Problems concerning the Lower Quaternary boundary in China

by

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The problem of the lower Quaternary boundary in the terrestrial deposits of China is indeed truly complex, as it not only concerns many manifestations and principles related to the erection of geological subdivisions, but moreover involves research disciplines which are extremely broad in scope. Discussion of the lower Quaternary boundary problem has become a pivotal topic among current Chinese Quaternary geologists and their colleagues from related disciplines. Workers, frequently from different disciplines, propose indicators and principles regarding the lower Quaternary boundary, thereby further developing and advancing this important subject.

However, regardless of from which perspective one begins, the diagnosis of this important geochronological subdivision, or temporal boundary in China, must be fundamentally based upon the empirical geologic conditions in order to advance research and develop conclusions. Obviously, the conclusions from associated international research and their related references must not be excluded, such that both the aspects of practical application as well as conjecture will establish principles of subdivision and construct foundations which will later be subjected to repeated scrutiny. Presented in this text are geochronological sections above and below a clearly demarcated Quaternary boundary that contain comprehensive diagnostic geologic characters. Through a theoretical perspective, the diagnostic characters that accurately reflect different geologic periods are interpreted as wide-ranging temporal chrons. Through a practical perspective, a universal Quaternary boundary line will itself accurately reflect unique characters with distinct indicators and easily recognizable diagnostic characters. This text recognizes that an accurate recognition of a Quaternary boundary line is only possible through this process of scrutiny.

In recent years, because the disciplines of stratigraphy have become progressively influenced by Quaternary glacial geology, which itself has become extensively integrated into other Quaternary sciences, particularly through the application of isotopic and paleomagnetic dating techniques, Chinese Quaternary research has developed into a synthesis of disciplines initiating the establishment of a multidisciplinary arena related to climatic stratigraphy. The cyclicity of climatic fluctuation between Quaternary glacial and interglacial stages has provided a foundation to subdivide and correlate Quaternary sediments, motivating numerous geologists, geographers, paleoclimatologists, paleontologists and paleoanthropologists.

Within the process of Quaternary climatic stratigraphy research, the basic theoretical problem encountered is the recognition of the Tertiary-Quaternary boundary. In other words, this geochronological subdivision, or geologic boundary line, represents the foundation for initiation into Quaternary research. However, numerous investigators apply different criteria in recognizing this boundary, and as such there are three distinct interpretations: (1) the Quaternary short-cycle chronological scale, with the lower boundary, sensu stricto, as the inception of the Quaternary in the lower section of the Sanmen Fm. (IVPP, 1959; Pei et al., 1963; Pei, 1962; Liu et al. 1959), at approximately over one million years in age and lying prior to the Jaramillo Subchron; (II) the Quaternary medium-cycle chronological scale, generally correlated to the Middle to Late Villafranchian of Europe, with the lower boundary lying paleomagnetically at either the Olduvai Subchron or the inception of the Matuyama Chron, correlating to radiometric ages of 1.8 Ma (Liu et al., 1966) or 2.4 Ma Liu et al., 1966; Li, 1979); (III) the Quaternary long-cycle chronological scale approaching 3.5 Ma to 4.0 Ma where the inception of global temperature degeneration, initiation of northern hemispheric glaciation and glaciation in the Himalayas, and the first appearance of the family Hominidae in China.(Jia et al., 1959; Li et al., 1977; Pu et al., 1977; Sun et al, 1979; Long et al., 1979; Qian et al., 1979; Chen, 1980) equivalent to the middle late Gilbert Chron. It is currently recognized that interpretation I is generally equivalent to the inception of loess deposition in China, although there are also a number of workers believe this period should represent the Middle-Late Pleistocene boundary. Interpretation II still retains a contingent of researchers supporting it, and interpretation III is becoming increasingly supported by new evidence from multidisciplinary sources.
This text endorses the fundamental principals and indicators that diagnose the long Quaternary chronological scale (interpretation III), which embraces at least two concepts. Firstly, the climate during the major glacial stages in the extensive middle and lower latitudes of China left characteristic indications of warming and cooling trends, and as such, these may be applied as the principle characteristics delineating Quaternary from the Tertiary sediments. The second concept is based on the timing of the earliest appearance of hominids in China, which should also be considered as the base of the Quaternary. The combination of these two concepts may be assumed to be penetrating preliminary research, from which it is extremely possible that revelations regarding the origin of man may be advanced, in addition to revealing several intrinsic characters relating to hominid genesis during the major interglacial periods.

