Chapter 2
History of Scientific Exploration of Yushe Basin

Zhan-Xiang Qiu and Richard H. Tedford

Abstract The Yushe Basin is a complex of subbasins that accumulated fluvio-lacustrine deposits. The Yuncu subbasin contains the longest, most complete stratigraphic record and yields abundant fossils from multiple horizons. Vertebrate paleontology began in China early in the twentieth century, and since the 1920s Yushe Basin figured prominently in recognition of pre-Pleistocene faunas of North China. Emile Licent's collecting campaign of 1934–1935 established the richness of Yushe Basin's fossils and stimulated later exploration by collectors for Childs Frick of the American Museum of Natural History. Many new taxa were based on Yushe Basin fossils, but field work languished through much of the last century. Renewed interest in Yushe led to the formal field project conducted jointly by a Sino-American team in the 1980–1990s. This field work documented the localities of early finds, analyzed the composite section and dated it by paleomagnetic reversal stratigraphy, and added important new fossil data.

Keywords Yushe Basin • North China • History of paleontology • Miocene • Pliocene • Pleistocene • Vertebrate fossils • Collaborative research

Z.-X. Qiu (✉)
Laboratory of Paleomammalogy, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Xizhimenwai Ave., 142, Beijing 100044, People's Republic of China
e-mail: qiuzhanxiang@ivpp.ac.cn

R. H. Tedford
Formerly Division of Paleontology, American Museum of Natural History, Central Park West at 79 St, New York, NY 10024, USA

2.1 Geographical Setting

The Yushe Basin is situated in the northern part of the low mountainous area of southeastern Shanxi Province. This mountainous area is bordered by two sub-parallel mountain ranges (shan) stretching in a NNE to SSW direction: the Taihang Shan to the east, and the Taiyue Shan to the west. The Taihang Shan are about 550 km in length, merging with the Yan Shan mountain ranges on the north and ending before reaching the Huang He (Yellow River) valley to the south, turning westwards and connecting with the Zhongtiao Shan. The highest peak of the Taihang Shan within Shanxi Province is 2097 m (Beitianchi Peak) above sea level. It also serves as the western border of the North China Plain. The Taiyue Shan are shorter but wider, and rather irregular in form, with their highest peak (Niujiao'an) being 2568 m above sea level. West of the Taiyue Shan is the Fen He (Fen River) graben, which is generally 300 m lower than the bottoms of the basins in the mountainous area of southeastern Shanxi (Fig. 2.1). To the north, the mountainous area is bordered by the Tongliang Shan, which extends roughly in a W-E direction, with peaks about 1700–1800 m above sea level. It serves as the watershed of the north-flowing tributaries of the Fen He and the south-flowing Zhang He system. The southeastern Shanxi mountains become lower southwards, merging into hilly landscapes with typical elevations of 1200–1300 m above sea level. The Zhuozhang River flows south in the central part between the two above-mentioned mountain ranges, with its height being about 990 m (around Yushe County) and 930 m (around Wuxiang County) above sea level. The presence of an upland south of Wuxiang makes the Zhuozhang River turn eastwards, then cut through the Taihang Shan, and finally empty into the Da Yunhe (the Grand Canal) on the North China Plain.

Tectonically, southeastern Shanxi is a small component of the huge Sino-Korean paraplatform. Its middle part is composed of the NNE-SSW stretching Wuxiang-Yangcheng Synclinorium (also known as Qinshui Synclinorium),

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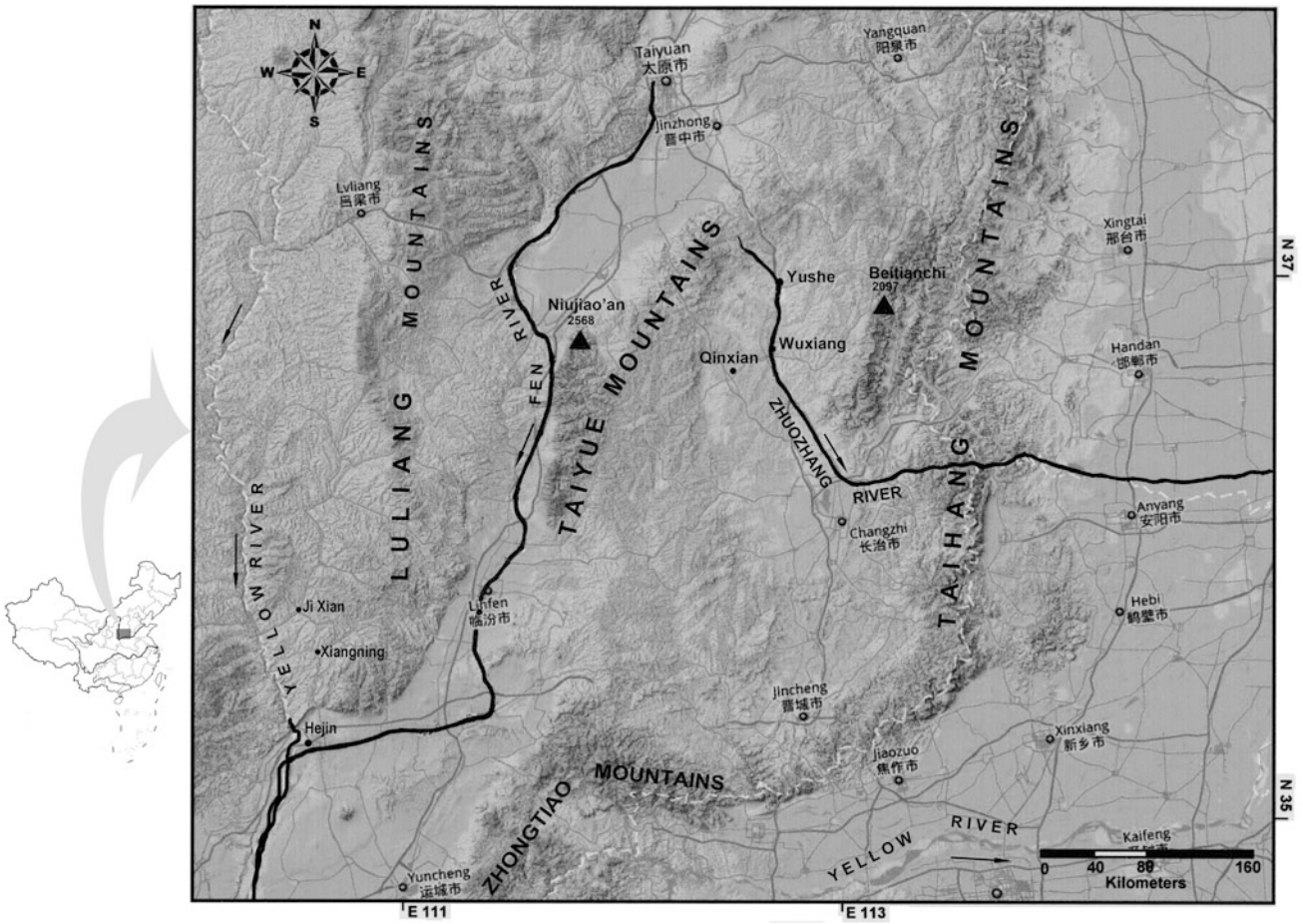

Fig. 2.1 Topographic map of southern part of Shanxi Province, south of the provincial capital, Taiyuan. Yushe is on the eastern edge of the Loess Plateau, west of the Taihang Mountains. The Yellow River (Huang He) is on the western margin of the map

bordered on the east and west sides by the Taihang Shan and Taiyue Shan. The axial part of the synclinorium is composed of Triassic red beds, which form vast hill outcrops in the axial part of the synclinorium. Fluvio-lacustrine sediments of the Yushe type are developed in a string of small basins, often of irregular form, in this axial part of the Triassic red beds. These basins can be separated roughly (from NNE to SSW) into Yushe, Wuxiang and Qin Xian basins. The sedimentary fill of the Yushe Basin is the best exposed, the most fossiliferous (especially rich in mammalian fossils), and the most extensively studied. Therefore, Yushe Basin was chosen as the target area of the present study. A number of small basins with later Cenozoic deposits, like the Siting, Xiangyuan, Tunliu, and others, are also developed south and southeast of this area (Fig. 2.2). However, they contain only incomplete portions of the Yushe Group, are not always fossiliferous, and thus are poorly investigated and paleontologically dated. They will not be dealt with in the present volume.

The Yushe Basin is not really basin-shaped in topography. If the 1100 m contour line is taken as the border of the basin, it is dendritic in configuration. The form and structure of the Yushe Group outcrops clearly indicate their origin in an integrated fluviatile system. The basin is partitioned by several blocks of Triassic bedrock trending mainly in the ESE direction, which control interfluves of this fluvial landscape. Fluvio-lacustrine sediments occupy more than half of the territory of the present-day Yushe County and a small part of neighboring Wuxiang County to the south. A fault may exist along the Zhuozhang River as evidenced by the reappearance of Triassic bedrock along the west bank of the river. Together with the Triassic red beds, the lowest part of the Yushe Group (the Mahui Formation) reappears along the west side of the inferred fault. Therefore, the west block is the uplifted one. The alluvial deposits of the recent Zhuozhang River sometimes make correlation of the sediments on both sides of the river difficult. All this compelled us to subdivide the Yushe Basin into five subbasins: Ouniwa, Nihe, Tancun, Yuncu and Zhangcun subbasins (Fig. 2.3).

The Ouniwa and Nihe subbasins are situated in the north, the former to the northeast, and the latter west of it. They are separated from each other by a narrow strip of the uplifted Triassic bedrock along the west bank of the Zhuozhang River

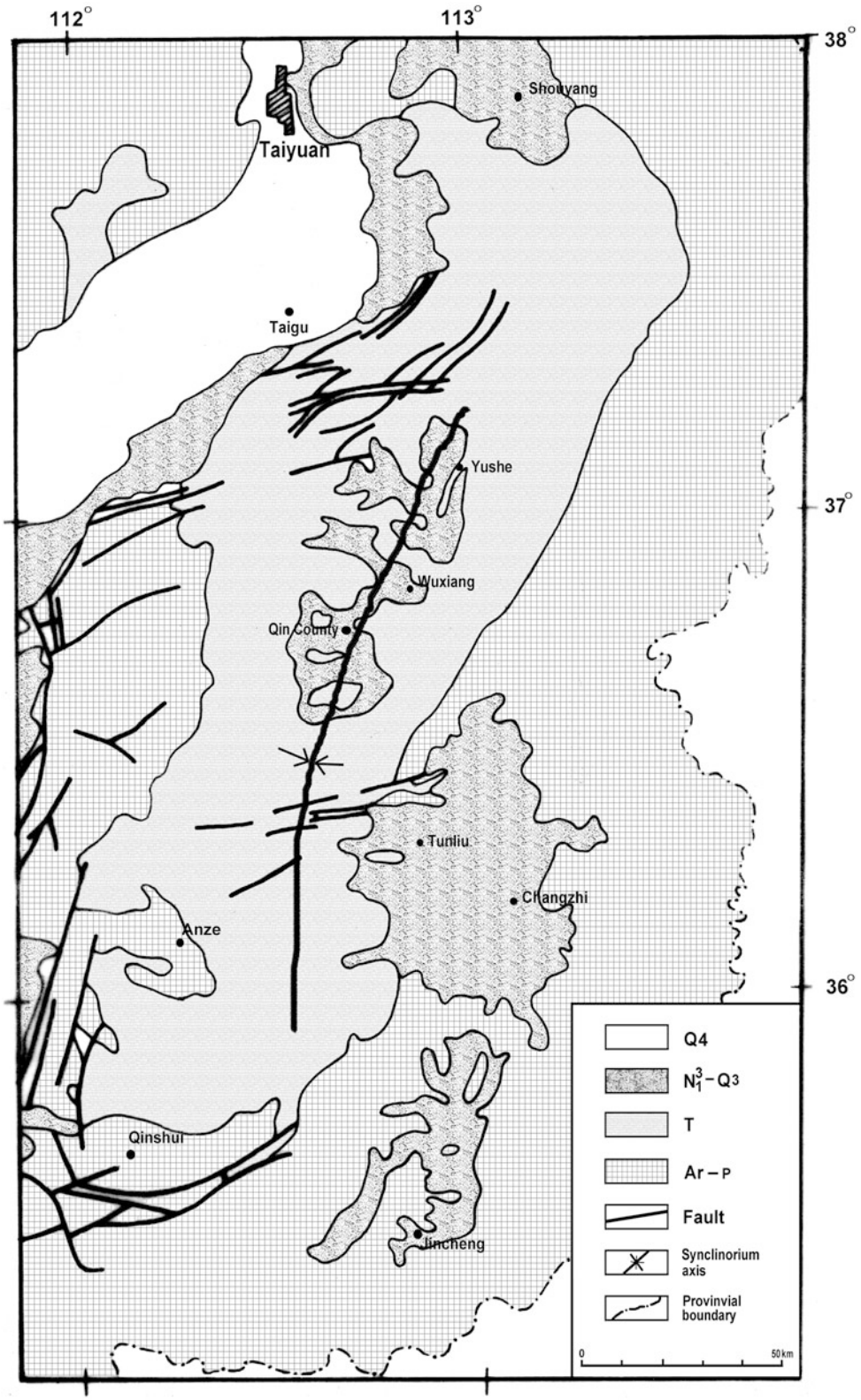

Fig. 2.2 Sketch map showing the location of the Yushe Basin, north of the Wuxiang Basin in the Qinshui Synclinorium (*heavy black curve*), and locations of other Late Neogene basins of Shanxi (excerpt from *Geological Map of Shanxi*, Cui and Wu 2002)

and recent alluvial deposits. The Nihe Subbasin is separated from the Yuncu Subbasin by a ridge of uplifted Triassic bedrock. However, the separation of the Ouniwa subbasin from the Tancun is obscured by the alluvial deposits developed at the border of the two subbasins. The middle pair, the Tancun and Yuncu subbasins, are clearly separated from each other by the

