections, as do the Museum of Comparative Zoology, Harvard University (Judith Chupasko and Mark Omura), and Kunming Institute of Zoology (Song Li). We thank all for opening their collections to us.

We thank the entire Springer staff, particularly Sudeshna Das, for their help in realizing the Yushe Basin volumes. The meticulous efforts of series editors Eric Sargis and Eric Delson are deeply appreciated. They encouraged the maturation of the final product and its artwork. Finally, we acknowledge the constructive help of external manuscript reviewers. They devoted considerable time to help us to improve and update the following systematic accounts. Their careful reading led to increased clarity throughout the volume.

Lawrence J. Flynn
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Chapter 1
Small Mammal Exploration in Yushe Basin, Shanxi Province

Lawrence J. Flynn and Wen-Yu Wu

Abstract Yushe Basin is an intermontane basin at the eastern edge of the Loess Plateau in northern China. Its fluvial, lake and superposed loess deposits accumulated during the last 7 myr and contain many fossiliferous horizons. Small mammal fossils occur throughout, and some fossil horizons produce diverse assemblages that appear to faithfully represent the micromammal component of Yushe paleocommunities. Yushe Basin includes assemblages that represent the late Baodean age (latest Miocene) microfaunas of North China, and document contrasting younger assemblages that characterize a distinct Pliocene Yushe chronofauna. Pliocene fossils represent two successive microfaunas that distinguish the Gaozhuangian and Mazegouan land mammal stage/ages. These are in turn distinct from the Pleistocene assemblages of Yushe that correlate with Nihewan and later faunas. The Sino-American project, especially in the interval of 1987–1991, developed the small mammal biostratigraphy of the Yuncu subbasin of Yushe Basin. Small mammal fossils occur in every Yuncu formation, from the Baodean age Mahui Formation, through the Pliocene Gaozhuang and Mazegou formations, to the early Pleistocene Haiyan Formation. Important elements of later Pleistocene faunas occur in overlying loess. Field teams collected specimens exposed on eroded surfaces and followed indications of small mammal concentrations to excavate bulk samples and process them for fossils by wet screening. Wet screening revealed a rich component of micromammal diversity to complement the wealth of larger species that previously had been known as surface finds.

Keywords Yushe Basin • Late Neogene • Biochronology • Small Mammals • North China • Screen Wash

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1.1 Introduction

The history of scientific exploration of Yushe Basin over the last century was chronicled in Chap. 2, Volume I, of the Springer series Late Cenozoic Yushe Basin, Shanxi Province, China: Geology and Fossil Mammals. Fossils from Yushe Basin have been known for nearly 100 years, and exploration culminated in the late 20th century in a joint Sino-American expedition led by members of the Institute of Vertebrate Paleontology and Paleoanthropology, Academia Sinica, (IVPP) and the American Museum of Natural History (AMNH). Important fossil sites had been found in the first half of the 20th century throughout Shanxi Province in North China (Fig. 1.1), including the classical Baode faunas (Kurtén 1952), localities in the Wuxiang area, lesser known finds from Shouyang, and the pivotal Yushe Basin. Yushe Basin was key because in one area "*Hipparion*" faunas of "Pontian" and younger age were overlain by Pleistocene faunas bearing the modern horse *Equus* (Licent and Trassaert 1935). The physical setting for fluvial and lacustrine deposition of the Late Neogene formations of Yushe in basins underlain by Triassic age bedrock was described in Volume I, Chapter 3.

Since the 1930s, special attention was given to the small mammal fossils preserved in the formations of Yushe Basin. Paleontologists Pierre Teilhard de Chardin and C.C. Young (1933) surveyed the Yushe area in 1932 and recognized the importance of Yushe Basin for its small mammal record. Teilhard de Chardin (1942) completed a monographic treatment of larger body size rodents that were well represented as fossils. Young embarked on a long career of study