Within recent years, new research and data obtained from disciplines including Quaternary glacial stratigraphy, paleomagnetic stratigraphy, palynology, vertebrate paleontology, paleoanthropology with its associated cultural relics, and structural geology, tend to support the long Quaternary scale, thereby allowing the possibility to shift the lower Quaternary boundary prior to 3.5 Ma and even as far back as 4.0 Ma.

Early Quaternary glacial remnants are abundantly documented within the geographic boundaries of China. Since the 1970's paleomagnetic stratigraphy has constrained several important ages, as exemplified by the Longchuan moraine in the Yuanmou Basin of Yunnan Province, which was deposited to the Mammoth Subchron as early as 3.1 Ma (Li et al., 1976; Cheng et al., 1977); the Hongya moraine in the Yuxian Basin of Yangyuan, Hebei Province, deposited subsequent to the Kaena Subchron, prior to approximately 2.6 Ma (Cheng et al., 1978); the first moraine in the Sanmen Gorge of Henan Province deposited during the Gauss Chron, prior to 3.2 Ma; and the Renjianao moraine in the Yushe Basin of southeast Shanxi Province, deposited prior to the Cochiti Subchron during the late Gilbert Chron, probably circa 4.0 Ma (Figure 1). The age determinations and paleomagnetic correlations confirm that these Early Quaternary moraines in China appeared during periods of major glaciation between 4.0 to 2.6 Ma. Based upon glacial climatology and stratigraphy, the obvious basal Quaternary boundary should therefore naturally be recognized at the base of the oldest moraine. In this manner, the boundary would expand the range of the Quaternary, chronologically and geographically, to encompass the aforementioned lithologic sections in addition to a portion of the *Hipparion* Red Clays that were originally assigned to the Pliocene; the first moraine in the Sanmen Gorge, originally assigned as Pliocene; and the Renjianao moraine that lies in the middle to lower Yushe Fm. and was initially assigned to the Pliocene" (Teilhard and Young, 1933). There is no concealing the fact that the concept of the long Quaternary scale is patently unacceptable to several current biostratigraphers. However paleomagnetic stratigraphy and glacial climatology allow age correlations of the Yushe Fm., the Sanmen Fm. (sensu lato), and the *Hipparion* Red Clays to be correlated to paleomagnetically dated Quaternary units including the Yuanmou Fm., the Xiaodudou and Lutouliang sections of the Nihewan Fm., and the Youhe Fm. This implies that not only are the geochronological distinctions between these sedimentary units not extensive, but moreover the lithologies themselves, as well as their overlying or underlying bounding sediments, almost all display indications of cold climate alteration.

Since the 1970s, due to rapidly developing palynological research in China, a great amount of valuable quantifiable scientific data has been obtained that document climatic fluctuation trends within the past four million years from within many regions of the China, and particularly from the controversial eastern regions. These data are in the renown sections including the aforementioned Yushe Fm.; the contemporaneous Xiatuhe section in the Taigu Fm.; the Nihewan Fm., including the neighboring *Hipparion* Red Clays and Hongya moraine; the Sanmen Fm. (sensu lato) that includes an underlying first moraine; in addition to the Youhe Fm. and other deposits that maintain stratigraphic units relating to the lower Quaternary boundary. These sections document a flora

*Translator’s note: Now exclusively Miocene.*
The Lutouliang section contains the basal member of the Nihewan Fm. in which there are three pollen zones, expressing the most characteristic assemblage among the other sections (Liu, 1980). Pollen Zone I in the basal part of the section contains a conifer forest complex dominated by Pinus and Picea, secondarily with Abies, with their counts reaching over 90%. In the middle of the section, or Zone II, the pollen complex shifts to a characteristic grassy woodland, represented by taxa including Artemesia, Chenopodium and Cruciferae. Zone III, at the top of the section, resembles the Zone I complex. It may be concluded then, that on the basis of the floral replacement within the three pollen zones, a correlation may be made to the extant floral zones of the high mountains in western China where Pinus, Picea, and Abies forests are prevalent, which is in contrast to the sparsely wooded grassy plains in the relatively low elevations of eastern China. The presence of these pollen complexes in the stratigraphic record not only indicates the inception of glacial stages and habitats, but moreover reflects the fluctuating nature between glacial stages, such that it is only under fluctuating glacial conditions that an entire floral complex may be successively repeated in time and space.

