Eco-environmental effects of the Qinghai-Tibet Plateau uplift during the Quaternary in China

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Abstract The Qinghai–Tibet Plateau uplifted >3000 m in the Quaternary period. The average rate of uplift was 1–1.1 mm/year. The uplifting has remolded the geomorphology of China. The landform in China was changed from west-low and east-high to west-high and east-low in three steps. The Qinghai-Tibet Plateau uplift is an important factor that affected the climate and the environment of China in the Quaternary period. It controls atmospheric circulation and climatic change in Asia and even the northern hemisphere, by dividing the westerlies into two branches: south and north. The plateau gradually became a heat source in summer and a cold source in winter. The uplift had a decisive effect on the formation of the East-Asia monsoon, which increased the climatic differences between the glacial period and the interglacial period. The climate and environment of China are characterized by the influences of the plateau uplift. The east of China became the south-east monsoon area, whereas the south-west became the south-west monsoon area and the north-west turned into an arid inland region. The Gobi and large-scale deserts that formed in the inland basins are ceaselessly extending. The climate of northern China became more arid as the Qinghai-Tibet Plateau continued to uplift. The Plateau uplift affected glacial evolvement and loess formation, and propelled the migration of cold- and warm-blooded animals, which differed from other regions of the world at the same latitude.

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Introduction

The Qinghai-Tibet Plateau (Fig. 1) has been through many periods of uplift in its geological history. Its altitude reached as high as 3000 m in the Quaternary period, and it has kept a trend of rapid uplifting. The Qinghai-Tibet Plateau not only had an important influence on the atmospheric circulation of the northern hemisphere, but also directly affected the climatic and eco-environmental evolution of China in the Quaternary period (Huairen and Xin 1985). Its remolded geomorphological pattern of the Chinese continent gave an impetus to form the East-Asia monsoon. The monsoon increased the Chinese climatic difference between the glacial period and the interglacial period. A comparatively special climate subsystem was formed in China in the Quaternary period. It caused the Chinese climate to deviate from that of the average status of climatic systems of the world and brought about a series of eco-environmental effects. Some effects included a change in snowline altitude and glacier scale, aggravation of aridity in northern China, the formation of desert and loess, and the migration of different biological groups compared with other regions of the world at the same latitude.

The plateau uplifting process

The Qinghai-Tibet Plateau (Fig. 1) uplift was an important geological event in the Quaternary period with an uplift of >3000 m (Baofu 1987). The average rate of uplift was 1–1.1 mm/year. The rate in the south was as high as 8.9 mm/year, and was faster than that in the north. The rate at latter stages was faster than that at the beginning. Just in the last 10,000 years, the plateau has uplifted 300–700 m, and is still rapidly uplifting now (Bingyuan and Baofu 1983).

The Qinghai-Tibet region used to be a section of the ancient Tethys Sea that that lay across southern Eurasia in

Fig. 1
Qinghai–Tibet plateau

the Permian era. The ancient Tethys Sea receded step by step from north to south while the continent became established. After experiencing the Hercynian Movement and the Indo-China Movement, the Kunlun Mountain and the Kekexili region in north Qinghai-Tibet rose above the sea surface. Until the Mesozoic period, the Yanshanian Movement caused large-scale geomorphologic patterns (mountain chains, a plateau plain, basins, rivers and other geomorphic units were arranged and combined on the surface). In the Late Eocene, the Himalayan Movement of the first phase compelled the Tethys Sea to entirely evacuate the whole Qinghai-Tibet region. A new era of geomorphic upgrowth started in Qinghai-Tibet region. The Himalayan Movement of the second phase caused the Himalayan Mountains to uplift in the middle Miocene epoch. It greatly reinforced surface relief, with movement of macroscale faults and the formation of folded block mountains and faulted basins.