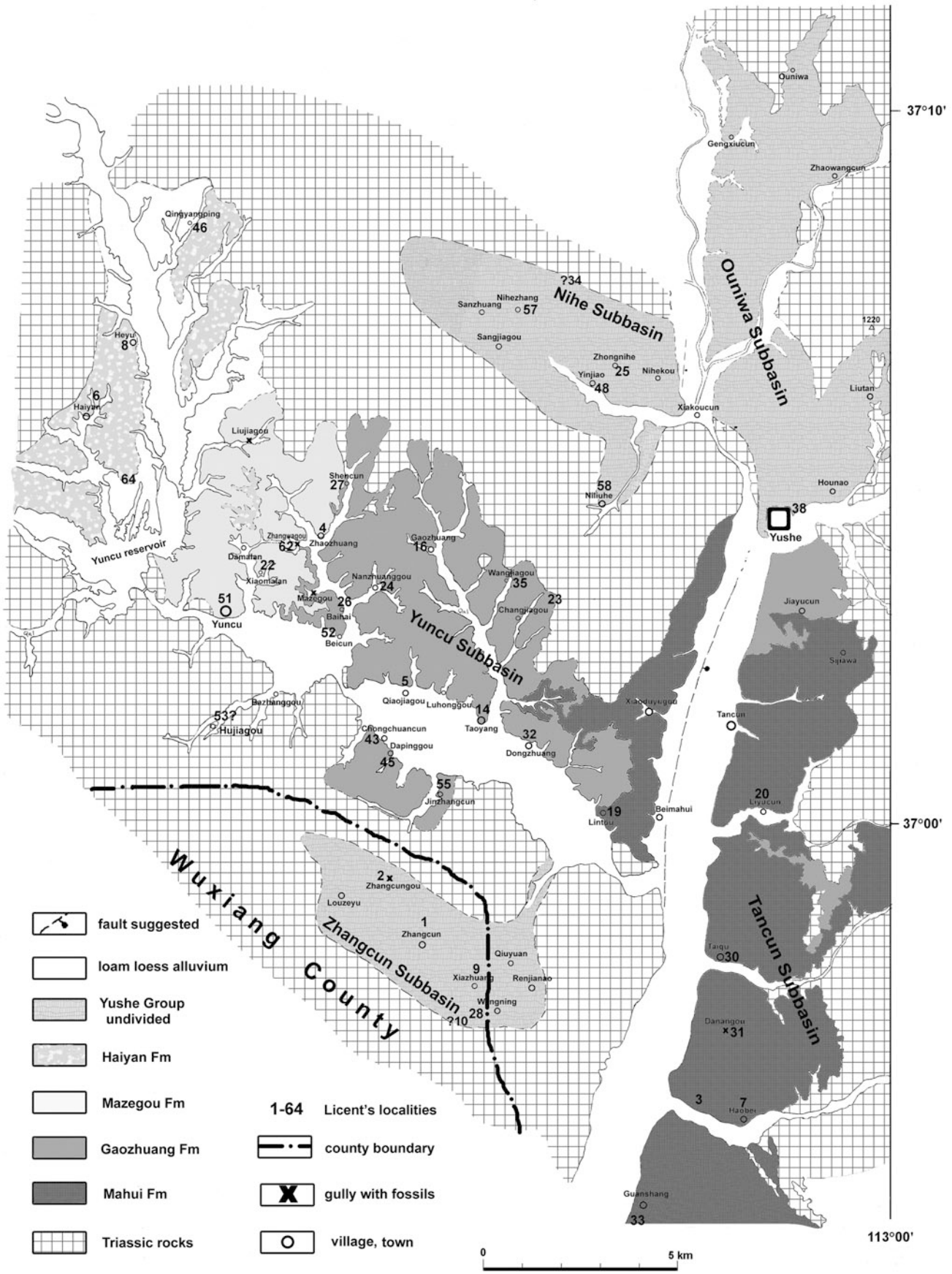

Fig. 2.3 Sketch map showing the distribution of Tertiary sediments in the five subbasins of the Yushe Basin (*numbers* denote Licent's localities)

uplifted Triassic bedrock and the alluvial deposits of the Zhuozhang River. The Tancun subbasin takes the form of a long strip, extending far south of the level of the southern-most Zhangcun subbasin. The Yuncu Subbasin is the largest subbasin, stretching farther westward than the other subbasins. To the south the Yuncu subbasin is separated from the southernmost Zhangcun subbasin by Triassic bedrock, with a narrow connection at their east ends. The major part of the Zhangcun subbasin lies in Wuxiang County, and is restricted to the west of the Zhuozhang River and the Guanhe reservoir.

Of the five subbasins, the Yuncu subbasin has the longest and most complete sequence of late Cenozoic deposits. The composite section measured by the SAYP (Sino-American Yushe Project) starts from the basal breccias of the Mahui Formation lying directly on Triassic bedrock near Beimahui in the southeastern corner of the subbasin. The Gaozhaung and Mazegou Formations overlie the Mahui Formation, and the latest deposits of the Yushe Group, the Haiyan Formation, occur in the westernmost part of the subbasin. The late Cenozoic deposits of the Ouniwa and Tancun subbasins are comparable in lithology with the lower part of the section of the Yuncu subbasin, which is equivalent to the Mahui Formation and probably the lower part of the Gaozhuang Formation. The Nihe Subbasin contains only a small part of the Mahui Formation and a major part of the Gaozhuang Formation. The Zhangcun subbasin contains probably the second most complete sequence of late Cenozoic deposits. Its basal to upper parts are comparable with the uppermost Mahui through Mazegou Formations of the Yuncu subbasin, while its middle part, the Zhangcun Formation, is mainly thin-layered variegated clays intercalated with paper-thin oil shale, a lithology not seen in the other subbasins. The Yuncu subbasin is not only the largest, but also the most fossiliferous among the five subbasins. The majority of the mammalian fossils in the historic collections came from this subbasin. Thus, it was chosen as the initial area for investigation with the aim of extending the study to the whole of the fluvio-lacustrine deposits in the other subbasins.

2.2 History of Fossil Collection and Related Geological Survey

2.2.1 Early Historical Records

It is well known that in historic times the mammal fossils of China had long been called "dragon bones" by the common people and treated as pharmaceutical material by medical scholars. Some (ex. gr., Jia and Zhen 1978) believe that the "dragon bone" had been known well before the Christian era, because this word first appeared in "Shan Hai Jing" (a book about the legendary stories of mountains and seas, allegedly taking place in the period from the Warring States to the Western Han Dynasty [476 B.C. to 8 A.D.]), collated and published by Liu Xiang (77-6 B.C.) and his son Liu Xin (?–23 A.D.) of the Han Dynasty. A careful reading of the "Shan Hai Jing" reveals that the phrase including the word is: "There are plenty of Tian Yong [an unknown kind of plant] whose form looks like the dragon's bone" (Liu et al. 2009 edition: 136). Thus "dragon's bone" is here used as a descriptor for the plant, not necessarily referring to the fossilized materials called "dragon bones" by later Chinese pharmaceutical scholars. Needham (1959: 619) suggested that the name "dragon bone" could be traced back to 133 B.C. according to historical records. At present it can hardly be ascertained whether this "dragon bone" is the same as that used later for pharmaceutical materials.

According to Li Shizhen's "Compendium of Materia Medica" (finished in 1578, but published posthumously in 1596), the first reliable record of the "dragon bone" as a kind of pharmaceutical material was in a medical book (no longer extant) written by Lei Xue (Lei Hiao in Andersson 1934), who lived in the Song Dynasty (420–479 A.D.) of the Southern Dynasties. There Lei Xue wrote: "The dragon bones from Shan Zhou [now Sheng Xian area, Zhejiang Province], Cang Zhou [now Cangzhou area, Hebei Province], and Taiyuan [capital city of Shanxi Province] are the best…". In another book written by Tao Hongjing (456–536 A.D.) of the Liang Dynasty of the Southern Dynasties, Shanxi was listed as the only place producing "dragon bones." As now known, Baode and Yushe had been the two major areas producing "dragon bones" in the early decades of the last century in Shanxi. This is fully in accordance with the historical records. Therefore, it may be safe to say that the earliest history of "dragon bones" can be traced to the fifth century, at least for the people living in Shanxi.

2.2.2 Initial Scientific Exploration (1918–1933)

Andersson's Collecting Campaign (1918–1923)

It is well known that J. G. Andersson, a Swedish geologist, was the foremost pioneer in finding fossil concentrations and organizing in situ excavations of *Hipparion* faunas in North China in the early years of the last century (Fig. 2.4). Adventurous stories of Andersson's scientific activities in China have been related in various publications (e. g. Andersson 1919, 1922, 1923, 1934; Mateer and Lucas 1985). Andersson was engaged as a mining advisor to the Ministry of Agriculture and Commerce of the Chinese government in 1914. Stimulated by frequent discovery of fascinating mammalian fossils during his geological survey

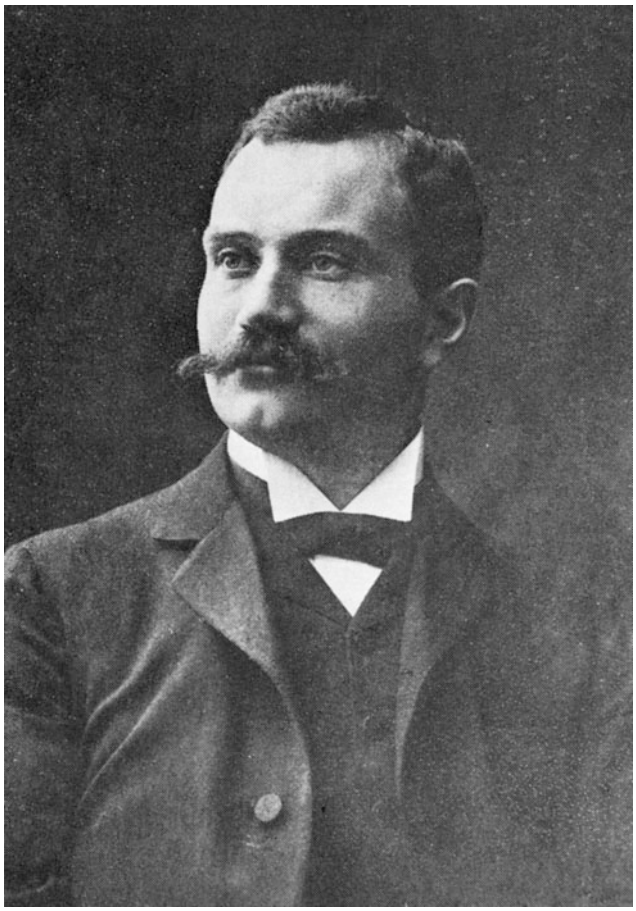

Fig. 2.4 Johan Gunnar Andersson (1874–1960)

in North China in 1916, he soon became an ardent fossil hunter. Lacking reliable information about the provenance of the "dragon bones" (mainly mammalian fossils) from the drugstores and pharmacy markets, Andersson turned to distributing circulars among the foreign missionaries in late 1917, soliciting help in providing information about the provenance of the "dragon bones and teeth" (Andersson 1919). Andersson's initiative was rewarded by information about the localities producing rich mammal fossils, including those from southeastern Shanxi. Andersson's most productive paleontological collecting activity lasted from 1918 to 1923 (vide Sefve 1927: 5) and resulted in establishment of the famous "Lagrelius Collection" at Uppsala University, Sweden.

It is a pity that no formal record of the first mammalian fossils obtained by Andersson's collectors from Yushe County can be found. Andersson did not pay much attention to the localities that yielded only poor fossils discovered during his early exploration. He may not have visited the Yushe-Wuxiang area as he never mentioned the county name Yushe in his publications. His emphasis first focused on localities along the Yellow River (Huang He) banks of Henan Province in 1918, and later on the localities around Baode County in northwestern Shanxi in 1919–1922.

A perusal of literature and old documents revealed that the first mammalian fossils from Yushe and the adjoining Wuxiang counties were found by Andersson's collectors Liu (Chang-Shan Liu) and *Pai* (properly, Bai), probably in the second half of 1922. Andersson sent his collectors to southern Shanxi as early as 1919, but the first find was made not in the Yushe-Wuxiang area, but around the Hejin district, according to the information provided by A. B. Lewis of the Protestant China Inland Mission at Hejin, a town in southern Shanxi. A small part of the Lagrelius Collection left in China is now housed at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP). On tags stuck to a lower jaw and a maxilla of *Equus* sp. we found the following words: "Lok. 32, *Chi Hsian* [Ji Xian County, 55 km north of Hejin], Liu, 19, 12, 1919." Judging from the locality numerical sequence, the localities of the *Hsiangning* (Xiangning, 40 km north of Hejin) County (Lok. 33–34) were probably discovered at the same time. Both Ji Xian and Xiangning counties lie immediately north of Hejin City (see Fig. 1.1). On tags stuck to three "*Cervavitus*" jaws we read: "*Shansi* [Shanxi], *Yü She Hsien* [Yushe County], S 15 li, Tancun, NE 3 li, Chu Tse Wa [this small town does not appear on modern maps], Liu and *Pai* [Bai], 20/11, and 24/11, 1922." Probably because of the paucity of the material, the specimens found from Yushe were not given catalogue numbers. The specimens found in the Wuxiang area bear in most cases locality numbers (Lok. 70–75, 77–81). A large number of cervine jaws and limb bones, bearing the number 73 and 76 are kept in the IVPP collection. Unfortunately, no labels with year of collection have been found with these specimens. In their paper about the Lagrelius Collection, Mateer and Lucas (1985: 11) wrote the following about Andersson's 1922 activity: "*Pai* [Bai], another of Andersson's Chinese assistants, was at that time [September to December, when Zdansky was working in Baode] in southeastern Shanxi collecting a forest *Hipparion* fauna quite unlike the *Baodezhao* [Baodezhou = Baode County] fauna." This is in full accordance with the nature of the fauna from the Yushe-Wuxiang area and the locality number sequence of the Wuxiang County. Andersson's Lok. 60–63 numbers were given to the localities found during Andersson's trip to Wanping (now in Beijing) and *Chengteh* (Chengde) of *Jeho* (now Hebei Province) in May 1922 (Andersson 1923: 84, 130). All this leads us to conclude that the specimens of the Yushe-Wuxiang area must have been found by Andersson's collectors in the later half of 1922.