For example, the pollen complex of Zone II should actually represent the advance of a primary glacial stage, while pollen Zones I and III represent the period subsequent to a glacial retreat. If the appearance of a pollen complex alterations in Zone II, Zone I, and III occur contemporaneously with other sections, but in a different dimension or space, this would be equivalent to what is occurring currently in the floral zones of the high mountain regions of Western China where, in the regions around the periphery of glaciers, there is a flora representing grassy plains and sparsely arboreal grassy plains, and in the further periphery lower elevations there is a gradual increasing floral replacement representing a sparsely arboreal grassy plain with Pinus, Picea, and Abies. In summary, this flora generally reflects glacial or glacial margin habitats.

It is necessary to point out that the pollen complex of Zone II at Lutouliang in the Nihewan Fm. is particularly similar to the pollen complexes in the Hongya moraine and the Hipparion Red Clays, with the latter predominantly containing an NAP complex represented by Chenopodiaceae, Artemesia, and Brassica, but with a distinct quantity of coexisting birch and other arboreal taxa that reflect a sparsely arboreal grassy plain. Moreover, the sediments containing a Pinus-Picea complex at the stratigraphic level of the Nangou Cold Stage (Zhou, 1979) lie precisely above the Hongya moraine and the Hipparion Red Clays, indicating that the Hongya glacier had already retreated but this region was still under the influence of a glacial margin climate.

Paleomagnetic results have established the top of the Lutouliang section to be within the vicinity of the lower Matuyama boundary, with the entire section being equivalent to the lower part of the Xiaodukou section, correlated to an age of 3.0-2.48 Ma. This is basically consistent with the ages of the Hongya moraine, the upper Hipparion Red Clays, and the Nangou Cold Stage (Cheng, 1978), and is evidence for a facies change relationship between the Hongya moraine overlying the Hipparion Red Clays and the fluviolacustrine sediments in the lower Nihewan Fm. (Qi, 1978). It is necessary to point out that although the facies change hypothesis was accepted long ago, actual studies have frequently neglected research relating to facies change problems.

In addition, palynomorphs including the Chenopodiaceae and Artemesia which represent a sparsely arboreal grassy plain, have been produced from glacial deposits and from the Renjianao moraine in the Yushe Fm. in southeastern Shanxi Province, in addition to the moraine at the base of the Taigu Fm. in central Shanxi Province; the glacial deposits in the neighboring Tuhe vicinity; and within the first moraine in the Sanmen Gorge of western Henan. However, the flora from the upper section's fluviolacustrine deposits, such as the Zhangcun Member in the middle Yushe Fm., the Taigu Fm., the Sanmen Fm. (sensu lato), and Youhe Fm., have fluctuated to predominantly
Figure 1. Correlation of paleomagnetic columns from the Yushe, Sanmen, Yuanmou, and Nihewan formations.
**Figure 2.** Comparison of Early to Late Pleistocene pollen data.
consisting of *Picea* and other Chinese cold adapted conifer forests. This is also reflected in Early Pleistocene sediments of other regions such as in the Qiangtan Fm. in the Yakou vicinity of the Kunlun Mountains on the Qinghai-Tibet Plateau (Kong et al., 1981) and in the Xigeda Fm. in the upper Yangzi (Jinsha) River bank and Aning River valley in Southwest Sichuan Province, as well as other localities (Liu, 1977), which contain cold to temperate alternating pollen complexes with almost all sharing a common model and pattern, and which are generally contemporaneous. An exception is the Yuanmou Fm. overlying the Longchuan moraine in the Yuanmou Basin of Yunnan Province. Although it is represented by non-glacial sediments relatively early, as represented by its middle and lower members, the Yuanmou Fm. still retains remnant genera including *Picea* and *Abies*. Particularly noteworthy is that in recent years there have been numerous palynologists that have summarized the diagnostic characters of the pollen-spore complexes in the Early Pleistocene of China (Xu et al., 1980) based upon fluctuation consistency, or warming-cooling trends, in the Quaternary. These palynologists have enthusiastically endorsed moving the basal Quaternary boundary to the stratigraphic position underlying the pollen-spore complex that is a clear indication of the first climatic deterioration. Thus the Zhangcun Member in the middle Yushe Fm. that has long been assigned to the Pliocene, would then be included in the Quaternary (Song et al., 1979). Paleomagnetic studies have been conducted in the Zhangcun member which indicate polarities that span the basal Gauss to beginning Matuyama chron at an age of 2.39-3.30 Ma. This chronology is nearly equivalent to the basal Nihewan Fm. which superficially represents glacial sedimentation. However, underlying the Nihewan Fm. is concealed an extremely thick set of sediments. This also occurs underlying the Zhangcun Member in the middle Yushe Fm., where there are documented over 100 m of the Renjianao moraine and glacial deposits. From this perspective, the basal boundary of the Nihewan Fm. has moved forward both spatially and chronologically.