The plateau surface and the Earth's crust remained comparatively steady during the Pliocene epoch. The primal plateau surface was characterized by gentle undulations at ~1000 m altitude, with a warm and humid climate, and numerous rivers and lakes. From the end of the Pliocene to the early Quaternary, the Himalayan Movement of the third phase started a new epoch of "World Ridge" development. The altitude of the Qinghai-Tibet Plateau was raised to ~2000 m in the Eopleistocene. The mountain regions were most likely over 3000 m. Because the plateau was not high enough at that time, the south-west monsoon could still span the plateau and went deep inland, and so numerous water systems and broad lake basins existed on the inner plateau. Climate began to affect differences between the western and eastern areas of the plateau in the glacial period when the plateau became raised to ~3000 m in the Mediopleistocene. Rainfall in the west and the north was less than for other regions, indicating the effect of the transverse mountain ridge on the southerly moving water vapor. In the Epipleistocene, the climate of the plateau became dry because at approximately 4000 m in height it severely obstructed the movement of the water vapor. As a result, the water body of lakes diminished and saline water occurred in some basins. Uplift of the plateau continued to speed up in the Holocene epoch. At present, the plateau region above 4500 m is suffering violent deplanation (CAS 1981, 1983). The large-scale uplift of the Qinghai-Tibet Plateau not only influenced Chinese geomorphic patterns and climate change, but also changed the climate and eco-environment in Asia and even the northern hemisphere (Huairen and Xiqing 1988). It was a main driving force in eco-environmental evolution in the Quaternary period (Xihao1991).

Changing geomorphic patterns

As a result of the intense uplift of the Qinghai-Tibet Plateau and the large-scale settlement of the eastern plains, the Chinese stepped land features were formed. The Yangtze and Yellow Rivers flow eastward to the sea because of the change in Chinese geomorphology from west-low and east-high to west-high and east-low. The stepped geomorphology of China has the following characteristics:

Qinghai-Tibet Plateau is the first step with an altitude of >5200–4000 m. It includes serras and dales, and many lakes. The second step strides over the Kunlun and Qilian Mountains from the Qinghai-Tibet Plateau on the north, and across the Hengduan Mountain on the east. Its altitude rapidly descends to 2000–1000 m. This step mainly consists of the rugged Yunnan-Guizhou Plateau, the Loess Plateau with its interlaced ravines, the gently undulating inner Mongolia Plateau, Sichuan Basin with its beautiful scenery, Tarim Basin with its widespread desert, and Junggar Basin with its broad grasslands. The third step consists of hills and plains at an altitude of <1000–50 m in the east of Daxinganling, Taihang Mountain, Wu Mountain and the east side of the Yunnan-Guizhou Plateau. It includes the gently undulating Northeast Plain, the far-flung North China Plain, and the middle and lower Yangtze River plains with numerous lakes, the south-east hills and the littoral plain with its flourishing forests.

Because of neotectonic movement and the East Asia Monsoon in the Quaternary period, three vulnerable zones of climate and eco-environment were formed. They are Qinghai-Tibet Plateau, desert loess, and re-claimed land from the sea.

Formation of the East Asia monsoon

The Qinghai-Tibet Plateau uplift had a decisive effect on the formation of the East-Asia monsoon (Zhisheng and others1991). The Qinghai-Tibet Plateau, with an average altitude of 2000 m, began to affect the geographic location and temperature of the Siberian pressure ridge in the early Quaternary. The high pressure was intensified and situated at 45°N over the plateau, but it was weakened and was situated at 30°N outside the plateau area. The basic mode of the East Asia monsoon was established (Zhenyao and others 1981). If there was no Qinghai-Tibet Plateau, monsoon circumfluence would not exist. The higher the plateau, the stronger the monsoon is, and the wider the area of its influence. The climatic effect of the plateau has subsequently been strengthened since the early Quaternary. The plateau acted as a heat source in summer and a cold source in winter. The westerly jet flow at middle and low levels was divided into two branches to the south and north. The north branch moved northwards and strengthened where the plateau and its mountains were uplifted. It changed the atmospheric circulation of wind systems, and adjusted the transport of water vapor and heat. In addition, the plateau uplift caused the East Asia monsoon and the South Asia monsoon to form. It attracted a muggy south wind from both the Indian Ocean and the west Pacific in summer, and reinforced a dry and cold north wind from Siberia and the Mongolia Plateau in winter. Therefore, the Qinghai-Tibet Plateau uplift is not the only reason for the occurrence and development of the East Asia monsoon but it has been an important driving force of global climate change since the late Cenozoic (Xudong 1984).