The material obtained by Andersson from the Yushe-Wuxiang area (see localities on Fig. 1.2), although not systematically studied until now, is by no means unimportant. A browsing of the monographs written on the Lagrelius Collection gives the following picture. Ten forms were described from Yushe Basin, as follows:

> *Canis* sp. (Zdansky, 1927), *Metailurus minor* (Zdansky, 1927), *Pentalophodon sinensis* (Hopwood, 1935), *Hipparion tylodus* (Sefve, 1927), *Hipparion parvum* (Sefve, 1927), *Dicerorhinus orientalis* (Ringström, 1927), *Rhinoceros* aff. *brancoi* (Ringström, 1927), *Propotamochoerus hyotherioides* (Pearson, 1928), *Procapreolus latifrons* (Zdansky, 1925), and *Gazella gaudryi* (Bohlin, 1935).

Among these fossils, specimens representing the two *Hipparion* species are holotypes, and that of *P. sinensis* was later chosen as the holotype of *Anancus sinensis* by Tobien et al. (1988).

The material collected from the Wuxiang area is more abundant than that of Yushe. About 20 forms were described or listed in the literature. The most important are the skulls of *Hipparion platyodus* (type, Lok. 70: Xigou, Wuxiang; Sefve, 1927) and *Hipparion ptychodus* (type, Lok. 73: Doujiaogou, Dongcun, Wuxiang; Sefve, 1927), partial skeleton of *Chleuastochoerus stehlini* (Pearson, 1928), skulls, jaws and postcranial skeletons of *Honanotherium schlosseri* (Bohlin, 1926), antlers of *Eostyloceros blainvillei* (type, Lok. 81: Hejiannao, Wuxiang; Zdansky, 1925), and large numbers of antlers, jaws and postcranial bones of *Cervocerus novorossiae* (Zdansky, 1925). Unfortunately, stratigraphic observations on these fossiliferous deposits were never reported by Andersson. Only later in 1933 did Teilhard de Chardin and Young present two sections (their Figs. 9, 10) showing the Cenozoic sediments between *Wuhsianghsien* [Wuxiang County] and *Chinhsien* [Qin Xian County] to be "fundamentally Pontian," but "overlain by a younger Sanmenian series of the same exact facies."

Fig. 2.5 P. Teilhard de Chardin (1881–1955)

Teilhard de Chardin and C. C. Young's Survey of 1932

In 1931 Liu Xi-Gu (*Liushikou*, in Teilhard de Chardin and Young 1933), a collector of the Cenozoic Research Laboratory of the Geological Survey of China, was sent to southeastern Shanxi to collect "dragon bones." Liu visited the Yushe and Qin Xian areas and reported the extensive presence of "dragon bones" there. This prompted Pierre Teilhard de Chardin and C. C. Young (Figs. 2.5, 2.6) to undertake a mule-back ride through southern Shanxi in July 1932. Teilhard de Chardin and Young published a short report on their reconnaissance trip in 1933, and Young's diary covering this trip was also published posthumously (Yang 2009). As calculated from the itinerary described in Young's diary, Teilhard, Young and Liu arrived at Shouyang railway station on July 9, 1932. With six hired mules they started their journey on July 11. Altogether they spent 18 days, from July 11 to July 27, to traverse southern Shanxi, ending at Houma City in the southwest part of the province, where they took a long-distance bus to start their way back to Beijing.

In order to see as many geological sections as possible, they first headed southward through the central part of the Shouyang basin (see Fig. 1.1), stayed overnight in Xiaxiang village (about 20 km south of Shouyang), then turned

Fig. 2.6 Yang Zhong-Jian (=C. C. Young, 1897–1979, *right*) and Zhou Ming-Zhen (=Minchen Chow, 1918–1996, *left*), photo taken in 1963

westward to Taigu County, and continued southeastward. On July 17, after having experienced their first violent rainstorm, they arrived at the town of Houmu (now renamed Gengxiu), a village in northern Yushe Basin (Fig. 2.7).

Teilhard de Chardin and Young stayed 1 day in Houmu, collected some fragmentary fossils in a section near the village, and purchased some better preserved specimens from the villagers in the evening. The purchased material included *Hipparion*, giraffid, and mastodont teeth. Their geologic observations were published in 1933, while the description of the fossils was included in Young's monograph on the mammalian fossils from Shanxi and Henan published in 1935. According to Teilhard de Chardin and Young (1933), the section at Houmu (Fig. 2.7) included three units: (1) the "torrential-lacustrine series" consisting of basal conglomerate of rounded Triassic boulders, violet sands and clays and yellow sands (layers 1–6), (2) the older "Red loam" and the younger "red loam," lying unconformably on a deeply dissected surface cut into all older rocks, and (3) the loess (Fig. 2.8). Preliminary determination of the mammals collected from the layer 2 of the section at Houmu (Loc. 26 of CRL) included *Mastodon* sp., *Stegodon* sp., *Chilotherium* sp., *Hipparion* sp., Suidae indet., *Moschus* sp., *Cervocerus* sp., Giraffidae indet. (*Alcicephalus*), *Gazella* and *Tragocerus*(?). Thus the layers 1–2 were considered "Pontian" in age (now Late Miocene). The fossils found on the surface of layer 6 were identified by C. C. Young as "*Siphneus*" and *Hyaena* cf. *variabilis*. In 1933 the presence of a true *Siphneus* (a zokor, which is an advanced, but not yet rootless myospalacine rodent) in layer 6 led Teilhard de Chardin and Young to refer the layers 3–6 to Sanmenian age (now known to be Late Pliocene).

Later in 1935, the fossils of the layer 2 were re-identified by Young as *Chilotherium* or *Rhinoceros* indet., *Hipparion* sp., *Moschus* sp., *Cervocerus* [should be *Eostyloceros*] cf. *blainvillei* (uncertain from Wuxiang, or Loc 26?), ?*Procapreolus rutimeyeri*, *Cervus* (*Axis*) *speciosus*, *Palaeotragus* cf. *coelophrys*, ?*Microtragus* sp., *Mastodon borsoni*, *Stegodon* sp. nov. (to be described in a later volume of this series), and *Siphneus zdanskyi*. Those of the layer 6 were re-identified as *Siphneus* [now *Allosiphneus*] cf. *arvicolinus* and *Hyaena* cf. *variabilis*.

Of these fossils the mandible of *Hyaena* cf. *variabilis* is still kept in the IVPP Collection (V 9800), and has been identified as *Chasmaporthetes* sp. by Qiu and Tedford, and discussed in the chapter on Hyaenidae of Volume III of this Springer series (under preparation). This would indicate that the uppermost part of "layer 6" is of Gaozhuangian age. A well-preserved suid lower jaw (RV 3501) called *Microstonyx erymanthius* and purchased from Tancun (questionable locality) is now identified as *Microstonyx major sinensis* by Li (to be published in Yushe Volume V).

At noon of July 18, Teilhard de Chardin and Young arrived at Tancun, a "dragon bone" purchase and transportation center. As stated by Young, the village head was the dominant "dragon bone" dealer. In his yard Teilhard de

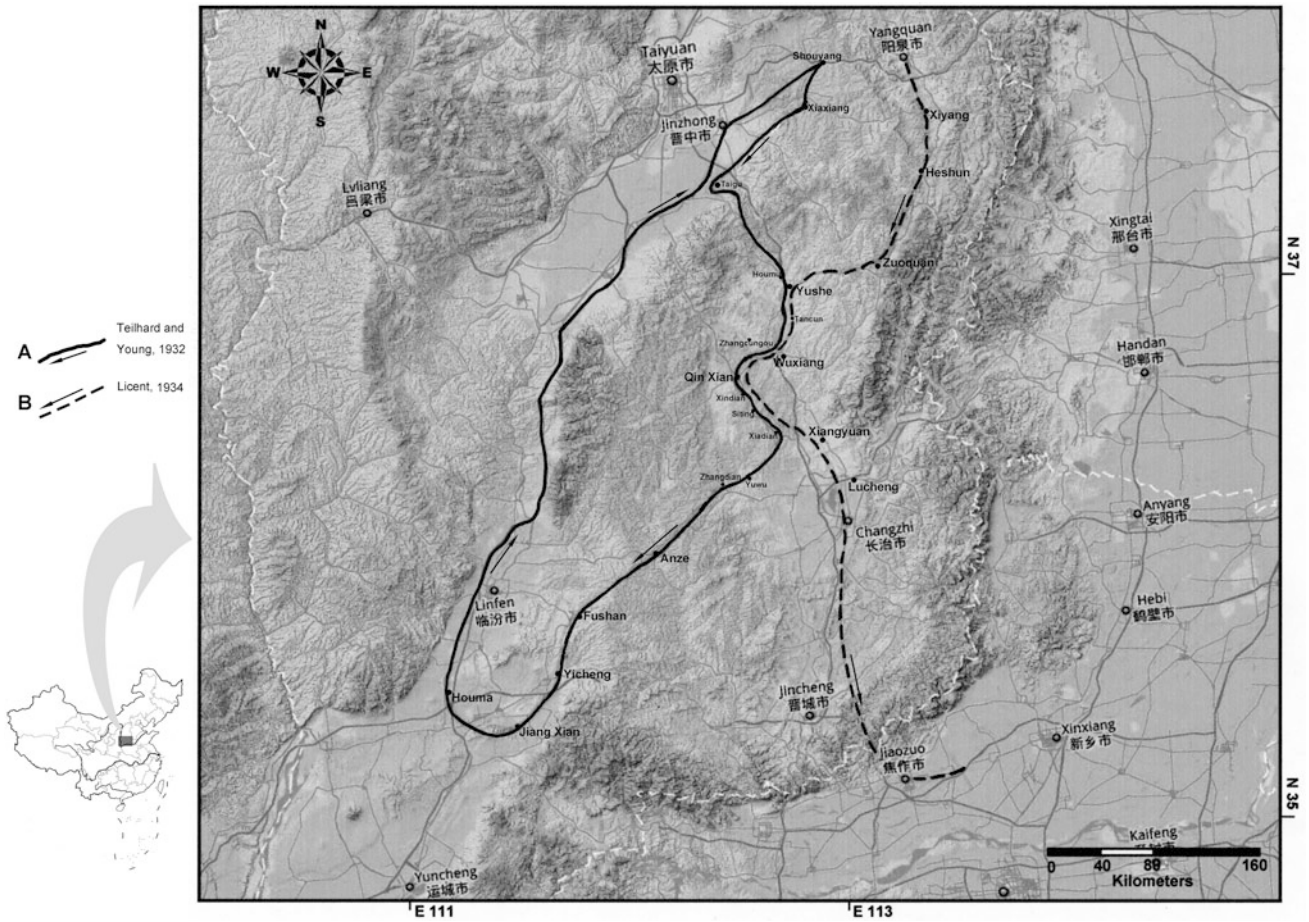

Fig. 2.7 Map showing geological reconnaissance routes in southern Shanxi followed by Teilhard de Chardin and Young, and later by Licent. *A* (*solid line*) Teilhard de Chardin and Young, 1932; *B* (*dashed line*) Licent, 1934

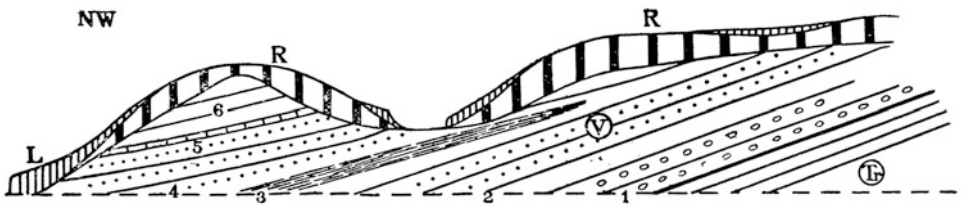

Fig. 2.8 Section near Gengxiu (originally Houmu, in Ouniwa Subbasin), drawn by Teilhard de Chardin and Young 1933. *Tr* Triassic beds; *V* violet freshwater series: *1* basal conglomerate, *2* lower sands, *3* dark, plant-bearing clays, *4* middle sands (turtle sands), *5* yellow sands and limestones, *6* upper sands; *R* red loess (originally "Red Loem"); *L* younger loess (originally considered the "Loess")

Chardin and Young saw "heaps of sadly broken bones," and in one of his rooms saw complete machairodont and gazelle skulls, suid jaws, proboscidean teeth, limb bones of *Hipparion*, and broken deer antlers, etc. The village head admitted that he first bought the fossils from nearby villages, and that they were then sold at Qin Xian, an intermediate county seat of the Changzhi-Taigu motor road, where the fossils were to be transported by buses and train to Beijing, or Tianjin. The village head even said that the better traffic service made the "dragon bone" trade in Yushe a more advantageous position than that in Baode. At the end of their visit, after much hard bargaining, Teilhard de Chardin and Young purchased five or six of the best preserved specimens at still very high prices, for example, one and a half dollars for a suid lower jaw.

Teilhard de Chardin and Young next visited *Changchiakou* (Zhangcungou) in Wuxiang County. Then they went first southwestward to *Chinhsian* (Qin Xian County), and then southeastward to *Hsintien* (Xindian, some 20 km [not 30 km as stated by Teilhard de Chardin and Young] from Qin Xian County seat), where the "Pontian" freshwater series ended.

Four hand-sketched profiles of the sections near *Changchiakou* and *Chinhsian* were published (Teilhard de Chardin and Young 1933, their Figs. 8–11). Their Figs. 9 and 10 showed clearly that the Cenozoic sediments between Wuxiang and Qin Xian contained "Pontian" faunas overlain by similar deposits with "Sanmenian" faunas. Confined to observations adjacent to the motor-road, they did not get a complete impression of the lateral extent of the basin fill, but the general stratigraphy and setting were accurately assessed. The late Cenozoic deposits were seen to be contained within the axial part of a synclinorium developed in Triassic rocks and to dip westward more or less in conformation with the eastern limb of the Triassic fold, so that the basal parts of the late Cenozoic strata were exposed only along the eastern borders of the basins.