Within recent years research involved in Quaternary mammalian complexes has also encountered new developments and breakthroughs. Traditionally, the three-toed horse *Hipparion* has represented the Miocene and Pliocene epochs (Pei et al., 1963; Pei, 1962; Wu et al., 1980; Tang, 1980). However, subsequent to the 1960s successive discoveries have been documented in Quaternary deposits from localities including Taigu and Wucheng in Shanxi (Li et al., 1974); Lingtai, Gansu; Nihewan, Hebei; and Youhe, Shaanxi; where *Hipparion* co-exists with certain Early Pleistocene Quaternary elements such as *Equus* and *Elephas*. These discoveries contradict the earlier conception that *Hipparion* could not exceed the upper Tertiary boundary. Additionally, at several localities there have been discoveries of taxa normally attributed to younger rocks but found in older stratigraphic positions. In the middle Yushe Fm. within the originally assigned Pliocene Zhangcun Member, there appears the genus *Pseudaxis* which gradually increases in abundance in the Middle Pleistocene. In the middle lower section of the early Pleistocene Nihewan Fm., the wooly rhinoceros, *Coelodonta antiquitatis*, has been repeatedly documented as well as other important members representing a glacial margin fauna that existed in the Middle to Late Pleistocene of North China. Most importantly, there is the co-existence of *C. antiquitatis* with *Hipparion* in the Nihewan Fm. (Tang, 1980). Thus vertebrate paleontologists cannot refrain from posing the question: What, finally, is the paleoecology and habitat that is represented here?

Naturally, in addressing this question, there is a necessity to advance serious research to facilitate a reasonable interpretation. Xue (1981) states that the stratigraphic position of the Youhe fauna indicates it predates the Nihewan fauna, such that these new occurrences are considered the first exploratory attempt at resolution. However, previously, Early Pleistocene stratigraphic age correlation was based upon the diagnosis of several mammalian faunas, such that a universal consensus was lacking between the discipline of paleomagnetic stratigraphy and in effect, several deposits were actually assigned to distinct time periods. For example, the Yuanmou Fauna was interpreted with an age between 1.5-3.1 Ma (Lin et al., 1978) and was thereupon considered

*Translator’s note: This reference is to *Proboscidipparion*, a perfectly legitimate Pleistocene genus.*
contemporaneous with the Nihewan Fauna. Moreover, formerly, there was a strong belief that the Nihewan Fauna and the Sanmen Fauna were undoubtedly contemporaneous. But current research indicates these correlations are suspect as the paleomagnetic evidence indicates the faunas represent distinct ages. The Sanmen Fauna initiates at 1.1 Ma, whereas the Nihewan Fauna is in decline prior to 1.5 Ma. The two may not only be unrelated, but moreover the distance between the inception of one and the termination of the other is nearly 0.4 Ma.