Duzheng and Youxi (1979) believed that the formation, development and transition of the ancient Chinese monsoon depended upon the Qinghai-Tibet Plateau uplift. It has obstructed the path of the west wind since the late Cenozoic. In the interglacial epoch, the environmental effect of the Qinghai-Tibet plateau as a heat source in summer was intensified. This increased the melting of ice and snow, increased the amount of ground cover and decreased reflectivity from the Earth's surface. The summer monsoon of Asia was intensified because the barometric gradient between the ocean and land increased. In the glacial epoch, the environmental effect of the Qinghai-Tibet plateau as a heat source in summer was weakened because the coverage area of ice and snow on the Qinghai-Tibet Plateau was extended and the reflectivity from the Earth's surface was increased. The summer monsoon of Asia was attenuated because the barometric gradient between ocean and land decreased.

Ancient monsoon activity has influenced the space-time evolution of climate and eco-environment in China since the Quaternary (Xihao and Zhisheng 1991).

Climate transition

The Qinghai-Tibet Plateau uplift had an important impact on the climate change of Asia and even the northern hemisphere in the late Cenozoic (Huairen 1985). The modern Qinghai-Tibet Plateau markedly influences the planetary wind-system and atmospheric circulation at middle and low altitudes (Duzheng 1955). According to Ruddiman and Prell (1989), Kutzbach and Guetter (1989), the Qinghai-Tibet Plateau uplift has been an important driving force of climate change in the northern hemisphere. The Qinghai–Tibet Plateau uplift caused biological migration and snowline changes at altitude from what they would be normally at that latitude(Du and Qinye1985). Geological and biological evidence reveals that the climatic difference between the west and the east of China was not obvious during the early Tertiary. It was not distinct until the Miocene epoch and particularly the Pliocene. The east of China became a south-east monsoon region, while the north-west turned into an arid inland region. The Gobi and other deserts appeared in some large inland basins, and are continuously expanding with the Qinghai-Tibet Plateau uplift (Tingru1983). Drought-enduring bush and steppe plants predominate in pollen assemblages in the west from late Pliocene to Eopleistocene. These remnants lessened gradually but still occurred in the early Tertiary period. The red earth that contains eolian dust sand developed in central China. A sequence of loess and paleosol began to develop, and tropical and subtropical vegetation was reduced rapidly from ~2.5 million year b.p. Since then, the intensity and range of the Asia monsoon circumfluence has enlarged. The effect of the Asia monsoon on the change in Chinese climate became more obvious. In the glacial period, a humid air current from the north Pacific shrank because of cold high-pressure air from Mongolia. The desert in western China expanded because rainfall rapidly decreased. Windblown dust was deposited rapidly. Thick-bedded loess formed on the Loess Plateau and even on the east plains.

The Qinghai-Tibet Plateau uplift made the western China climate dry because sea breezes from the Indian Ocean were obstructed, and the Chinese East monsoon did not reach that far. The climate of western China will become increasingly arid as the Qinghai-Tibet Plateau continues to uplift. Based on the analytical result of loess grain size analysis, the later into the Quaternary period, the coarser the loess grain size is. The content of the most coarse grade-scale (grain size of 0.25–0.1 mm) increased from 0.7% in the Eopleistocene period to 1.9% in the Epipleistocene. The climate in the glacial period was drier and colder than before the Quaternary.

The Qinghai-Tibet Plateau uplift changed the atmospheric circulation and obstructed humid air currents from going deep into northern China. Original latitudinal climatic zones suffered disturbance and destruction (Zhenyao and others 1981). In the glacial epoch of the Quaternary, the climate zone and cyclone courses were forced to move southwards because of powerful cold currents from North Asia, which frequently intruded into inland China. Southern forest gradually receded south-east. The climate became drier and colder: the temperature dropped by an average of 9 °C from the late Tertiary period. As the plateau uplift has increased, so the grassland and desert invade southwards. The south borderline of loess deposit crossed the Yangtze River and even reached the West Bank of Taihu Lake in the Epipleistocene period. The subtropical forest withdrew southwards to approximately 20°N.

In summary, under the general background of global climatological change, the wave-like property of climate change with cold-warm and dry-wet alternations was very distinct in different regions of China in the Quaternary period. This polycycle existed with an alternation of the glacial period and interglacial period in western China, and a periglacial period and a interperiglacial period in eastern China (Jiaqi 1995).