Finished with the Yushe-Wuxiang-Qin Xian areas, Teilhard de Chardin and Young turned southwestward, passing through *Yüwuchen* (Yuwu town) and Zhangdian of Tunliu County, then to *Fuchengchen* (Fucheng town, now Anze County), Fushan, *Icheng* (Yicheng County), and *Chianghsien* (Jiang Xian County), and finally, on July 27, arrived at Houma city. From Houma city Teilhard de Chardin and Young returned to Beijing.

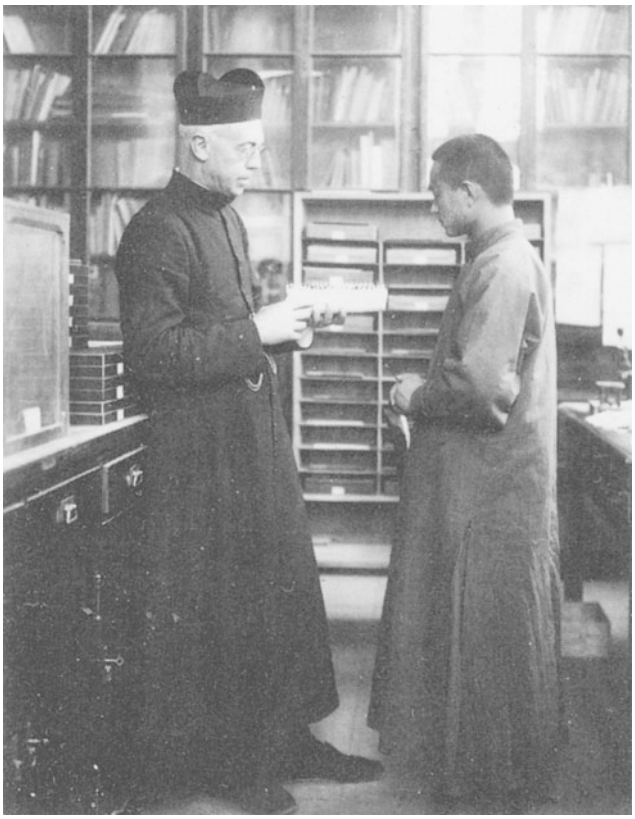

Fig. 2.9 Emile Licent (1876–1952, *left*) in the 1930s at the *Musée Hoang-ho Pai-ho de Tientsin*

2.2.3 Period of Extensive Collection and Study (1934–1945)

Licent's Collecting Campaign (1934–1935)

The discoveries made by Teilhard de Chardin and Young were thought of particular importance at that time because the fluvio-lacustrine character of the "*Hipparion* fauna"-bearing deposits radically differed from the classical *Hipparion* red clay facies widely distributed in North China. This fact aroused the interest of the French Jesuit Father Emile Licent of the *Musée Hoang-ho Pai-ho de Tientsin* (now Tianjin Natural History Museum).

Emile Licent (Fig. 2.9) was an important figure in the history of the development of the natural history museums in China. As a missionary he was sent to China as early as 1914. However, his main goal was apparently to initiate natural science investigations in China. Early on, he had already obtained large paleontological collections from Qingyang (Late Miocene *Hipparion* fauna) in Gansu, *Sjara-osso-gol* (now Hongliuhe, Wushen Banner; Late Pleistocene fauna) in Nei Mongol, and Nihewan (Early Pleistocene *Equus* fauna) in Hebei. He eventually launched a new campaign of collecting fossils in the Yushe area in the mid-1930s, resulting in obtaining about 2,300 specimens there. Licent left China in 1938, 1 year after the Anti-Japanese War broke out and Tianjin was occupied by Japanese troops.

Licent left Beijing on June 8, 1934. Arriving at Shijiazhuang (capital city of Hebei Province) on June 9, he first turned westward to Yangquan, then turned southward along the west side of the Taihang Shan Mountains, via Xiyang, Heshun and Zuoquan (then Liao Xian), then turned westward again, and on June 26 he arrived at Lintou village of the Yuncu Subbasin (Figs. 2.7, 2.10), where there was a Catholic parish church, then led by a Dutch Father, P. Landolinus Bonekamp.

Licent started his prospecting and excavation first at a gully east of Lintou, called Heilingou (differently transliterated as *Hu Lien Keou*, *Ho Lien Keou*, and *Ho Lin Kou* in Licent's diary, vide Appendix III). The work at Lintou had to be terminated on July 3 because of the unaffordable demand for compensation asked by the landowner, according to our interviews in 1994 and 1997 with the villagers who knew of Licent's activities in those days either directly or indirectly from their older generations. Licent then went to Zhangcungou (*Tchang tsoun keou* in Licent's diary) in the Zhangcun Subbasin. He carried out major field work there and stayed until July 26. On July 27 he returned to the Yuncu Subbasin, stayed in Shencun (*Chen ts'ouna* in Licent's diary) until August 2. Licent collected and purchased fossils widely in the area nearby

Fig. 2.10 Church in Lintou village (built in 1884; photo by Z.-X. Qiu, August 1997)

from Gaozhuang (*Kau tchoang* in Licent's diary) in the east, at Baihai (*Pai hai tze* in Licent's diary) in the south, and from Damalan in the southwest and Haiyan (*Haiyen* in Licent's diary) to the west of Shencun. On August 3 he returned to Lintou to wind up field work. He stayed there until August 10. From his diary it is clear that Licent not only organized excavations in the areas near Lintou, Zhangcungou and Shencun, but also extensively purchased specimens from villagers living nearby at the time. On August 10 Licent left Lintou for a reconnaissance trip in southeastern Shanxi. He prospected large areas of Qin Xian, Siting, Lucheng, Changzhi, etc. Then, via Jiaozuo of Henan Province, he headed northward and was back in Tianjin on September 26, 1934.

According to Licent's diary and recollections of the local villagers, Licent was accompanied by two Chinese facilitators. The villagers of Lintou told us that they were called Mr. Zhang and Mr. Wang, but the villagers of Zhangcungou insisted they were bodyguards named Wang and Tian. One of the "dragon bone" collectors hired by Licent was "*Lu cull*," a name which appeared very often in Licent's diary as a major helper and collector. A third Chinese facilitator called "*Lei hoie tchang*," sometimes "*Lien tchang*," was a local "dragon-bone" dealer, whose Chinese name should be correctly spelled as Hao Lin-Zhong according to the opinion of the Zhangcungou villagers. Many old villagers of Zhangcungou still remember him, saying that he was a native of Shibi, a little town about 5 km southeast of Zhangcungou, but belonging to Wuxiang County. He served as an agent dealing with the local people on behalf of Licent. Another local Chinese who played a rather important role in excavation near Zhangcungou was "old Ho," a villager of Zhangcungou. He directed most of the excavation work there. Father M. Trassaert, an entomologist, who joined the *Musée Hoang-ho Pai-ho de Tientsin* in 1934, came to Zhangcungou on July 5. He participated mainly in the work of the Zhangcungou area. Licent always hired local people as laborers, sometimes more than ten people, plus as many as seven mules or donkeys.

Licent visited the Yushe area again in 1935, first departing from Tianjin on May 22. This time he continued westward beyond Shijiazhuang to Yuci, then turned southward and arrived at Yuncu on May 29. He stayed mainly in the western part of the area, visiting Damalan, Zhaozhuang, Haiyan, Gaozhuang, and elsewhere. He did not organize any excavation this time, but purchased many specimens

during his travel. On June 9 he stayed overnight in Lintou and left for Wuxiang the next day. From there he went to Changzhi and then turned westward to prospect areas in Huoshan County. On June 18 he returned to Yuci via Taigu, and arrived at Tianjin on June 19.

After their first year's work, Licent and Trassaert published a short article in 1935. In this article the studied area was considered to comprise three "minor basins": *Changtsun* (Zhangcun), Yushe, and *Yünchuzhen* (Yuncu). The Yuncu basin was the largest and was selected as the most representative of the three. The smaller Zhangcun basin was characterized by the particular lithology of the middle part of the deposits (thick "marlish beds," with abundant fish remains).

The lithology of the Yushe basin was not indicated in their geologic sketch-map. The "Pliocene lacustrine deposits" were subdivided into three "zones," based on lithology and paleontology. All the fossil mammals listed in their article were preliminarily identified by Teilhard de Chardin, who claimed partial authorship and made a number of corrections to reprints of that article (analysis of Schmitz-Moormann 1971, Tome V: 2232, 2241–2242).

Zone 1 was "mostly exposed and fossiliferous near *Lingt'ou* [Lintou]" and represented by "hard consolidated conglomerates and dark red sandstone, immediately derived from the underlying Permo-Triassic beds." "It contains a typical Pontian fauna" (Licent and Trassaert 1935).

Zone 2 was best studied in the Zhangcun subbasin. Deposits were "less coarse, and a typical lacustrine condition is prevailing: green and bluish marls, containing many bird, turtle, fish-remains, freshwater shells… and plant remains." A "remarkable type of strepsiceros Antilope" [cf. *Antilospira*] and a specimen of "*Castor majori*" [later transferred to *Dipoides*] "characteristic of the Ertemte fauna" were collected. This led the two French authors to conclude that "a middle Pliocene age seems to be indicated" by the mammalian fauna (Licent and Trassaert 1935).

Zone 3, studied in the Yuncu Subbasin, was "chiefly sandy, with the presence however of two layers of marl at the middle of the deposits … indicating perhaps a maximum in the lacustrine conditions" (Licent and Trassaert 1935). Zone 3 rests with "clear erosional breaks and even overlapping" upon Zone 2. As to the age of Zone 3, Licent and Trassaert were inclined to separate it into two phases: the lower part containing "a big *Hipparion*, already associated with *Bison*, but without any sure trace of *Equus*," and a "thick lamelled Elephant," which should be older than the upper part containing the typical *Equus* fauna.

Licent and Trassaert's work was of considerable importance, for it remained, for 40 years, the basis for the geology and stratigraphy of the Yushe Basin fill. Nevertheless, a series of ambiguities and inconsistencies exist. Firstly, the geologic sketch-map appended to the article (Fig. 2.11 here) showed basically concentric patterns of distribution of the deposits, while in the text it was clearly stated that the deposits were all westward dipping. Furthermore, the largest area of outcrops as shown in that map was that of the Zone 3. This is far from being true as proven by our own observations during the 1987–1988 field seasons.

Secondly, the composite section covering the deposits of the three zones taken from a cliff near Zhangcungou (Fig. 2.12, left) seemed rather misleading in that Zone 2 included also the lower half of the red loam, and the upper half of the red loam represented Zone 3. Furthermore, the dark red sandstone of Zone 1 should not have appeared in this area if the deposits were all westward dipping. Huang and colleagues measured the same section, but referred these deposits to layers 26–34 (upper member) of the Zhangcun Formation (Huang and Guo 1991, their Figs. 1–6; here Fig. 2.12, right). Our re-examination of the Zhangcungou cliff section in 1997 revealed that the deposits exposed at the very base of the cliff are still yellow sandstones, and a left mandibular ramus of *Paramachairodus schlosseri* was found there in situ (vide Chapter of the Felidae, Volume III of the present series), and we purchased some cheek teeth of *Hipparion houfenense* (vide Chapter of the Equidae of volume IV of the present series). The base of the section would therefore belong to Zone 2. The faunal lists given by Licent and Trassaert (1935) for their Zones 1–3 seemed to be based largely on the evolutionary levels of the listed mammals, without reliable ties with their factual stratigraphic positions in the section.

Teilhard de Chardin's Study of the Fossils Collected by Licent

During 1937–1945 the Yushe and Wuxiang region became part of the battle-zone, prohibiting field work there. However, study of the fossils collected from Yushe was carried on successfully in the laboratory by Teilhard, to whom the task was apparently entrusted by Licent. Unfortunately, Teilhard succeeded only in accomplishing half of his original plan to publish eight monographs covering all the Yushe mammalian fossils. Together with Trassaert, he published three monographs on the Yushe ungulates: on the Proboscidea, Camelidae, Giraffidae and Cervidae (Teilhard de Chardin and Trassaert 1937a, b) and on Cavicornia (Teilhard de Chardin and Trassaert 1938). With the worsening situation in Tianjin caused by its occupation by the Japanese troops, Teilhard had to transfer some of the Yushe fossils, mainly small to medium sized rodents and carnivores, to Beijing. Together with Pierre Leroy, Teilhard established a new institution in Beijing, the Institut de Géobiologie. He used this as a vehicle to publish the Yushe