Currently, paleomagnetic results indicates the age of the Youhe Fauna cannot predate the inception of the Nihewan Fauna*. Therefore, the proposal of whether or not to recognize it as underlying the Nihewan Fm. must be postponed until a later more auspicious time. On the other hand, several *Hipparion* faunas originally assigned to the Pliocene, in addition to the Yushe Fauna, display magnetic signals with ages generally consistent with the time periods associated with the Yuanmou fauna and the Nihewan Fauna. However, the inception of the Yushe faunal development predates the Yuanmou or Nihewan faunas, yet correlates to them reliably. Therefore, the correlation and superposition of Pliocene and Pleistocene deposits based originally upon the subdivision of vertebrate faunas is still unsatisfactory (Barbour, 1925, Barbour et al., 1926). Henceforth, it will be very necessary to rely on data provided by paleomagnetic stratigraphy and other dating techniques to again cautiously review the problem of each individual faunal age assignment.

The study of paleoanthropology and its associated cultural artifacts increasingly tends to be associated with the long Quaternary scale. Advanced research and excavations have progressively moved the discoveries of fossil hominids and cultural artifacts into older deposits. In 1964 Lantian Man was discovered in the older loess deposits, lying stratigraphically in the lower Xiehu Fm., and determined paleomagnetically to lie between the Jaramillo Subchron and the inception of the Bruhnes normal Chron, with an age ranging between 0.75-0.80 Ma (Ma et al., 1978) but not to exceed ~1.0 Ma. In 1965, isolated molars of Yuanmou Man were discovered as well as Paleolithic tools from the upper Yuanmou Fm., determined paleomagnetically to lie approximately in the Gilsa Subchron at an age of ~1.7 Ma (Li et al., 1976). In 1978 the Xiaozhangliang Paleolithic artifact level was discovered at Nihewan, approximately in the middle to lower portion of the Xiaodukou cross-section, and is correlated probably to the basal Matuyama boundary, conjectured at an age of ~2.4 Ma. Based upon the research of Professor Lanpo Jia, the artifacts of the Xiaozhanglian horizon are believed not to have been manufactured by the most primitive hominids (Long, 1980). In addition, these Paleolithic artifacts coexist with *Hipparion* and *Coelodonta*. Nevertheless, based upon this data, several paleoanthropologists have surmised that in China, the appearance of the Hominidae and the production of tools have a history that is still the world's earliest.

Currently, however, the hominid fossils and cultural artifacts discovered within China are proved to be younger compared to other countries and are chronologically far removed from the East African sites that exceed 3.0 Ma, with some discoveries possibly pushing the history of hominid antiquity past 3.5 Ma. Currently, there is an international contingent of paleoanthropologists that recognize the history of hominid development to predate 3.0 Ma. Most recently, in the deposits of China, there have also been indications signifying the possibility of even older hominid fossils and cultural artifacts. Therefore, from the perspective of paleoanthropology, this text recognizes the Lower Quaternary boundary to lie between 3.5 Ma to approximately 4.0 Ma.

Based upon what is currently known, tectonic activity within China during the Early to Middle Quaternary is relatively conspicuous even without the consideration of intensity and scope. This activity also cannot be distinguished from the initiation and development of Quaternary glaciation. The inception of large-scale tectonic activity over a relatively broad region is noted from the end of the Tertiary to the initiation of the Quaternary glacial stages, with other episodes.

* Translator’s note: This statement is blatantly erroneous.
sustained continuously into the Early Quaternary. This activity created an unconformable surface upon which there accumulated deposits including the Hongya moraine in Yangyuan and Yuxian Co., Hebei Province; the moraine at the base of the Taigu Fm. in Shanxi Province (Guo et al., 1956); the Renjianao moraine at the base of the Yushe Fm.; the first Sanmen Gorge moraine in Yuxi Co.; the Chuanxijinsha Anding moraine (Quaternary Glacial Study Group, 1977); the Longchuan moraine at Yuanmou, Yunnan Province; and the Jingxian moraine on the Qinghai-Tibetan Plateau (Duan et al., 1979). It is quite evident that this broad-scale tectonic activity preceding the Quaternary glacial stages is extremely significant.