The Qinghai-Tibet Plateau uplift had a decisive impact on the distribution of water and heat in the Quaternary. It directly affected glacier types and snowline altitude. Rainfall was concentrated on the windward slope of the plateau but decreased in the inner plateau. This phenomenon began in the late Tertiary and was aggravated gradually in the Quaternary.

The west plateau had the onset of a glacial environment while the periglacial environment was developing in the east of China. Although the glacial period in the west corresponded to the periglacial period of the east as a whole, the time that the east changed to a periglacial period was a little later than that of the west. In contrast, the periglacial period changed in the east a little earlier. Diversity of climatic change began to occur in China in the late Tertiary period. Climate differences between the south and the north of China intensified in the Mediopleistocene period. The multipolarity of climatic change appeared in the Epipleistocene and was similar to the multipolarity of today.

Effect of eco-environment

The evolution of the climate and eco-environment has been controlled by both the tectonic-climatic cycles in the glacial period and their feedback mechanisms since the Pliocene (Dianqing and Xihao 1986). The vicissitude of winter and summer Asia monsoons and the environmental effect of their mutual growth and decline have determined the evolution of the ancient climate and eco-environment in China. In the late Cenozoic, the annual range of climate and the change in humidity and temperature together controlled the evolutive history of the environment. All Chinese glaciers, deserts and loess are a result of the neotectonic movement and East Asia monsoons in the Quaternary.

The Qinghai-Tibet Plateau uplift and East Asia monsoon activity had important impacts on glacial evolution, which not only controlled the plateau glacier evolution but also created favorable climate condition for the formation of mountain glaciers in the regions of the middle and lower Yangtze River. They accelerated the formation of an arid and semi-arid climate in the north-west. They had a decisive effect on the spread of deserts and the deposition of loess. They brought about biozone migration that differed from other areas of the world with the same latitude.

Changes in the glacier and snowline

The Qinghai-Tibet Plateau uplift had a vital role in water-heat distribution and directly influenced glacier types and snowline altitude in China in the Quaternary (Yafeng and others 1989).

The plateau glaciers were formed by both the Qinghai-Tibet Plateau uplift and East Asia monsoon activity. In the early Quaternary, the plateau uplifted to ~2000 m, and the East Asia monsoon began to occur. Humid airflow from the Indian Ocean advanced northwards because the plateau was not high enough to prevent it. During the glacial epoch, glaciers just developed on some "upheaved islands" of the Himalayas (Xihao and Yongzhao 1990). The optimal period of Qinghai-Tibet glacier development was in the middle Quaternary. The plateau was uplifted to ~3000 m and the monsoon had increasingly strengthened. The snowline descended and the glaciers were at their maximal size and activity. The glacial cap covered several mountains of thousands of square kilometers. In the late Quaternary, the Plateau uplifted to ~4000–4500 m. Patterns of high rainfall moved eastward and away from the plateau center. The development of the plateau glaciers ceased and their size was greatly decreased (CAS 1986).

It was the formation and change of the East Asia monsoon that determined the history of the Quaternary glacier in the middle and lower Yangtze River (Tingdong 1995). The environmental effect of the East Asia monsoon allows us to understand the formation of mountain glaciers in Lushan, Poyang and Dagu.

The Quaternary glacier and snowline in China were characterized by (1) the later in the Quaternary period it was, the higher the snow line was, and the smaller the glacier size; (2) the frequency of ancient glaciers in the east was less than that in the west; (3) the largest mountain glacier occurred in the Mediopleistocene period, and (4) although the air temperature was reduced, the driest and the coldest conditions restricted glaciers from growing in the last glacial period.

Desert: extending or dwindling

The advancement and retreat of the monsoon played an important role in changing the area of the desert. The dry, cold winter anticyclone monsoon from Mongolia affected the formation and development of the Chinese desert. From 35 to 50°N and from 75 to 125°E, the modern deserts of northern China are a result of a dry climate. The distance that the summer monsoon reached inland determined the dryness of the desert region. Depending on the dryness, the Chinese deserts can be classified into three regions.