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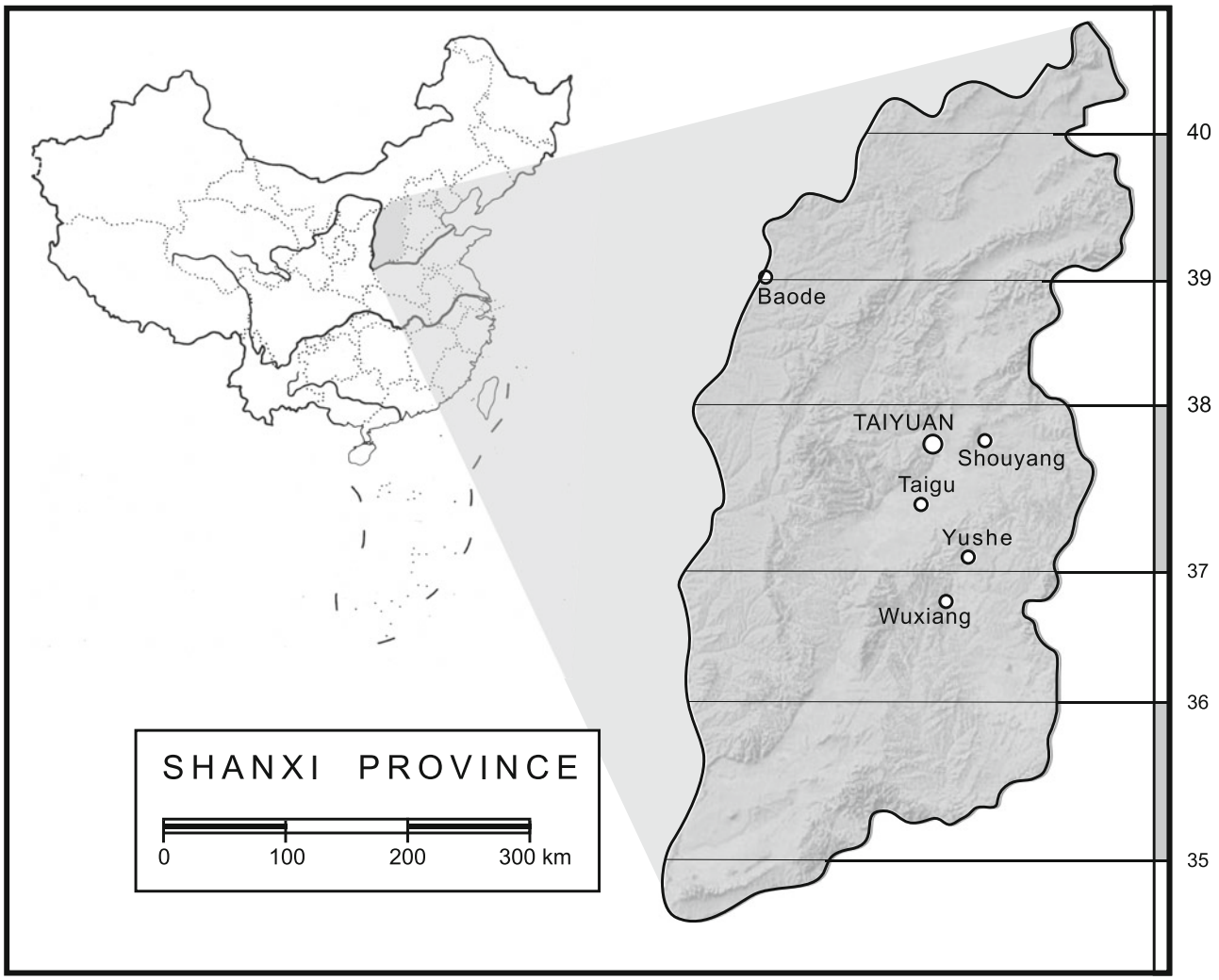


Fig. 1.1 Location of Shanxi Province within North China, indicating important fossil-producing regions: Baode, Shouyang, Yushe, and Wuxiang. Artwork by Frank Ippolito (AMNH) adapted from Fig. 1.1 of Volume I of this series

of small mammal fossils that in repeated instances influences the modern interpretation of Yushe microfaunas, as will be seen in the following chapters. Young (Chungchien Young, Zhong-Jian Yang) may be seen as the father of modern vertebrate paleontology in China.

Fossils were entombed throughout the deposits of Yushe Basin, so that superposed assemblages today represent successive samples of past biotas. The sediments were mainly gravels, sands and silts that accumulated to an aggregate thickness of about 800 m, and the entire series was blanketed by loess. Given generally limited cementation, fossils that accumulate on modern surface exposures due to erosion can be extracted easily from adhering matrix. The dating of Yushe sediments was presented in Chap. 4 of Volume I (Opdyke et al. 2013) in a tandem analysis of fossils and paleomagnetism: given an understanding of approximate age from fossils, characteristic magnetozones were correlated with the known magnetic time scale. In the case of Yushe, Late Neogene in age and known to contain early Pleistocene fossils at the top, the magnetochrons could be identified with characteristic chrons C1r to C3An, including the classical Matuyama, Gauss, and Gilbert chrons. In millions of years (Ma, megaannum) these date to about 2 to 6–7 Ma, with younger fossils from the loess. As noted in Volume I we use the prevailing concept of the Pleistocene beginning at about 2.6 Ma (Mascarelli 2011).

The modern epoch of research on Yushe Basin faunas began in 1978 when Zhan-Xiang Qiu and IVPP began stratigraphically controlled reconnaissance. It was clear (Qiu 1987) that the subbasins of Yushe (the Yuncu, Nihe, Ouniwa, Tancun, and Zhangcun subbasins) offered a laboratory in which to study on a fine scale mammalian biostratigraphy for North China. The Yuncu subbasin in particular presented a series of formations that spanned late

Miocene to early Pleistocene time. By 1987, Zhan-Xiang Qiu and Richard H. Tedford (AMNH) had mounted a collaborative Sino-American investigation of the geology and fossil mammals of Yushe Basin. Their teams concentrated on the Yuncu and Tancun subbasins of Yushe, collecting fossils throughout, and documenting nearly 200 fossil sites (Fig. 1.2a–c). Stratigraphic provenance was carefully controlled for each locality, which was numbered in sequence of study and given a prefix YS for "Yushe site". The present volume focuses on the micromammal component of the fossils produced from Yushe.

1.2 Small Mammal Recovery

Through most of the 20th century, Yushe small mammals appeared in field collections that had been retrieved as surface finds (Teilhard de Chardin 1942). These fossils represented mainly large body-size species of rabbits, beavers, bamboo rats, and zokors (the latter, an evolutionary radiation of subterranean muroids endemic to northeastern Asia). Such surface finds were comparable to those of large mammals found while prospecting: opportunistic finds, usually of single individuals. However, there was a strong bias against representation among fossils of small-body size. Today, important specimens are still found by prospecting, as by current field teams supported by the Yushe County Museum.

A fundamentally different approach for collecting small mammals was introduced to Yushe Basin in 1987 when the Sino-American group began a campaign of wet-screening productive sites. Figure 1.2a–c highlight many of the most important localities that were screened in Yuncu subbasin in 1987 and 1988, and in Tancun subbasin in 1991. Localities were found by prospecting, surface finds indicating concentrations of remains. Where the fossils indicated preservation of small mammals, the team quarried bulk samples of sediment (Fig. 1.3).