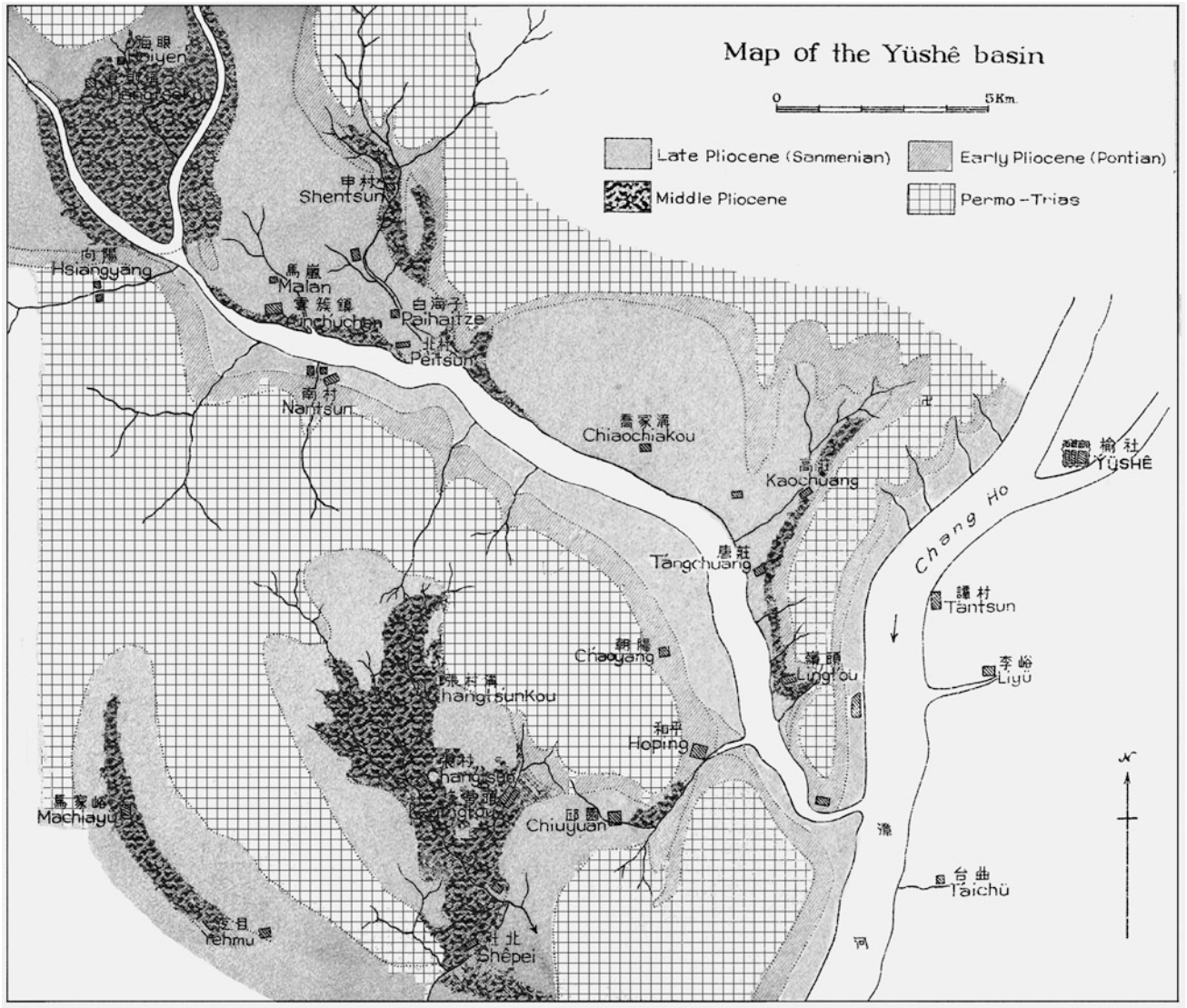

Fig. 2.11 Geological sketch map of Yushe Basin (mainly Yuncu subbasin) drawn by Licent and Trassaert (1935)

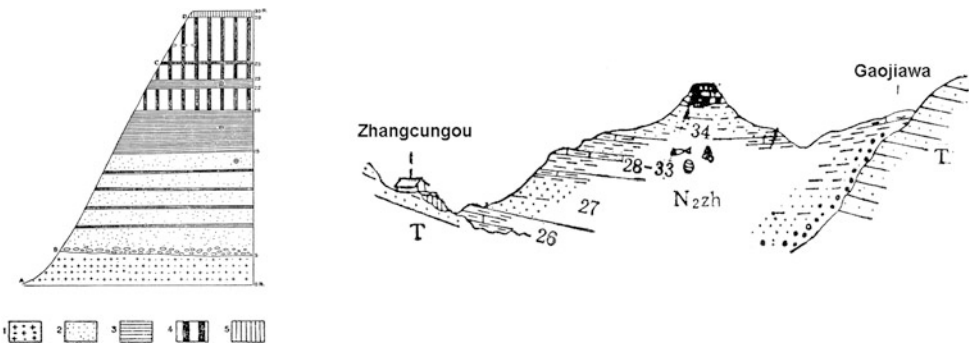

Fig. 2.12 Comparison of two sections across the excavated cliff near Zhangcungou village. *Left* section measured by Licent and Trassaert (1935): *1* dark red sandstone, *2* yellow sand, *3* dark marl, *4* red sandy loam, *5* loess; *AB* Zone 1, *BC* Zone 2, *CD* Zone 3. *Right* section measured by Huang and Guo (1991): Units 26–34 equivalent to those on *left*

fossil rodents, mustelids and felids together with their living species distributed in China through 1945 (published as Teilhard de Chardin 1942; Teilhard de Chardin and Leroy 1945a, b). When Teilhard left China in 1946, the study stopped abruptly, leaving the Canidae, Ursidae, Hyaenidae, Viverridae, Rhinocerotidae, Equidae, and Suidae unstudied. Of these latter families only a small fraction was later treated (vide infra).

Fossil Collecting Supported By Childs Frick (1932–1937)

Childs Frick, curatorial associate of the American Museum of Natural History, started to support the collecting of mammal fossils in Yushe from 1932. Encouraged by Walter Granger, he hired the skilled professional collector Gan Quan-Bao (*Kan Chüan Po*, nicknamed "Buckshot"), who had been trained during the museum's Asiatic expeditions in China and Mongolia (Andrews 1932). Gan's activities were funded by Frick and supervised by Dr. Erik T. Nyström, a geologist affiliated with the Sino-Swedish Scientific Research Association based in Taiyuan, the capital city of Shanxi Province. Knowing that Nyström's assistants came across some "dragon bones" in the Shouyang area in 1928, Gan started his prospecting in this area in January 1932. Gan found two areas south of Shouyang where active "dragon bone" mining was going on. Seven sites were situated west of the Zheng-Tai railroad (from Shijiazhuang [Zhengding], capital city of Hebei Province, to Taiyuan), around "*Pai Tao Tsun*," which is 16 miles west of Shouyang. Sixteen sites were located south of the Shi-Tai (then Zheng-Tai) railroad and south of "*Chang Chia Chuang* [Zhangjiazhuang]." He worked these sites, including purchase of material from 1933 to 1937. As mentioned in earlier work by Teilhard de Chardin and Young (1933: 209–212), in the Shouyang basin the violet, "fluviatile or lacustrine series" produces "*Caprolagus* sp. [*Caprolagus brachypus* in Young, 1935, now *Sericolagus brachypus*] and *Siphneus* cf. *tingi*" [*Siphneus* cf. *chaoyatseni* in Young, 1935, now *Yangia chaoyatseni*] of "Sanmenian age." Elsewhere, in the Xiaxiang (*Shiahsiang*) basin, "some 200 meters of powerful conglomerates and violet sands" contain "typical Pontian fossils" like "*Hipparion*, *Chilotherium*, *Alcicephalus* [Giraffidae indet. in Young, 1935], etc." The Frick Collection of the 1930s verifies this generalization. The records of individual taxa, occurring together *Percrocuta* (*Adcrocuta*?) and *Eostyloceros*; *Stegodon* and *Chleuastochoerus*; *Chasmaporthetes* and *Canis* or *Bison* and *Dinofelis*, suggest a temporal range for the Shouyang area comparable to that represented by the Yushe Group 90 km to the south.

During this interval of collaboration with the Sino-Swedish Scientific Research Association, Childs Frick also engaged Xi-Gu Liu (who had visited Yushe for the Cenozoic Research Laboratory) to collect in the Baode and Fugu areas. Consequently the Frick Collection came to include material from there as well as from the Yushe and Shouyang areas.

Meanwhile, Gan got the news that the Yushe district, 90 km south of Shouyang, produced more and better "dragon bones." By the end of 1934 Dr. E. Nyström, now Director of the Sino-Swedish Scientific Research Association and living in Beijing, got to know from Teilhard de Chadin that rich fossils had been found from the Yushe area by Licent's party. Nyström immediately gave instructions to Gan to go to Yushe. While Gan was working at Zhaozhuang in May 1935, Licent came to Yuncu on May 29 and got to know about Gan's collecting activities in the Yushe area. The two parties met on June 1. To avoid direct confrontation with Licent, Gan intentionally arranged his subsequent work there in the absence of Licent's party. Gan continued his extensive collecting in 1936. As a result, he sent more than two hundred parcels to New York. Since Frick was then interested mainly in carnivores and horned ruminants, the material collected by Gan from Yushe belonged mostly to those groups. The total number of the specimens collected by Gan is 298, according to our personal count (226 formally recorded in AMNH Archives, see Appendix VI). The existence of this collection was noted several times in the literature (Teihard de Chardin and Trassaert 1937b; Teilhard de Chardin and Leroy 1945a, b), but the collection has not been studied, nor even widely known. After 1968, when the Frick Collection was donated to the AMNH, the specimens from Yushe became accessible.

In the summer of 1936, accompanied by Charles L. Camp of the University of California, Berkeley, to search for Triassic therapsid fossils in southern Shanxi, C. C. Young visited the Yushe-Wuxiang area again (Yang 2009). This time they started their journey from the Yangquan railway station, went directly southward, via Xiyang and Heshun, to Liao Xian (now Zuoquan), then turned westward to Yushe. They again visited the same "dragon bone" dealer in Tancun, and saw a large quantity of various fossils, including very well preserved skulls. They also saw a large and impressive house, which was still being built. Apparently, the dealer had made money from the "dragon bones" since 1932. Unfortunately, Young failed to purchase any fossils because of unbelievably high prices demanded by the "dragon bone" dealer.

2.2.4 Relatively Stagnant Period (1945–1975)

C. C. Young and Dong-Sheng Liu (=Liu P. T.) described (1948) some specimens obtained from Shanghai drugstores, allegedly transported from Yushe. The material included some hyaenids, rhinoceroses, and other large mammals. The type skull with mandible of *Leecyaena lycyaenoides* was the best specimen among them, and is now kept in IVPP.

Field work in Yushe was not immediately resumed after the establishment of the People's Republic of China in 1949. In 1955, a team headed by Liu Xian-Ting, a paleoichthyologist of the Laboratory of Vertebrate Paleontology, Academia Sinica, was sent to the Yushe-Wuxiang area. The primary aim of the team was to find more material of Triassic mammal-like reptiles, the first fossils of which were discovered some 20 years previously. Finding vertebrate fossils in late Cenozoic deposits was only the secondary purpose of the team. They departed from Beijing on September 12, arrived at Taiyuan by train on the 13th, and at Taigu by car on the 14th. From Taigu they used camels as the means of transportation and spent 5 days to reach the Wuxiang County seat on September 19. Excavations were primarily focused on the dicynodont fauna from the Triassic rocks in the Louzeyu area (Wuxiang County). From October 9 to 16 the team stayed in Zhangcungou to prospect the vertebrate fossils of the late Cenozoic fluvio-lacustrine deposits. Well preserved fish fossils were excavated from the greenish and bluish marls. Unfortunately, the team failed to find any important fossil mammals. From October 21 to 25 some excavations were carried out in localities near Gaozhuang (Jingjiagou, Field No. 5541; Ya'ergou, Field No. 5543) of the Yuncu Subbasin, where a number of *Hipparion* teeth were found (vide Chapter on Equidae of Volume IV of the present series), and the type material of the murid rodent *Chardinomys yusheensis* was collected (Jacobs and Li 1982). From October 25 to November 2 excavations were successfully carried out at Hounao, a new locality 1.7 km northeast of the Yushe county center. Well preserved specimens of rhinos, suids and cervids were unearthed there. During this time a delegation of vertebrate paleontologists from the Soviet Union headed by J. A. Efremov, visited some of the excavation sites (Zhangcungou and Hounao). The delegation arrived by train at Yuci on October 27, visited Zhangcungou on October 29, Hounao on 30th, and departed Yushe on October 31. The field work ended on December 2. As far as the mammalian fossils are concerned, Hounao was the major new locality discovered in 1955. Excavation was resumed at Hounao in 1956 (Field No. 5679) with the result that the small pocket of mammalian fossils was totally exhausted.

In 1962 *Liu Hsien-T'ing* (Xian-Ting Liu) and *Su Te-Tsao* (De-Zao Su) published their description of the fish fauna found from the Yushe-Wuxiang area in 1955–1956, and listed altogether 13 species, most of which were cyprinids (Liu and Su 1962). All these fish specimens are kept today in IVPP. Unfortunately, the fossil large mammals found from Yushe during 1955–1956 have never been systematically studied, except a few isolated *Hipparion* teeth mentioned by Qiu et al. (1987).

Chang-Kang Hu (1962) created a new species of *Metacervulus*, *M. lepidus*, based on a perfectly preserved skull donated to IVPP by a Shanghai amateur collector, allegedly found from Yushe.

In a review of the Chinese Cenozoic stratigraphy, Pei et al. (1963) first transformed Licent and Teilhard de Chardin's "Yushe series" to Yushe Formation and relegated the zones to lower, middle and upper divisions, but no real conceptual advance was made. New geological investigations were deferred until the early 1970s when the Geological Bureau of Shanxi Province began the 1:200,000 scale mapping of Shanxi Province. The Yushe Basin was contained in the Fenyang-Pingyao Quadrangle (published by the Geological Bureau of Shanxi Province in 1976). The local geologists elevated the Yushe Formation to group status, and chose the sequence in the Zhangcun subbasin as the type section for a three-fold subdivision of the Yushe Group (Renjianao, Zhangcun and Louzeyu Formations). The lithostratigraphic units as above defined owed much to concepts of the 1930s: the Rejianao Formation represented the coarse colluvium and alluvium at the base of the section; succeeded by the Zhangcun Formation, mostly fine sands and clays (including "oil shales") of a dominantly lacustrine nature; and at the top, the Louzeyu Formation sequence of sands, clays and marl representing a mostly fluviatile regime with minor lacustrine events. The latter unit was inferred to rest unconformably on the Zhangcun Formation, which truncated the Renjianao Formation itself. As measured in the Zhangcun Subbasin the Yushe Group was about 460 m thick (Fig. 2.13).

2.2.5 Renewed Study, Late 1970s and Early 1980s

In the late 1970s and the 1980s interest in studying the geology and paleontology of the Late Cenozoic deposits of the Yushe-Wuxiang area was renewed principally by three groups of workers as highlighted in the following. The emphasis of research became increasingly multidisciplinary.