Related paleomagnetic studies indicate this activity probably initiated between 3.0 Ma and 4.0 Ma, such that it is evident that the unconformable surface subsequently created represents the Lower Quaternary boundary. A second phase of tectonic activity occurred at the end of the first interglacial stage prior to the inception of the second glacial stage that affected the Yuanmou Fm. in Yunnan; the Nihewan Fm. in Hebei; the Yushe and Taigu formations in Shanxi; represented the original occurrence of the first moraine in the Sanmen Gorge of Henan; and furthermore caused the inception of deformation, rifting, orogeny, and subsidence to create other relatively clear regional unconformable bedding planes. The Gongwangling moraine (Wang et al., 1966) at Lantian, Shaanxi; and the second moraine in Sanmen Gorge (Jia et al., 1959; Sun, 1959) were both deposited upon an unconformable surface created by this activity. Paleomagnetic research indicates this tectonic activity began approximately between 1.2-1.5 Ma which can be recognized as the boundary between the Early and Middle Pleistocene, as it is not only clearly identifiable, but moreover is also supported as such by many other associated disciplines.

If one considers eustatic parameters associated with several marine transgressions that are intricately related to interglacial sedimentation in Eastern China, it may be noted that there was a relatively great range of orogenesis and subsidence caused by tectonic activity in the Early to Middle Quaternary. The first marine transgression in the Early Quaternary occurred during the first interglacial stage (Ling, 1977; Yang et al., 1979) generally between 1.8-2.4 Ma. These transgression deposits occur in the central-upper section of the Nihewan Fm., as well as within fluviolacustrine deposits of several other regions. The range affected by this transgression was extensive, as witnessed in such areas as a portion of the Hebei Platform, the Beijing region, the Yanjing Basin, the Yangyuan and Yuxian basins, the Yuncheng Basin in Shanxi, and the Weihe River Valley in Shaanxi, where Early Quaternary marine horizons bearing Foraminifera are correlated to each other (Wang et al., 1981; Wang, 1981). However, at present these marine sediments exist at different elevations, as exemplified by the Beijing region, where a majority is recognized at depths between 400 m to 600 m below sea level. The same horizons in the Yangyuan and Yuxian basins have been elevated to 900 m elevation; while in the Weihe River Valley (currently at 500 m elevation) these Quaternary marine deposits are subsided to 1,000-1,500 m, beneath current sea level. This is therefore evidence that since the Quaternary, the orogenic range between each region in North China may have reached 1,000-2,000 m. Consequently, it is necessary to objectively recognize the strength and range of Quaternary tectonic activity, such that it is impossible to believe similar affects in other regions of China did not occur, particularly in the southwest and western regions of China.

In summary, research relating to the problem of the lower Quaternary boundary through perspectives such as Quaternary glaciology, paleomagnetic stratigraphy, palynology, vertebrate paleontology, paleoanthropology and its associated artifacts, in addition to the study of recent tectonic activity, have advanced a synthesized approach to determine the Lower Quaternary boundary to lie at 3.5-4.0 Ma. This boundary underlies the Renjianao moraine, the moraine in the lower section of the Taigu Fm., the first moraine in the Sanmen Gorge, the Longchuan moraine, the Jinsha-Anding moraine, and the Jingxian moraine. It also corresponds to the conclusions of interdisciplinary research and recent developmental trends, as this temporal boundary line is not only clearly recognizable in the field, but moreover may be distinguished to express unique characteristics in the evolutionary development of a distinct geologic age.
Finally, the authors of this text wish to take this opportunity to express their position on the discussion of the lower Quaternary boundary problem. Although the authors agree with the perspective of a long Quaternary stage, contradictory opinions are also recognized. The authors recognize the most recent course of developments involving the complex factors controlling global climatic evolution in recent years are quite complex, as represented by fields including geophysics, geochemistry, and global tectonics, as well as the complete mutual relationship between organic and inorganic fluctuations. Upon careful consideration of the problem, it is difficult to avoid inaccuracies relating to one or another unilateral aspect. Thus the authors aspire to positively encourage scholarly discussion, which will rectify errors, and promote an earlier unification of colleagues in their efforts to ultimately resolve the problems of the Lower Quaternary boundary.

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