Of the eighty localities producing small mammals, the Sino-American team selected two dozen that appeared to be particularly productive. The Sino-American field team sacked bulk samples of loosely consolidated matrix for processing. The Town of Yushe Hotel allowed us to process these samples on the premises; this involved drying (samples spread out on tarps), soaking in buckets, and screening the wet sediment (Fig. 1.4). We used tandem screen boxes made of wood, a coarse mesh in the bottom of a small inner box, which fitted neatly into a larger fine-mesh box. The fine screen had a mesh size of 0.5 mm on a side. The screening took place by agitating boxes in large tubs to wash water over the sediment. This removed clays, and the water could be reused. Most lithologies were amenable to soaking and screening, but some clayey materials were broken down by flocculation induced by kerosene pre-treatment. The many pairs of screen boxes allowed processing samples from multiple localities at the same time. Our Appendix lists fossils retrieved by both surface collection and initial sorting of bulk test samples from all YS localities that yielded small mammals. The appendix includes invertebrates and non-mammal vertebrates and lists small mammals prior to the systematic study of the following chapters.

In 1991, Zhu-Ding Qiu added a complement to this procedure. He brought a large pair of aluminum boxes modeled after a design used by Volker Fahlbusch. Mesh sizes differed slightly: 2 mm coarse screen and 0.5 mm fine screen. This was particularly useful for processing large volumes of sediment from single localities. A further advantage was that the boxes could be set up for washing in the field. A hose carrying water from a pond or stream and powered by a pump supplied a continuous spray washing over the fossiliferous sediment (Fig. 1.5).

A key to screening by either technique was assuring that the matrix was thoroughly dry. After drying fresh samples completely, we screened matrix, dried again, and screened at least one more time. The second or third wash removed most of the remaining clays – if the sediment was dry (Fig. 1.6). The resulting concentrate of sand grains and bone was then processed for fossils. The large fraction (smaller volume) could be sorted by hand, but the fraction remaining in the fine screen, a large volume, was too fine to sort reliably, even with magnification. Will Downs took charge of this concentrate and sorted out the fossils by means of heavy liquids. He used a settling tube of sodium polytungstate to float off the sediment from the higher density bones and teeth. Will processed many kilograms of concentrate in his laboratory in Flagstaff, Arizona, carefully retrieved small teeth and bones by microscope, and then prepared these for study.

1.3 Small Mammal Study

Microfossils collected during the joint Sino-American campaigns are in the permanent collections of IVPP in Beijing. They have been assigned V numbers. Some old specimens have revised RV numbers – see explanation by Qiu and Tedford (2013). Older collections bear various numbering schemes, including collections of the Tianjin Natural History Museum (TNHM) which have THP or TNP prefixes, and materials of the Frick Collection (AMNH) with the F:AM prefix. The Tianjin Natural History Museum was known, years ago, under the French name *Musée Hoang-ho Pai-ho de Tientsin*, with acronym HHPHM. Some fossils, including