Geological studies of Beijing University. During the 1970s and the first half of the 1980s, Jia-Xin Cao, her students, and coworkers of Beijing University, conducted a geologic survey of the Taigu-Yushe-Wuxiang area. In the Yushe Basin they concentrated their work in Zhangcun

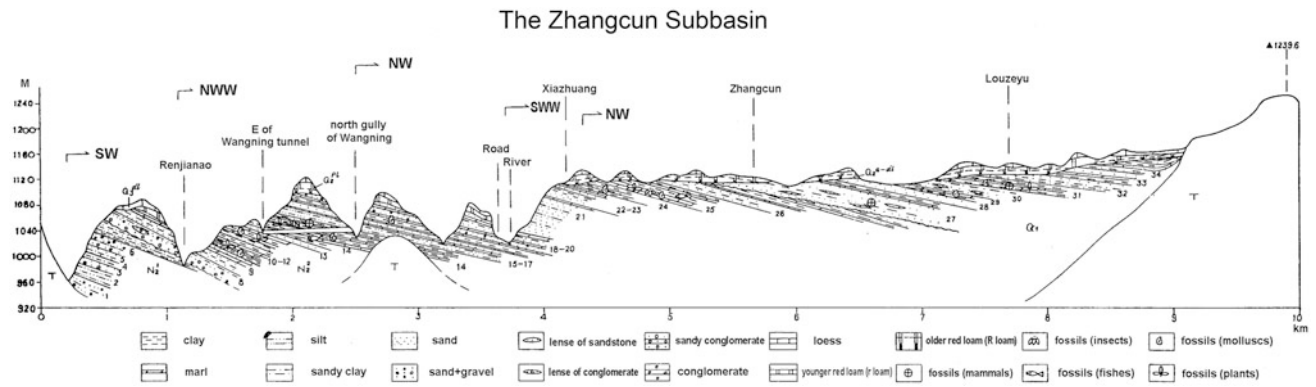

Fig. 2.13 Section of Zhangcun Subbasin measured by the geologic mapping team of the Geologic Bureau of Shanxi Province (redrawn from Plate 17 in the explanatory text of the Fenyang-Pingyao quadrangle, 1976)

subbasin (Cao 1980; Cao and Wu 1985; Cao and Cui 1989). Their study laid emphasis on reconstructing the depositional paleoenvironment, based on stratigraphic divisions proposed by the Shanxi geologists with the implication that major events in the Zhangcun subbasin held for the whole of the Yushe Basin. From the point of view of vertebrate paleontology, the most important find during their survey was a slab with "*Chilotherium*" skeletons from the basal level of the Zhangcun Formation near Wangning village in 1980, now kept in the Yushe County Museum (Fig. 2.14). The palynological record (Cao and Cui 1989) showed that the mesic floras of the lower part of the Zhangcun Formation represented a subtropical to warm-temperate climate, while the more xeric assemblages in the upper part of the Zhangcun Formation represented a warm-temperate climate approximating that of the southern part of North China of today.

A major contribution to the study of the Yushe area was made by Ning Shi, then a postgraduate student of Jia-Xin Cao, during the years of 1986–1993. In a comprehensive monograph on the Zhangcun subbasin, Shi (1994) created a new Formation, the Wangning Formation, lying between the Renjianao and Zhangcun Formations. Based on palynologic, mineralogic, paleomagnetic and ^{10}Be investigations, Shi was able to date the four Formations of the Yushe Group in the Zhangcun subbasin as follows: Renjianao: 5.5–4.5 Ma; Wangning: 4.5–3.5 (or 3.4) Ma; Zhangcun: 3.5 (or 3.4)–2.3 Ma and Louzeyu: 2.3–1.5 Ma. Sedimentation in that area began at about 5.5 Ma, some million years after deposition began in the Yuncu subbasin.

Paleomammalogy research by IVPP. In 1978 Zhan-Xiang Qiu, then head of the newly established Neogene Division of the IVPP, started a plan to resume the study of the Yushe fossil mammals kept in the Tianjin Natural History Museum (TNHM), and left unstudied by Teilhard de Chardin. A series of geologic surveys was conducted, with particular efforts to obtain more reliable information about the provenance of the fossils to be studied. Qiu first visited the Yushe Basin in October 1978. Later Qiu and his colleagues (Hang Jia, and Wei-Long Huang of the TNHM) started extensive prospecting of the area in 1979 (February) and 1980 (May and July–August). During these surveys mammal fossils were also collected, some in situ, and some purchased (see Appendix VII). In July–August 1985, Qiu, De-Fa Yan, Hang Jia and Wei Dong studied the Yuncu Subbasin in more detail, and measured some sections.

The field work revealed that the Yuncu subbasin might be more representative of the whole Yushe Basin than the Zhangcun subbasin. The Yuncu subbasin is almost totally separated from the Zhangcun with only a possible connection by a narrow strip of outcrops of fluviatile sediments. The Yushe Group in the Yuncu subbasin is more complex, dominated by fluviatile environments, and nearly twice as thick as in the Zhangcun subbasin. Qiu et al. (1987) resolved the lithostratigraphic sequence in the Yuncu subbasin into four sedimentary cycles, each beginning with coarse clastics and fining upward. Accordingly, a new lithostratigraphy was proposed: The Mahui Formation, containing a basal colluvium and characterized by yellow cross-bedded sands fining upward to muddy sands, clays and marls. It is overlain, locally unconformably, by the Gaozhuang Formation dominated by fluviatile sands and ending in mudstones and marls. These deposits are disconformably overlain by the Mazegou Formation, hard muddy sandstones and mudstones with its top often obscured by alluvium. The final unit, the Haiyan Formation, is horizontal and thus lies with angular unconformity across the gently dipping Mazegou Formation. It is composed mostly of fine sandstones and siltstones with local clays and marls.

Meanwhile Qiu et al. (1980, 1987) studied the hipparionine fossils of Yushe and other late Neogene basins. Qiu (1987) also published a monograph on the Pliocene and Pleistocene Hyaenidae of the Yushe area, based on his study

Fig. 2.14 "*Chilotherium*" skeletons found near Wangning village by Cao's party in 1980. The slab is currently mounted in the Yushe County Museum

during his stay in Germany (1982–1984) of the hyaenid specimens kept in IVPP. Heintz Tobien, Guan-Fang Chen and Yu-Qing Li undertook a revision of the Yushe Proboscidea (Tobien et al. 1986, 1988).

Paleontological study by the Institute of Geology and Paleontology, Nanjing. From 1979 to 1985 several groups of invertebrate paleontologists and paleobotanists intermittently collected fossils in the late Cenozoic deposits in middle and southern Shanxi. Their results were compiled into a special volume, and presented at the INQUA Congress XIII held in Beijing (Huang and Guo 1991). Authors of this volume included scientists of the Institute of Geology and Paleontology, Nanjing, Academia Sinica (Bao-Yu Huang, Bao-Ren Huang, Zhen Wang, Ling-Yu Tang), North China Bureau of Oil Geology, Ministry of Geology and Mineral Resources of China ([now Ministry of Land and Resources of China] Shu-Yuan Guo, Jing-Zhe Wang, Ze-Run Zhang), Shanghai Natural History Museum (Hui-Ji Wang), and Institute of Geography and Limnology, Nanjing, Academia Sinica (Rui-Jin Wu). Although their study areas covered a vast territory of middle and southeastern parts of Shanxi Province, special emphasis was laid on description of the invertebrate and plant fossils they discovered in the Yushe Group. The most remarkable alteration in stratigraphic division they suggested was discarding as distinct the Louzeyu Formation (they included it in the Zhangcun Formation), and the creation of a new unit, the Gengxiu Formation, based on a suite of siltstones and clays with rich ostracod fossils. About 30 m thick, the Gengxiu Formation unconformably overlies the Yushe Group but underlies the Lishi loess in a section 500 m north of the village Gengxiu (formerly Houmu) in the Ouniwa Subbasin. They also believed that this suite of siltstones and clays produced the derived zokor (originally *Siphneus* cf. *arvicolinus*, revised as *Allosiphneus arvicolinus*) fossils reported by Teilhard de Chardin and Young (1933). As a result, they thought that the age of the Gengxiu Formation of the Ouniwa Subbasin could prove to be older than that of the upper member of the Zhangcun Formation ("Louzeyu Formation") in the Zhangcun Subbasin, but it would still be a basal Pleistocene unit, correlatable with Licent and Trassaert's Zone 3.

More recently, Shi (1994) resurrected the Louzeyu Formation and redefined it based on facies analysis and

Fig. 2.15 Photo taken in the yard of the Yushe County Guest House in October 1980. *Front row* H. Tobien (*center*), Zhou Ming-Zhen (to his *right*, *third* from the *left*), Zhan-Xiang Qiu (*second* from *left*); K. Heissig (*third* from *right*), *Back row from left to right* Zhi-Hui Guo (TNHM), Wei-Long Huang (TNHM), De-Fa Yan (IVPP), Zhe-Ying Chen (Shanxi Institute of Archeology), Hang Jia (IVPP), Guan-Fang Chen (IVPP), Yu-Qing Li (TNHM)

mineralogical differences between the Zhangcun and Louzeyu Formations. Based on his paleomagnetic data, Shi Ning roughly compared the age of the Louzeyu Formation with that of Qiu and colleagues' Haiyan Formation, both early Pleistocene deposits (reversely magnetized, early Matuyama Chron). Following upon the work of Shi (1994), a Nanjing Institute team reanalyzed the palynological record of the Zhangcun Formation and found significant environmental change just following the Gauss-Matuyama boundary (Liu et al. 2002).

Interest in the Yushe Basin by the Global Community. By the mid-1980s the Yushe Basin became well known to vertebrate paleontologists for its wealth of fossils from numerous horizons, which would lend to creating a real local biostratigraphy. Among the foreign paleontologists who visited Yushe, Prof. H. Tobien and Dr. K. Heissig came from Germany in October 1980 (Fig. 2.15). In 1982, Dr. R. H. Tedford (May), Dr. L. Ginsburg of Muséum National d'Histoire Naturelle, Paris, (September), and Dr. A. Forstén from the University of Helsinki, Finland (October) all saw basin deposits. Later (1987) Prof. J. Desmond Clark of the University of California, Los Angeles (May), and Drs. S. Mahmood Raza and I. U. Cheema representing the Geological Survey of Pakistan and the Pakistan Museum of Natural History (September) visited the area.

2.3 Field-Based Research of the Sino-American Yushe Project (SAYP, 1987–1998)

The idea to initiate a Sino-American joint project to combine a thorough restudy of the late Cenozoic fossil mammals held in China (Licent Collection) and the USA (Frick Collection), coupled with field work and techniques used in

present-day bio- and chrono-stratigraphy, was first put forward by Richard H. Tedford as early as 1981 (letter of January 23, 1981, to Prof. Chow Minchen (Ming-Zhen Zhou), then director of IVPP). While talking with Dr. Chuan-Kui Li, a top specialist on Chinese Neogene micromammals who was visiting the AMNH in January 1981, Tedford mentioned the fossils from Shanxi localities in the Frick Collection and expressed his hope to develop a joint project with Chinese colleagues. Tedford roughly delineated the possible future field work, emphasizing magnetostratigraphy and the related mandatory mapping and section measuring in the most important basins in Shanxi Province. While attending the "*Hipparion* Workshop" held at the AMNH from 2 through 10 of November 1981 (see Eisenmann et al. 1988), Tedford and Zhan-Xiang Qiu had many good conversations about the details to develop a joint project. In May 1982, Tedford was invited to China so that he could get acquainted with the IVPP Neogene Group and explore the details of joint work in the field and laboratory. Accompanied by Qiu, Tedford spent a couple of days visiting southeastern Shanxi (Fig. 2.16). Unfortunately, the scheduled visit to the Shouyang Basin, the origin of an important part of the Shanxi fossils in the Frick Collection, failed because of unexpected difficulties in getting special permission for foreigners to go there at that time. However, Tedford enjoyed the field experiences in Yushe and Wuxiang counties, and his imagination for the potential for biostratigraphic studies was captivated.

Qiu was granted a Humboldt scholarship for one and a half years' stay at Gutenberg University in Mainz (June 1982, to the end of 1983), and Tedford had an Australian project during 1983, Tedford and Qiu agreed to postpone organization of the project until 1984.

Qiu finished his Humboldt scholarship in June 1984. En route back to Beijing, Qiu was invited to visit the AMNH in early July. During this short stay in New York, Tedford and Qiu spent much time on details of the preparation of the joint project proposal. The latter half of 1984 was a busy time for Tedford to draw up the first draft of the proposal, which was ready in August of that year. Gradually we realized that the joint project should be confined to the Yushe-Wuxiang Basin. Meanwhile the final list of the participants of the project had been fixed. The formal grant proposal was completed in August 1985, and was received on October 10 by the NSF (USA). Unfortunately, the project was rejected by NSF reviewers who thought that the project had "too many goals," unrelated to the "important questions of ape and human origins," and demanded too large a budget. However, we were encouraged to submit the proposal again, with a smaller budget and narrower project. At last, on July 7, 1987, the SAYP was launched by a formal notice of the acceptance of the grant proposal EAR 8709221 under the title "Neogene Rocks and Faunas, Yushe Basin, Shanxi, PRC" (July 1987, through June 1989) was received. The project was followed by another grant under the title "Evolution and Faunal Turnover in the Neogene of Northeastern Asia" (July 1991, through June 1993).

2.3.1 Field Campaigns

Under the auspices of "Neogene Rocks and Faunas, Yushe Basin, Shanxi, PRC" intensive field work began, mainly in the Yuncu subbasin in the first 2 years. Subsequent work by SAYP documented the Tancun subbasin, added observations throughout Yushe Basin, and complemented these studies with reconnaissance in Wuxiang Basin.

1987 (September 4–October 3)

Participants: R. H. Tedford, L. J. Flynn, N. D. Opdyke, W. R. Downs, Zhan-Xiang Qiu, Wen-Yu Wu, De-Fa Yan, Jie Ye, Xiao-Feng Chen (postgraduate student), Yi-Zheng Li (postgraduate student), Gen-Zhu Zhu (assistant curator of the IVPP Museum), Tai-Ming Wang (Yushe County Museum; Fig. 2.17).

Geology: Study was concentrated on two basal formations, the Mahui and the lower part of the Gaozhuang (Fig. 2.18). About 20 km^2 of Yuncu subbasin were mapped in reconnaissance fashion; five long sections plus several shorter ones were measured: CAN (Nanmahui), CAB (Beimahui), CAL (Lintou), CAH (Shagou), CAJ (Jingjiagou) and CAG (Gaozhuang).

Paleontology: Prospected Lintou, Gaozhuang, and Nanzhuanggou areas of Yuncu subbasin, with 77 localities catalogued (YS1 through YS77). Large mammalian fossils: With the help of the local people most of Licent's and IVPP 1955–1956 localities in the Yuncu subbasin and their stratigraphic position were settled. Micromammals: Surface finds of skull and jaw material of small mammals at different levels of the Mahui and Gaozhuang Formations indicated that the possibility in finding richer micromammal fossils in the future was very high. Ten micromammal sites were sampled by screen washing and the concentrate was partly sorted in the field.

Magnetostratigraphy: Paleomagnetic sampling from fine-grained sediments of the Mahui and Gaozhuang Formations were systematically conducted by Neil Opdyke and his assistants at approximately 3.5–5 m intervals.

1988 (September 4–October 9)

Participants: The Americans were the same as in 1987; from the Chinese side: Zhan-Xiang Qiu, Zhu-Ding Qiu, De-Fa Yan, Wen-Yu Wu, Guan-Fang Chen, Yu-Qing Li (TNHM), plus from Mainz, Germany, for 1 week, Norbert Schmidt-Kittler (Figs. 2.19, 2.20).

Fig. 2.16 R. H. Tedford (*right*) and Zhan-Xiang Qiu (*front left*) observing a *Stegodon* skull at Yushe County Museum in May 1982

Geology: The upper part of the Gaozhuang Formation, the Mazegou and Haiyan Formations were studied. The entire stratigraphic 800 m column was assembled using altogether 25 sections. The mapping of the entire Yuncu subbasin (about 300 km^2) was completed at 1:50,000 scale.

Paleontology: Prospected areas included Taoyang, Baihai, Nanzhuanggou, Zhaozhuang, Mazegou, Malan, Liujiagou, Songyangou, and other parts of Yuncu subbasin. Most of Licent's richly fossiliferous sites of Pliocene and Pleistocene ages were located. Screen washing about 30 sites produced concentrate for sorting, which yielded new small mammal samples. Altogether about 60 new vertebrate localities were catalogued (YS78 through YS137).

Magnetostratigraphy: Systematic sampling was conducted in Mazegou and Haiyan Formations.

1991 (September 13–30)

Participants: R. H. Tedford, L. J. Flynn, W. Downs, Jie Ye, Zhu-Ding Qiu, Wei Dong, Yu-Qing Li, Guan-Fang Chen, Xiaoming Wang and Tai-Ming Wang (Fig. 2.21).

Field work: Systematic prospecting and fossil collection in the Tancun subbasin, with relocation of the type locality

Fig. 2.17 Part of the team welcomed by local people in front of the Yushe County Guest House in September 1987. *Front row* Xiao-Feng Chen (IVPP, *third left*), Wen-Liang Jia (Yushe County Museum, *fifth left*), Zhan-Xiang Qiu (IVPP, *fourth right*), W. R. Downs (*third right*), Wen-Yu Wu (IVPP, *second right*). *Second row* De-Fa Yan (IVPP, *first left*), Gen-Zhu Zhu (IVPP, *third left*), Jie Ye (IVPP, *fourth left*). *Third row*, *left* Tai-Ming Wang (Yushe County Museum)

Fig. 2.18 Trio of team geologists (*left* to *right* Zhan-Xiang Qiu, R. H. Tedford, and Jie Ye) taken in front of the Yushe County Guest House in September 1987

Fig. 2.19 Inside the Yushe County Museum. Wen-Liang Jia, Zhan-Xiang Qiu and R. H. Tedford examine specimens being prepared for display (*photo* L. Flynn, September 1987)

for *Neocricetodon grangeri*, and screening at several localities below and above the Mahui Formation-Gaozhuang Formation contact. Localities YS138 through YS171 were found and catalogued.

Magnetostratigraphy: Four sections were measured and sampled in the Tancun subbasin, CAW+CAWL (Sijiawa) and CAU+CAUL (Jiayucun). In Yuncu subbasin, magnetic samples were added to constrain the Early Pleistocene CAQ section at Qingyangping.

1994 (October 5–11)

Participants: R. H. Tedford, Zhan-Xiang Qiu, Xiaoming Wang, Jie Ye, Wen-Yu Wu, and Tai-Ming Wang.

Field work: Cursory survey of the Yushe Group in the Zhangcun subbasin was carried out. The Renjianao, Wangning and Zhangcungou areas were prospected. Prospecting and tracing the boundary between the Triassic rocks and the Yushe Group in Jiayucun, Dengyucun, Taiqu areas of the Tancun subbasin, and the Liutan area of the northern Tancun subbasin were also conducted.

1997 (August 9–15)

Participants: Zhan-Xiang Qiu, Wei-Long Huang (TNHM) and Tai-Ming Wang.

Field work: The main purpose of the year's trip was to visit Licent's famous Loc. 2, Zhangcungou (Wuxiang County) of the Zhangcun subbasin, which Licent used as the main base for his geologic survey and excavation, and as center of his fossil purchasing activities, for more than 3 weeks, from July 3 to 26 in 1934. With the help of the local people, we located the exact place where Licent made his excavation and found the section he used to illustrate his subdivision of the deposits of this area. Later, Haobei, Dongfangshan and Danangou of the Tancun subbasin, Dazhai and Nanhedi of the Ouniwa subbasin, and Yimen of the Wuxiang Basin were also visited.

While surveying Zhangcungou village, we made inquiries about Licent's collecting activities in this area. Three old villagers (Fig. 2.22) provided us with the following information. There were two foreign fathers (a yellowish and a blackish), apparently Licent and Trassaert, accompanied by two bodyguards (Wang and Tian) with seven mules. They hired a "dragon bone" dealer, Hao Lin-Zhong (then middle-aged) from Shibi village of the Wuxiang County, as their agent in charge of collecting and purchasing fossils. The foreigners made some excavations mainly in a gully near Xiongshujia village (no longer extant).

The cliff in the gully near Xiongshugou is apparently the section presented by Licent and Trassaert in 1935 and later by Huang and Guo in 1991 (vide supra, Fig. 2.12, field image in Fig. 2.23). We revisited this gully and found a *Paramachairodus* mandible in the upper part of that section, indicating an age comparable with that of the Mazegou Formation in the Yuncu subbasin.

1998 (October 8–13)

Participants: R. H. Tedford, Zhan-Xiang Qiu, Hong Zhao (assistant curator of the IVPP Museum) and Tai-Ming Wang.

Field work: The main purpose of the field work was to investigate the deposits of the Ouniwa subbasin, especially the thick basal conglomerate layers near Nanhedi.

Supplementary surveys and reconnaissance were conducted by different groups for all subbasins in the years 1991,

Fig. 2.20 Attending the dedication ceremony of the Yushe County Museum in September 1988. Sitting behind the desk, from *right* to *left* W. Downs, L. Flynn, N. Schmidt-Kittler, N. Opdyke, R. Tedford, Z.-X. Qiu, Y. Zhang (Vice-director of Bureau of museums and archeology of Shanxi Province), and other officials

1994 and 1997–1998, with the aim to get a better understanding of the geological history of the Yushe Basin as a whole.

2.3.2 Publications

Concomitantly with the field work, short papers concerning field and laboratory results appeared during the interval 1989–1996. A dozen titles are listed here in chronological order:

1. Tedford, R.H., Flynn, L.J., Qiu, Z.-X., 1989. Neogene faunal succession, Yushe Basin, Shanxi Province, PRC. Journal of Vertebrate Paleontology 9 (supplement to No. 3), 41A.
2. Flynn, L.J., Tedford, R.H., Qiu, Z.-X., 1990. The Yushe chronofauna: faunal stability in the Pliocene of North China. Journal of Vertebrate Paleontology 10 (supplement to No. 3), 23A.
3. Qiu, Z.-X., Tedford, R.H., 1990. A Pliocene species of *Vulpes* from Yushe, Shanxi. Vertebrata PalAsiatica 28 (4), 245–258.
4. Tedford, R.H., Flynn, L.J., Qiu, Z.-X., Opdyke, N.D., Downs, W.R., 1991. Yushe Basin, China: paleomagnetically calibrated mammalian biostratigraphic standard for the Late Neogene of eastern Asia. Journal of Vertebrate Paleontology 11 (4), 519–526.
5. Tedford, R.H., Qiu, Z.-X. (1991). Pliocene *Nyctereutes* (Carnivora: Canidae) from Yushe, Shanxi, with comments on Chinese fossil raccoon-dogs. Vertebrata PalAsiatica 29 (3), 176–189.
6. Flynn, L.J., Tedford, R.H., Qiu, Z.-X., 1991. Enrichment and stability in the Pliocene mammalian fauna of North China. Paleobiology, 17 (3): 246–265.

Fig. 2.21 Part of the 1991 Sino-American Yushe team in front of the Yushe Guest-House. *Seated from right* Tai-Ming Wang, Will Downs, Dick Tedford, Larry Flynn; *standing from right* Guan-Fang Chen, Yi-Zheng Li, Jie Ye, Zhu-Ding Qiu, Wei Dong

7. Wu W.-Y., Flynn, L.J., 1992. New murid rodents from the Late Cenozoic of Yushe Basin, Shanxi. Vertebrata PalAsiatica 30(1), 17–38, 2 pl.
8. Flynn, L.J., 1993. A new bamboo rat from the late Miocene of Yushe Basin. Vertebrata PalAsiatica 31, 95–101.
9. Flynn, L.J., Wu W.-Y., 1994. Two new shrews from the Pliocene of Yushe Basin, Shanxi Province, China. Vertebrata PalAsiatica 32 (2), 73–86.
10. Flynn, L.J., Qiu, Z.-X., Opdyke, N.D., Tedford, R.H., 1995. Ages of key fossil assemblages in the Late Neogene terrestrial record of northern China. Geochronology Time Scales and Global Stratigraphic Correlations. SEPM (Society for Sedimentary Geology) Special Publication 54, 365–373.
11. Tedford, R.H., 1995. Neogene mammalian biostratigraphy in China: past, present, and future. Vertebrata PalAsiatica 33 (4), 272–289.
12. Tedford, R.H., Qiu, Z.-X., 1996. A new canid genus from the Pliocene of Yushe, Shanxi Province. Vertebrata PalAsiatica 34 (1), 27–40.

2.4 Problems Related to the Historical Fossil Collections

The Wade-Giles romanization of the Chinese geographic names used in the past produced a considerable degree of misunderstanding that any reader who skims through the present series will acutely feel. Fortunately, the Pinyin Romanization System was officially decreed by the Chinese government in 1979. Since then the new system has widely been accepted in China and abroad. In order to avoid further misunderstanding, the Pinyin Romanization System is applied throughout the present volume. The old names

Fig. 2.22 Some of the Zhangcungou villagers consulted by Qiu in August 1997. *Front, from left to right* De-Jun Hao (1911?–), (Z.-X. Qiu), Ming-Wen Hao (1926–), Ming-Zhong Hao (1932?–)

using the Wade-Giles system are avoided as far as possible, and when necessary to use, they are written in italics.

The fossil collections studied in the course of our research comprise altogether seven parts, the first four of which were obtained during the 1920s–1930s. These are: (1) the unstudied fossils of the Lagrelius Collection obtained by Andersson's assistants during the 1920s from the Yushe-Wuxiang area, which are now kept in IVPP; (2) the major part of the Licent Collection held in Tianjin Natural History Museum (catalogued as THP and TNP); (3) a small portion of the Licent Collection now housed in IVPP (catalogued as RV or V); (4) the Childs Frick Collection kept in the American Museum of Natural History (catalogued as F:AM); (5) the specimens collected by the Laboratory of Vertebrate Paleontology in the 1950s, now housed in the IVPP; (6) a small number of specimens in the Yushe County Museum; and (7) the few specimens obtained by the Neogene Division of IVPP since 1979–1980 (catalogued as QY), plus the larger collection built during the execution of the Sino-American Yushe Project from 1987 to 1998 (catalogued as YS), now housed in the IVPP.

The Licent Collection comprises the bulk of the specimens studied in the present series. The total number of these specimens is about 2,300. At first, these fossils were not regularly numbered or catalogued in situ. On some of these fossils, serial numbers and dates were written in ink. For instance, "5, 4/VII, 1934" means specimen No. 5, collected on July 4, 1934. These specimens with serial numbers and dates serve as a good check on the localities, since they were entered in Licent's field notes. All the fossils collected by Licent's parties in 1934–1935 were systematically catalogued later in the *Musée Hoang-ho Pai-ho de Tientsin* in 1935 or 1936. The numbering system started from 10,000 without prefix. They were apparently casually numbered, without systematic or locality consideration. So, neighboring numbers can be given to fossils belonging to different taxa and different localities. The person in charge of the cataloguing (probably Father Haser, who was said to know

Fig. 2.23 Landscape of Licent's Loc. 2 (*Changts'unkou*), northwest view, photographed by Qiu in August 1997. X: site of Licent's 1934 excavation. One of the two gullies southeast of the excavation site would be where Licent and Trassaert measured their section in 1934

both French and Chinese) apparently did not participate in the field work and did not know these localities in the field, because there are various incorrect assignments and transliterations of the Chinese characters for the localities. The following are the most obvious mistakes:

(1) Loc. 15, *Ichuangts'un* is an incorrect transliteration from French to Chinese of the Loc. 4, *Chaochuangts'un* (Zhaozhuang village), since the simplified and cursive-hand Chinese character *Chao* (Zhao in Pinyin Romanization) looks very much like a Chinese character Yi.
(2) Loc. 14, *Hsingyangts'un* and Loc. 18, *Laohsiangts'un* are both incorrect transliterations of the Loc. 44, *Taoyangts'un* (Taoyang village).
(3) Loc. 16, *Kaochaungts'un* is the same as Loc. 15, *Kaochuang* (Gaozhuang).
(4) Loc. 49, *Chaments'un* is Loc. 63, *Yiments'un* (Yimen village, see Appendix IV).
(5) Loc. 57, *Hsuhochangts'un* may be the wrong transliterations of the *Ni Ho Chang* (Nihezhang).
(6) Loc. 60, *Litats'un* is Loc. 20, *Liyuts'un* (Liyu village).
(7) Loc. 61, *Soanhots'un* may be Loc. 25, *Nihots'un* (Zhongnihe village).