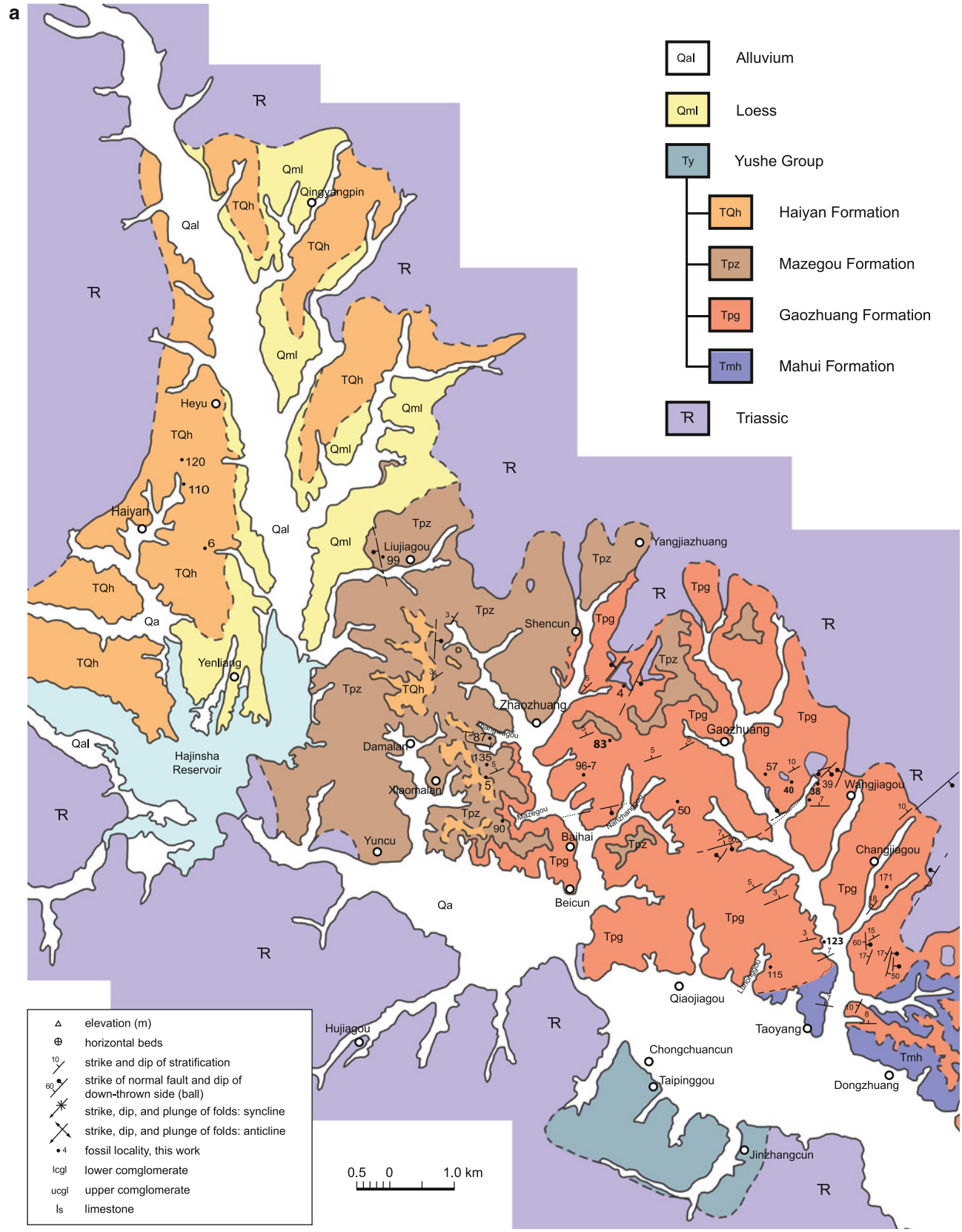
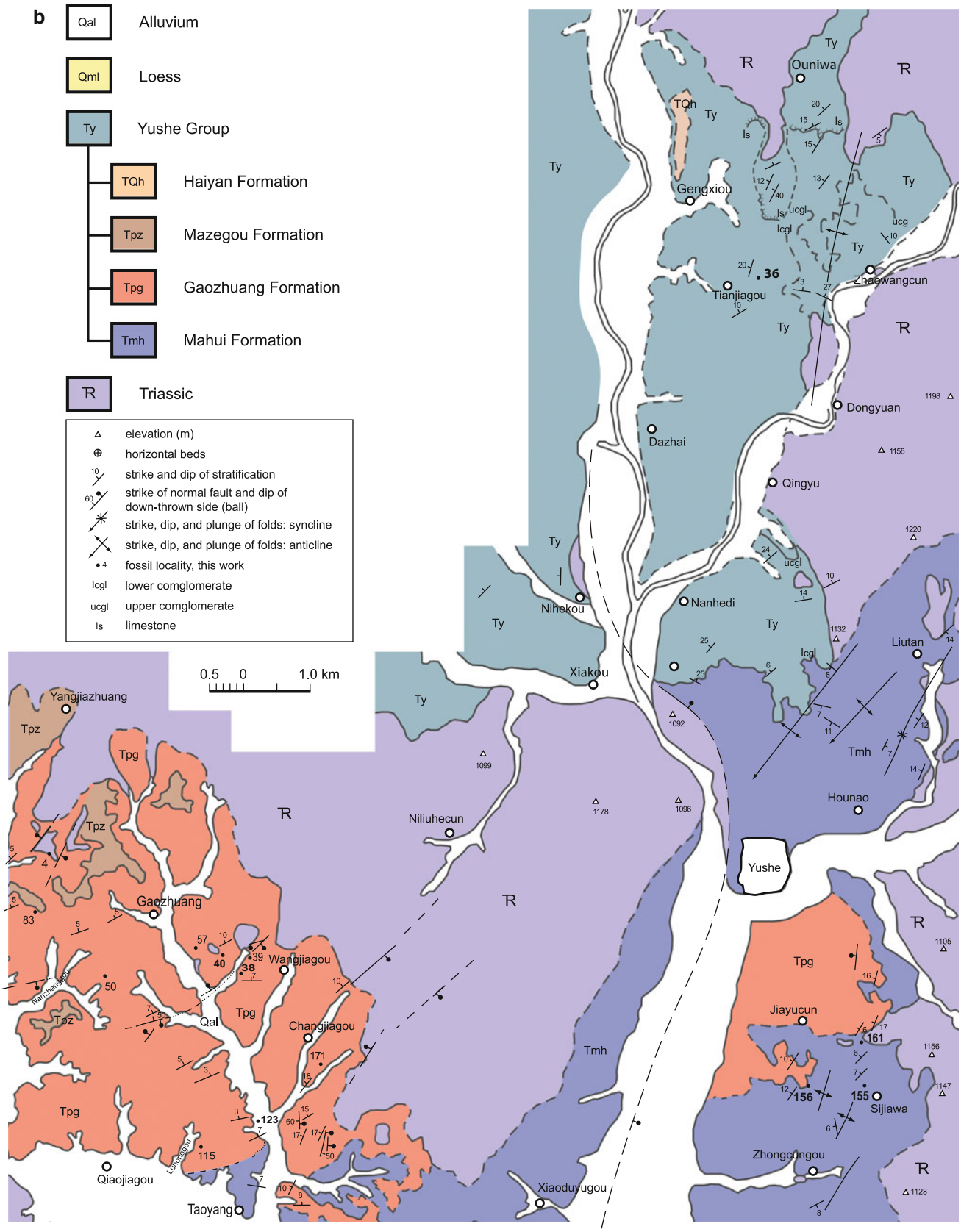


Fig. 1.2 **a**–**c**. Geological maps of Yushe subbasins prepared by the Sino-American mapping teams (1987–1998), showing lithostratigraphy, structure, and fossil localities. Figure 1.2a, formations exposed in Yuncu subbasin. Figure 1.2b, the northern Yushe subbasins (Nihe-Ouniwa area) and northern part of the Tancun subbasin. Figure 1.2c, most of the Tancun subbasin and lower Yuncu subbasin deposits on opposite sides of the Zhuozhang River. Maps by Frank Ippolito (AMNH) adapted to illustrate the distribution of small mammal localities



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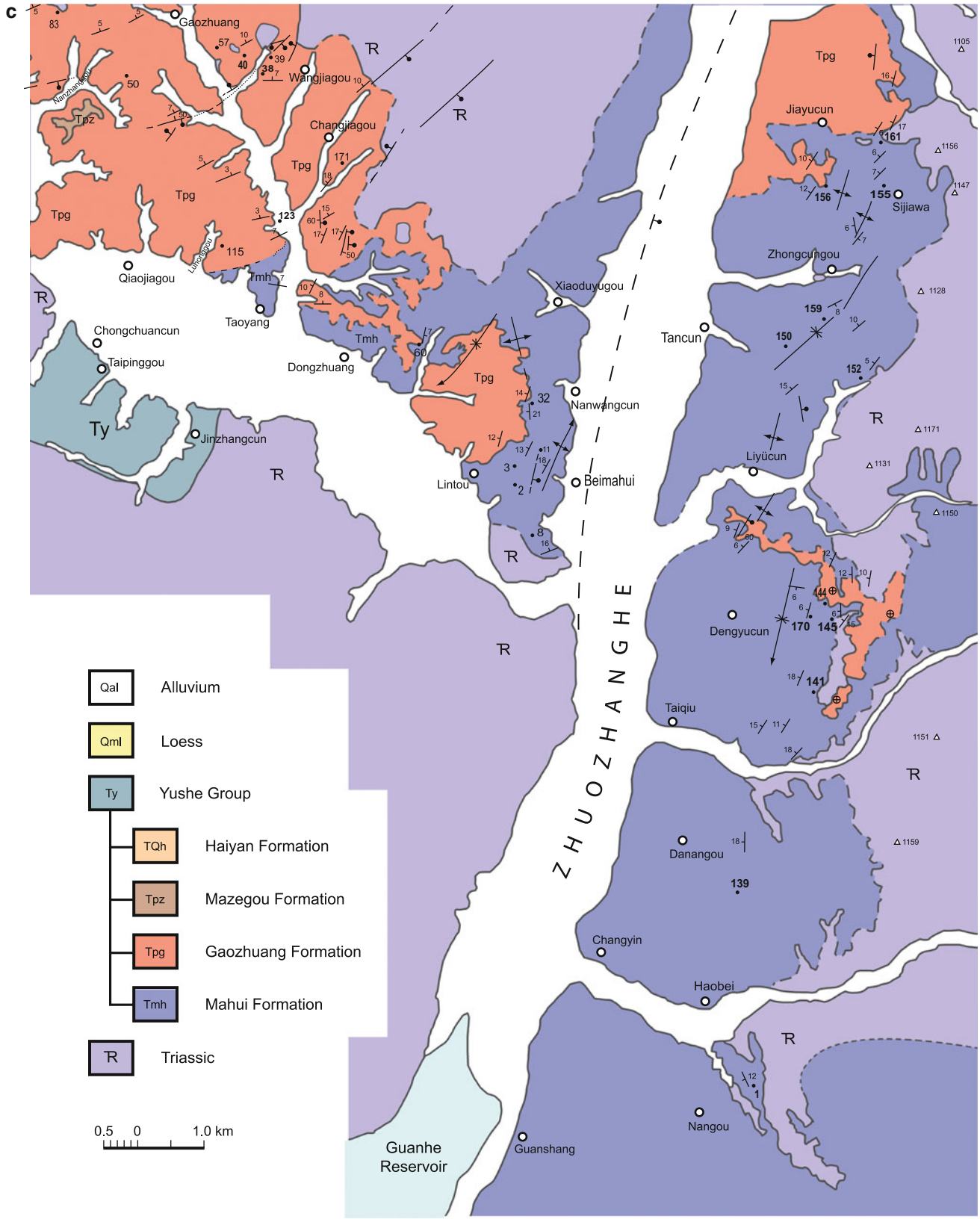

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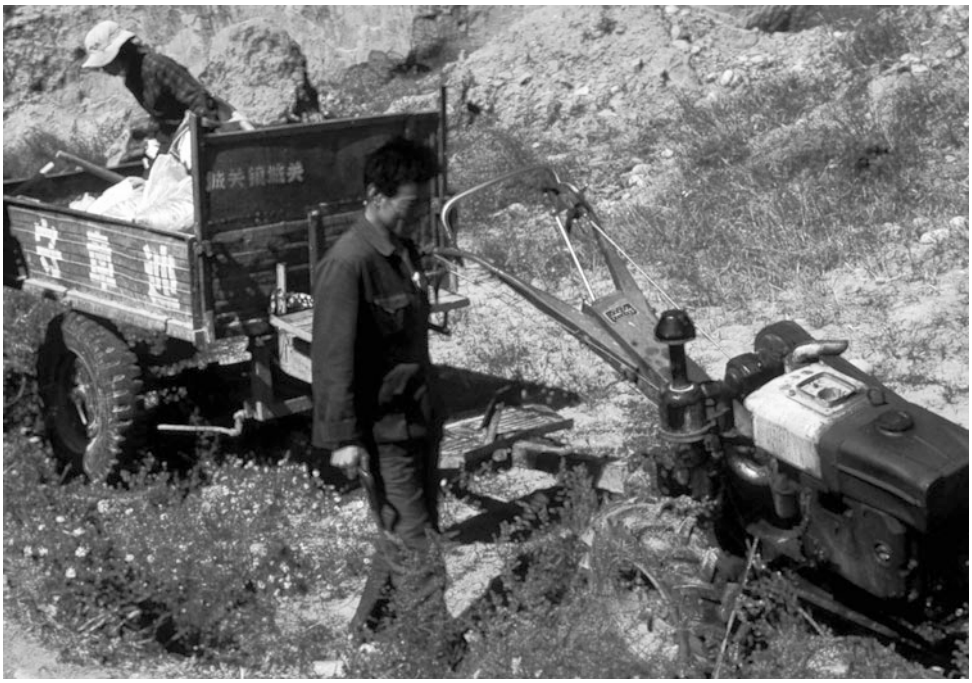