While describing the first skull of *Plesiohipparion houfenense* of the Licent Collection (Qiu et al. 1980) Qiu and Wei-Long Huang, then in charge of the curation of the vertebrate fossils in the Tianjin Natural History Museum, felt the inconvenience of using the numbering system without an institutional prefix. They proposed to add the prefix THP (T for Tianjin, H for *Hoang-ho Pai-ho*, P for Paleontology) to the given numbers pertaining to the Licent Collection, and TNP (N for Natural History) for the specimens other than the Licent Collection. A small number of specimens of the Licent Collection lost their original numbers for unknown reasons. For them new TNP numbers were given. In many cases the provenances of these specimens are unknown.

The catalogue numbers for the studied specimens now housed in the IVPP contain serial numbers prefixed with V. This system has been in use since 1937, when the Cenozoic Research Laboratory moved to Sichuan Province after the Anti-Japanese War broke out. Prior to 1937, no unified catalogue system existed. For instance, the specimens briefly described by C. C. Young in 1935 were not systematically catalogued. Sometimes, locality numbers can be

found written on the specimens. A few Yushe specimens found from 1937 to 1949 were catalogued with prefix V in the old collection at the IVPP (for example, V 517–526, see Young and Liu 1948). During the wartime, a small part of the Licent Collection was transferred from Tianjin to Beijing, temporarily housed in the Institut de Géo-biologie. After founding of the People's Republic of China in 1949, these specimens became the property of the Laboratory of Vertebrate Paleontology, the predecessor of the Institute of Vertebrate Paleontology and Paleoanthropology, to which these transferred specimens now belong. Working for both the Cenozoic Research Laboratory and the *Musée Hoang-ho Pai-ho de Tientsin*, Teilhard de Chardin used the number system without prefix regardless of where the specimens were housed. The studied specimens now housed in the IVPP are given new numbers prefixed by RV (R for *Re-catalogued*) and the first two numbers denote the year, with their original THP numbers in brackets. For instance, RV 4503 (THP 10552) means the specimen was studied and published in 1945. It was from the Licent Collection, but now belongs to the IVPP. Unstudied specimens of the Licent Collection now kept in the IVPP are given a serial number with prefix V when they are studied and published, with their original THP numbers in brackets.

The specimens procured in 1955–1956 by the Laboratory of Vertebrate Paleontology, Academia Sinica, bear only field locality numbers (for instance, 5544, 5679). In 1979, prior to the Sino-American Yushe Project, while prospecting the Yushe area, Qiu and Huang collected and purchased a number of specimens. They bear the locality numbers prefixed with QY (see Appendix VII). All the specimens procured over the course of the SAYP since 1987 bear unique locality numbers with the prefix of YS. When studied, these specimens are given catalog numbers prefixed by V.

Since many of the specimens, often the best-preserved skulls and jaws, were purchased from local villagers, their provenance is either lacking, or in cases with locality information, serious verification is needed. The general strategies we adopted are as follows. The first is to use as far as possible the fossils proven to be found in situ. Sometimes, these specimens may be unimportant for systematic study, but sufficient to prove the existence of certain forms in time and space. The second is to use as far as possible the degree of congruence between the mode of preservation, color, hardness, completeness, etc. of the fossils and the lithology of the designated locality. The third is to use preferably localities remote from the dragon-bone purchase centers, often a large village or town (zhen pertains to township in Chinese, while "zhuang" and "cun" correspond to village). Places such as Zhangwagou ("gou" is gully in Chinese) or Shennan'ao ("ao" is depression in Chinese), are more likely real fossil localities.

Our goals were to reconstruct locality information as accurately as possible to tie all collections to the stratigraphy, be they the fruits of historical explorations in the area, or new findings in the field. This maximizes the value of Yushe Basin fossils for biostratigraphy, and hopefully for recognition of characteristic fossil assemblages. Ultimately our goal is to apply all observations to test the durations of paleofaunas, recognize faunal turnover, and refine Late Neogene biochronology.

References

Andersson, J. G. (1919). Dragon-hunting in China. *Far Eastern Review, 1919*(November), 1–11.

Andersson, J. G. (1922). Current palaeontological research in China. *Bulletin of the American Museum of Natural History, 46*(3), 727–737.

Andersson, J. G. (1923). Essays on the Cenozoic of northern China. *Memoir of Geological Survey of China, A3*, 1–152.

Andersson, J. G. (1934). *Children of the Yellow Earth*. London: Kegan Paul, Trench, Trubner & Co.

Andrews, R. C. (1932). *Natural history of Central Asia, vol. 1. The new conquest of Central Asia. A narrative of the explorations of the Central Asiatic Expeditions in Mongolia and China, 1921–1930.* New York: American Museum of Natural History.

Bohlin, A. B. (1926). Die Familie Giraffidae mit besonderer Berücksichtigung der fossiler Formen aus China. *Palaeontologia Sinica C, 4*(1), 1–208, 12 plates.

Bohlin, A. B. (1935). Cavicornier der *Hipparion*-Fauna Nord-Chinas. *Palaeontologia Sinica C, 9*(4), 1–66.

Cao, J.-X. (1980). A study of Cenozoic strata and depositional environment of the Taigu-Yushe-Wuxiang area, Shanxi. *Quaternaria Sinica, 4*(1), 77–82 (in Chinese).

Cao, J.-X., & Cui, H.-T. (1989). Research of Pliocene flora and paleoenvironment of Yushe Basin on Shanxi plateau, China. *Scientia Geologica Sinica, 4*, 367–375.

Cao, J.-X., & Wu, R.-J. (1985). The characteristics of sediments and landform evolution of the late Cenozoic down-warped basin in Yushe and Wuxiang district, Shansi. *Quaternaria Sinica, 6*(2), 48–54 (in Chinese).

Cui, Z.-K., & Wu, T.-S. (2002). Geologic map of Shanxi. In L.-F. Ma (Ed.), *Regional geologic maps of China* (pp. 133–140). Beijing: Geological Publishing House.

Eisenmann, V., Alberdi, M. T., De Giuli, C., & Staesche, U. (1988). Volume I: Methodology. In M. O. Woodburne & P. Y. Sondaar (Eds.), *Studying fossil horses* (pp. 1–71). Leiden: E. J. Brill.

Geological Bureau of Shanxi Province. (1976). *Geologic Fenyang-Pingyao Quadrangle*. Beijing: Geological Publishing House.

Hopwood, A. T. (1935). Fossil Proboscidea from China. *Palaeontologia Sinica C, 9*(3), 1–108.

Hu, C.-K. (1962). A new species of *Metacervulus* of Yushe, Shansi, with notes on Pliocene muntjaks of China. *Vertebrata PalAsiatica, 6*(3), 251–261 (in Chinese with English summary).

Huang, B.-Y., & Guo, S.-Y. (1991). Stratigraphy. In B.-Y. Huang & S.-Y. Guo (Eds.), *Late Cenozoic stratigraphy and paleontology from Central-Southern region of Shanxi* (pp. 1–70). Beijing: Science Press.

Jacobs, L. L., & Li, C.-K. (1982). A new genus (*Chardinomys*) of murid rodent (Mammalia, Rodentia) from the Neogene of China, and comments on its biogeography. *Géobios, 15*(2), 255–259.

Jia, L.-P., & Zhen, S.-N. (1978). Dragon and dragon bone. In Editorial board of the Journal "Fossils" (Eds.), *Fossil World* (pp. 132–137). Beijing: Science Press (in Chinese).

Li, S.-Z. (1596). *Compendium of Materia Medica* (1982 edition). Beijing: People's Hygiene Publishing House.

Licent, E., & Trassaert, M. (1935). The Pliocene lacustrine series in central Shansi. *Bulletin of the Geological Society of China, 14*(2), 211–219.

Liu, G., Leopold, E. B., Liu, Y., Wang, W., Yu, Z., & Tong, G. (2002). Palynological record of Pliocene climate events in North China. *Review of Paleobotany and Palynology, 119*, 335–340.

Liu H.-T. (=Liu X.-T.), & Su T.-T. (=Su D.-Z.). (1962). Pliocene fishes from Yüshe Basin, Shansi. *Vertebrata PalAsiatica 6*(1), 1–26 (in Chinese with English summary).

Liu, X., Guo, P., & Liu, X. (2009). *Shan Hai Jing*. Shenyang: Wanjuan Publishing Company (in Chinese).

Mateer, N. J., & Lucas, S. G. (1985). Swedish vertebrate palaeontology in China: A history of the Lagrelius Collection. *Bulletin of the Geological Institutions of the University of Uppsala New Series, 11*, 1–24.

Needham, J. (1959). *Mathematics and the sciences of the heavens and the earth* (*Science and Civilisation in China 3*). Cambridge: Cambridge University Press.

Pearson, H. S. (1928). Chinese fossil Suidae. *Palaeontologia Sinica, C5*(5), 1–75.

Pei, W.-Z., Zhou, M.-Z., & Zheng, J.-J. (1963). *Cenozoic Erathem of China*. Beijing: Science Press (in Chinese).

Qiu, Z.-X. (1987). Die Hyaeniden aus dem Ruscinium und Villafranchium Chinas. *Münchener Geowissenschaftliche Abhandlungen, A9*, 1–110.

Qiu, Z.-X., Huang, W.-L., & Guo, Z.-H. (1980). Notes on the first discovery of the skull of *Hipparion houfenense*. *Vertebrata PalAsiatica, 18*(2), 131–137 (in Chinese with English summary).

Qiu, Z.-X., Huang, W.-L., & Guo, Z.-H. (1987). The Chinese Hipparionine Fossils. *Palaeontologia Sinica, New Series, C25*, 1–243 (in Chinese with English summary).

Ringström, T. (1927). Über Quartäre und Jungtertiäre Rhinocerotiden aus China und der Mongolei. *Palaeontologia Sinica C, 4*(3), 1–23.

Schmitz-Moormann, K. (Ed.). (1971). *Pierre Teilhard de Chardin, L'Oeuvre Scientifique* (10 Vols., 4634 p). Freiburg: Walter-Verlag, Olten und Freiburg im Breisgau.

Sefve, I. (1927). Die Hipparionen Nord-Chinas. *Palaeontologia Sinica C, 4*(2), 1–91.

Shi, N. (1994). The Late Cenozoic stratigraphy, chronology, palynology and environmental development in the Yushe Basin, North China. *Striae, 36*, 1–90.

Teilhard de Chardin, P. (1942). New rodents of the Pliocene and Lower Pleistocene of North China. *Publications de l'Institut de Géobiologie, Pékin, 9*, 1–101.

Teilhard de Chardin, P., & Leroy, P. (1945a). Les Félidés de Chine. *Publications de l'Institut de Géobiologie, Pékin, 11*, 1–58.

Teilhard de Chardin, P., & Leroy, P. (1945b). Les Mustélidés de Chine. *Publications de l'Institut de Géobiologie, Pékin, 12*, 1–56.

Teilhard de Chardin, P., & Trassaert, M. (1937a). The Proboscideans of South-Eastern Shansi. *Palaeontologia Sinica C, 13*(1), 1–85.

Teilhard de Chardin, P., & Trassaert, M. (1937b). Pliocene Camelidae, Giraffidae and Cervidae of South-Eastern Shansi. *Palaeontologia Sinica New Series C, 1*, 1–69.

Teilhard de Chardin, P., & Trassaert, M. (1938). Cavicornia of South-Eastern Shansi. *Palaeontologia Sinica New Series C, 6*, 1–107.

Teilhard de Chardin, P., & Young, C. C. (1933). The late Cenozoic Formations of S. E. Shansi. *Bulletin of Geological Society of China, 12*, 207–248.

Tobien, H., Chen, G.-F., & Li, Y.-Q. (1986). Mastodonts (Proboscidea, Mammalia) from the Late Neogene and Early Pleistocene of the People's Republic of China. Part 1. *Mainzer Geowissenschaftliche Mitteilungen, 15*, 119–181.

Tobien, H., Chen, G.-F., & Li, Y. Q. (1988). Mastodonts (Proboscidea, Mammalia) from the Late Neogene and Early Pleistocene of the People's Republic of China. Part 2. *Mainzer Geowissenschaftliche Mitteilungen, 17*, 95–220.

Yang, Z.-J. (2009). *Section of section* (C.C. Young's field notes of 1932–1936, in Chinese). Beijing: Science Press.

Young, C. C. (=Yang Z.-J.) (1935). Miscellaneous mammalian fossils from Shansi and Honan. *Palaeontologia Sinica C, 9*(2), 1–42.

Young, C. C., & Liu, P. T. (=Liu D.-S.) (1948). Notes on a mammalian collection probably from the Yushe series (Pliocene), Yushe, Shansi, China. *Contributions from the Geological Institute, National University of Peiping 8*, 273–291.

Zdansky, O. (1925). Fossile Hirsche Chinas. *Palaeontologia Sinica C, 2*(3), 1–94.

Zdansky, O. (1927). Weitere Bemerkungen über fossile Carnivoren aus China. *Palaeontologia Sinica C, 4*(4), 1–30.