Fig. 1.3 Wen-Yu Wu collecting bulk samples of sediment for screening near Beimahui, utilizing one of the methods of hauling tons of material (Photo by L. Flynn, Sept. 1987)

Fig. 1.4 Screening operation at the Yushe Hotel, showing tandem screen boxes, drying tarps for discrete samples, buckets to soak the dried sediment in water, and wash tubs in which the boxes are agitated (Photo by L. Flynn, Sept. 1987)

Fig. 1.5 Zhu-Ding Qiu in Taiqiu area, Tancun subbasin, with tandem aluminum screens (coarse fraction visible, hose from pond supplying water), and curious admirers. L. Flynn, Sept. 1991

Fig. 1.6 Will Downs carefully drying washed sediment prior to rewashing, while keeping locality matrix separated. Downs then processed concentrated matrix by heavy liquids and retrieved microfauna by microscope examination (Photo by L. Flynn, Sept. 1991)

rodents studied by Teilhard de Chardin (1942), were published with the HHPHM acronym.

The Sino-American team was fortunate in greatly expanding the small mammal representation of the communities that evolved in Yushe Basin. Diverse shrews and moles, squirrels and dormice, dipodids, hamsters, and mice were faunal elements that had been poorly represented or completely absent from older collections. The studies of the material presented here are collaborative, and due to richness of the fossils, the editors engaged specialists to study some groups. To facilitate current and future comparative work, we have made molds and casts of much of the material.

Editors Flynn and Wu most depended on the experience and advice of Zhu-Ding Qiu. Qiu specifically undertook description of dipodids and squirrels, but encouraged us in many ways. In the course of his dissertation undertaken at Southern Methodist University, Dallas, Texas, under Professor Louis L. Jacobs, Xiaofeng Xu studied the beavers; this effort was later advanced by Qiang Li. Shao-Hua Zheng, authority on zokor evolution, undertook the analysis of Myospalacinae. Recently Ying-Qi Zhang kindly took on study of the Yushe voles. Remaining groups were the responsibility of the editors, but in all tasks we depended on the help of the staff of IVPP who care for the collections, and the curators who freely share information.

Our Yushe project localities were plotted on the composite biostratigraphy developed in Volume I (Fig. 1.7). We modified the biostratigraphy of Fig. 4.8 of Volume I, original artwork by Frank Ippolito, to combine both parts and present localities in a single figure. While the entire membership of our field teams participated in this, it was the guidance of R.H. Tedford and Z.-X. Qiu that inspired the fine scale biostratigraphic control that we use. This framework was developed by careful attention in the field and by the insistence, particularly by Dick Tedford, of tying physical localities to master sections. The age relationships of individual sites are well resolved. Localities of historic importance for fossil occurrences developed by Licent, Frick collectors, and later by IVPP were also placed in the sequence.

Small mammals occur in all stratigraphic units of Yuncu subbasin. The oldest small mammals are from middle to upper parts of the Mahui Formation, about 6.5 Ma. The youngest sites, other than those in the red and yellow loess, are from high in the Haiyan Formation, about 2.2 Ma. This biostratigraphic and dating framework for the Yuncu subbasin (Fig. 1.7) is used throughout this volume. The composite biostratigraphy unifies the separate but complementary studies by different authors on the various groups of small mammals. For some groups significant fossil material came from localities from Tancun subbasin. These fossils can be projected into the Yuncu master chronology by means of stratigraphic distance from the chron 3An-chron 3r reversal recognized in both subbasins in Chap. 4 of Volume I (Opdyke et al. 2013, p. 75).

While Yushe Basin played an important role in the history of paleontology of China, the small mammal component to Yushe faunas was heretofore poorly known. Our studies since 1990 have led to the description of 18 new species of small mammals. We are now able to characterize the diverse small body-size organisms of the Late Neogene communities of this region. They document changes in the Pliocene mammalian faunas of northeastern Asia, and play a role in understanding development of modern Asian communities. They constitute an important element in definition of

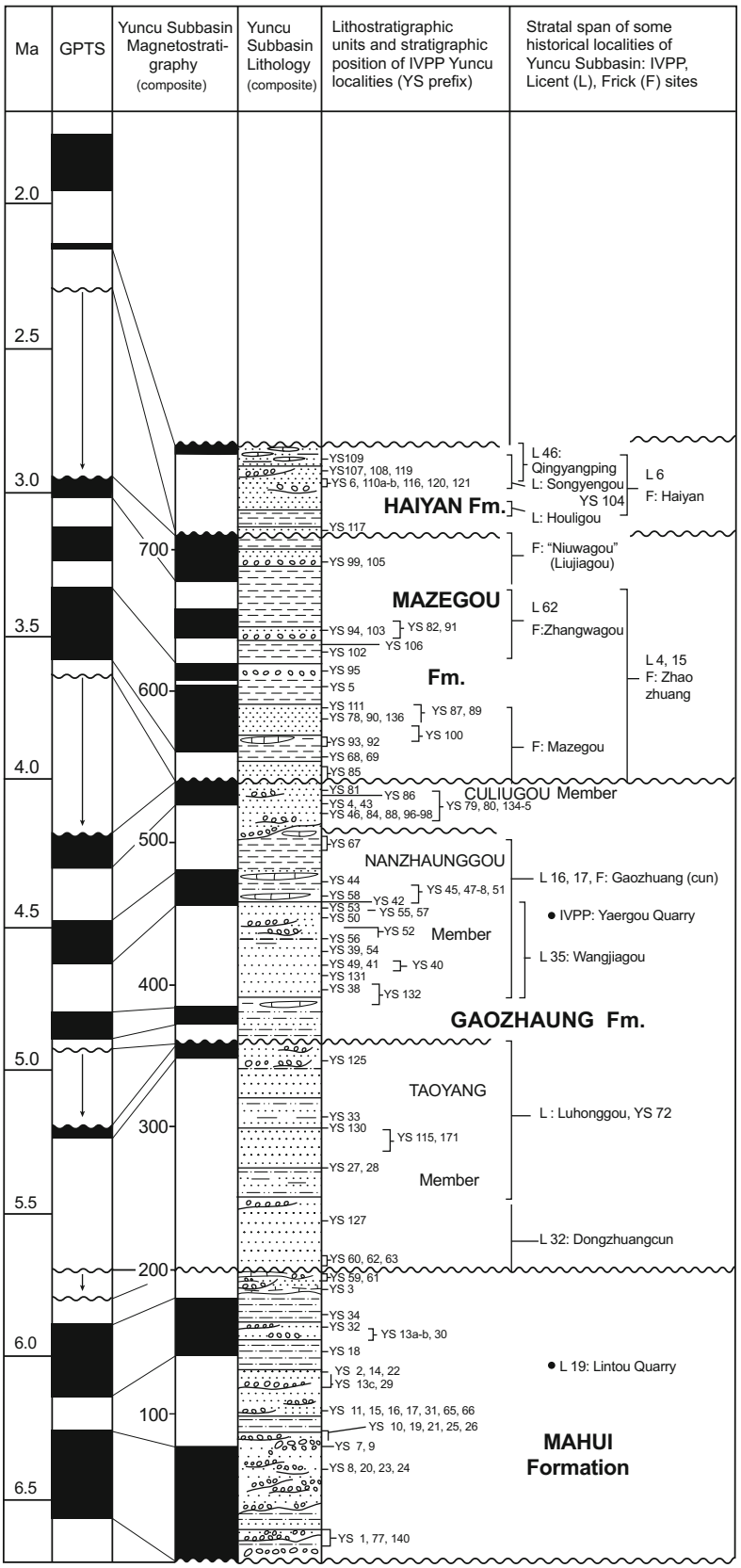

Fig. 1.7 Composite Yuncu subbasin lithology with observed magnetostratigraphy and correlation to the GPTS of Cande and Kent (1995). Adapted from Volume I to show relative positions of fossil localities mentioned in the text

Pliocene biochrons, the Gaozhuangian and Mazegouan Land Mammal Stage/Ages (Qiu et al. 2013). The Yushe small mammals complement the faunal history of the region in a continuous record from approximately 6.5 to 2 Ma.

Acknowledgements First, we acknowledge again our friend and micromammal colleague, the late Will Downs. His energy, tenacity, and sharp wit lie at the foundation of the success of our small mammal collecting. He is part of every chapter in this volume, and a part of every volume of the Yushe series. In addition, he embodied the good will and productivity of the Sino-American team, which co-leaders Zhan-Xiang Qiu and Dick Tedford nurtured. We thank reviewers Louis Jacobs, Jon Baskin, and Lou Taylor for their constructive reviews of this chapter. We appreciate their efforts and those of all reviewers who consistently supported our efforts in producing this volume.

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Chapter 2
The Lipotyphla of Yushe Basin

Lawrence J. Flynn and Wen-Yu Wu

Abstract Insectivoran mammals have been recovered by Sino-American field teams from various localities in each formation of the Yuncu and Tancun subbasins. They were an important component of late Miocene through Pliocene faunas of North China. One hedgehog has been found in late Pliocene and Pleistocene localities. Moles, however, are diverse and occur throughout the Miocene and Pliocene section, with one early Pliocene record of the water mole *Desmana*. The Yushe collection includes the Pliocene talpine *Scaptochirus*, which is at present the oldest fossil of this genus. Shrews are also diverse, including multiple representatives of the tribes Soricini, Nectogalini, and Beremendiini. Presence of a blarinine suggests immigration of this element from North America by 6 Ma, and morphological similarity with beremendiines suggests that recognition of these groups should be reviewed. The early Pleistocene Haiyan Formation has yielded only *Sorex*, and to date only *Crocidura* has emerged from the Pleistocene loess. Declining insectivoran diversity corresponds with a hypothetical decline in mean annual temperature. The insectivoran component of Yushe shows affinity with fossil and living faunas of North China, and a majority of elements are shared broadly across Eurasia. Two taxa at least (*Yunoscaptor* and *Soriculus*) also occur in South China, indicating former wide distribution of these genera, and suggesting southward retraction of their preferred paleohabitat from Shanxi Province since the Pliocene.

Keywords Yushe Basin • North China • Late Neogene • Lipotyphla • Insectivores • Shrews • Moles

2.1 Introduction

Across North China, Late Cenozoic deposits reveal high species richness among micromammals of late Miocene and Pliocene age. Certain productive localities, such as Ertemte and Bilike, both Inner Mongolia (Fahlbusch et al. 1983; Qiu and Storch 2000), attest to this diversity within the insectivoran component of small mammal communities. Yushe Basin demonstrates this richness for Shanxi Province as well. One aspect of the importance of Yushe is in its aggregate of successive localities. While no single Yushe sample is as large as that of Ertemte or Bilike, in aggregate, the Yushe localities show great insectivoran richness. Of the many insectivoran specimens described in this chapter, nearly all were recovered by our field parties. An exception is the excellent (large) specimen of *Erinaceus* found in 1935 for Childs Frick and the American Museum of Natural History (AMNH) by Quan-Bao Gan.

The diversity of insectivorans as preserved in the Late Cenozoic deposits of Yushe Basin matches that seen today in North China, although some taxa imply changes in distribution. The composition of the fauna also suggests that the Yushe region insectivoran fauna showed significant differences from both South China and northern Asia (Inner Mongolia northwards).

Our progress in this study depended not only on the fine fossil collections of the Institute of Vertebrate Paleontology

Note: This chapter includes one or more new nomenclatural-taxonomic actions, registered in Zoobank, and for such purposes the official publication date is 2017.

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and Paleoanthropology (IVPP) in Beijing, but also on the recent mammal collections of the AMNH and of the Museum of Comparative Zoology (MCZ) at Harvard University, and of the Kunming Institute of Zoology (KIZ). Measurements are in millimeters unless otherwise noted.

2.2 Systematics

The relationships of the higher categories of small mammals loosely called "insectivores" remain controversial. Insectivorans, as traditionally conceived, are not monophyletic, but the core group of hedgehogs, moles and shrews is a natural group and most workers (e.g., McKenna and Bell 1997) utilize the higher taxon Lipotyphla Haeckel, 1866 for them. Currently, it appears that Solenodontidae is sister taxon to Lipotyphla (Douady and Douzery 2009) and the more inclusive group is modified as Eulipotyphla. Because the possible relationships of Erinaceidae, Talpidae, and Soricidae have varying support, we list them in that order without subordinal grouping.

2.2.1 Family Erinaceidae Fischer, 1814

Erinaceus Linnaeus, 1758
Erinaceus olgae Young, 1934

Referred material: V8893, complete left m1 from late Pliocene locality YS5. F:AM 76707, right mandible bearing complete dentition, including enlarged lower incisor (damaged tip) and three antemolars between it and p4, plus three molars; minor breakage anteriorly and at the condyle, the angle, and the coronoid process. Specimen collected in 1935 from the Nan Zhuang Gou area by Q.-B. Gan ("Buckshot"), who was employed by Childs Frick.

Distribution: Hypodigm material from Zhoukoudian (Localities 1, 2). Additional material from Yushe Basin: V8893 collected in 1987 from locality YS5, Mazegou Formation, 3.3 Ma; Nan Zhuang Gou specimen from a unit, probably loess, overlying the mid-Pliocene sediment.

Revised diagnosis: Large species of *Erinaceus* characterized by reduced paraconid on p4: paraconid is low and the paralophid is directed anterolingually; cingulum is absent on p4 and weak on lower molars.

Remark on nomenclature: Young (1934) named this species to honor Mrs. Olga Hempel-Gowen, "indefatigable secretary of the Cenozoic Laboratory". The published spelling of the species was "olgai", which is corrected here as *Erinaceus olgae*.

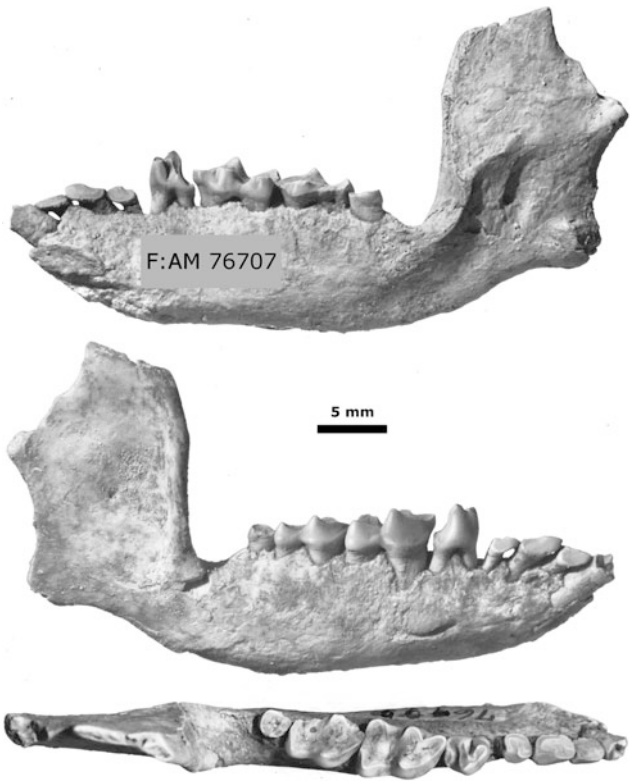

Fig. 2.1 *Erinaceus olgae*, right dentary with dentition, F:AM 76707, in medial (above), lateral, and dorsal (below) views (photography by Chester Tarka, AMNH)

Description: F:AM 76707 is a well-preserved dentary with moderately worn dentition (Fig. 2.1). The dentary bone is comparable in living *Erinaceus amurensis*, whose present range includes the Yushe area (Corbet 1988). The ventral border of the dentary is straight, depth uniform at about 8 mm from p4 to m3. Anterior from p4, the dentary bears a laterally thickened and strong symphysis that accommodates the long root of the enlarged incisor. Posteriorly the ramus narrows, with rising angle. The ascending ramus is vertical and coronoid is high. The condyle is positioned 5 mm above the tooth row. The mental foramen is low on the dentary, below the posterior part of p4, and the mandibular foramen is in the ascending ramus behind m3.

The dentition includes the procumbent incisor, generally considered the homologue of i2. It is followed by three simple antemolars, the middle one largest, and usually considered the canine. These teeth are worn, with a longitudinal crest located buccal to their midline. Each has a single root that projects posteriorly. The three are crowded together, combined length of 7.6 mm, and are followed by a small diastema. The second and third antemolars have low