1. The east desert region, which is semi-arid and arid desert steppe. It is affected by a northerly dry, cold monsoon in winter and a southerly warm, humid monsoon in summer. The annual rainfall is between 200 and 400 mm. Semi-fixed dunes and fixed dunes predominate.
2. The west desert region is arid and an extremely arid harsh desert. This region is controlled by a dry, cold anticyclone from the Mongolian plateau, and the warm, humid summer monsoon from the ocean is not able to reach there. The annual rainfall is <100 mm. Most of the dunes are mobile.
3. The northern Xinjiang desert region is an arid desert. It is affected by westerly air currents and an air mass off the Arctic Ocean. The annual rainfall is between 100 and 200 mm. The monsoon distributes rain more evenly here.

The boundary between the desert and the loess is located in east inner Mongolia, the north Shanxi plateau and the south Ordos plateau. In the glacial epoch, the desert advanced towards the loess area because the summer monsoon atrophied and rainfall was markedly decreased. The winter monsoon and its environmental effects strengthened. In the interglacial epoch, the stabilized desert moved back and mobile dunes were fixed because the winter monsoon was correspondingly weakened. The summer monsoon was greatly strengthened and brought more rainfall. The environmental effect of the summer monsoon was significant.

The ancient eolian sand layer and loess in the depositional sequence are regarded as indicative of a winter monsoon prevailing. The prevailing wind direction of the winter monsoon can be determined by the slopes of the windward side and bedding structures in the ancient dunes. The fossil soil embedded in the ancient dunes is indicative of summer monsoon domination (Guangrong and others 1988; Guangrong and Jiong 1990). The desert appeared to shift backwards when more rainfall was carried there. The mobile dunes were changed into stabilized or semi-fixed dunes. Therefore, the history of monsoon activity can be rebuilt by the distribution of eolian sand, loess and fossil soil in the desert region. The fossil soil layers were dated to be ~25,000, 9000, 7000, 6000 and 5000 ab.p. and were found in the strata profile of the east desert region. They indicate strong summer monsoons in the interglacial periods of the last glacial epoch and in the optimal period of the Holocene (Guangrong and others 1988).

Because the Qinghai-Tibet Plateau's uplift restricted the west wind within more southern latitudes, the west wind current in the south of the plateau remained stable. The northern freezing air moved southward and crossed the Yangtze River. An eolian sand layer as thick as hectare was deposited on the regions of Jiujiang, Pengze, Nanchang and Poyang Lake in 26,000–14,000 b.p.

Formation of Chinese loess

The formation of the monsoon and loess are linked with the Qinghai-Tibet Plateau' uplift (Qingyu and others 1988). Huairen and Xiqing (1988) regarded the loess as eolian deposits that occurred under conditions of a dry, cold climate in the glacial epoch. The oldest Wucheng loess was restricted to the Loess Plateau in the north-west, whereas Lishi loess reached the coastland of north Huaibei. The newest Malan loess of Epipleistocene crossed the Yangtze River. It was found in the Lushan region (Zaoyu and Zhongli 1994).

Migration of the biozone

The biozones migrated under the influence of the Qinghai-Tibet Plateau' uplift and the climate of Quaternary period in China. The fossil beds of cold and warm biota were alternately superposed in the regions at 30–40°N. The northerly biome moved into the south of China in the glacial epoch and the southern biome migrated northward in the interglacial epoch. For instance, the fauna of *Coelodonta antiquitatis* and *mammuthus* moved south to more than 34°N in the Epipleistocene. A fossil of *Coelodonta antiquitatis* was found in Shanghai, and so was 5° further south than that of the other regions in the world with the same latitude. The southern boundary of coniferous forest that grows in cool temperate zones reached 31°N to the Zhejiang province, to the Guizhou province in the south-west and to south Tibet. The earlier in the glacial epoch it was, the further south they reached, and the further they reached into the Yunnan-Guizhou plateau. In the Dali Glacial Epoch, *Picea* and *Abies* moved southward to Qinling-Daba Mountain, Dabie Mountain, Tianmu Mountain, Baizu Mountain, and Yu Mountain.

In the interglacial epoch, the tropical biome moved northward. Elephant and peacock fossils were found widely in the Quaternary stratum in northern China and even the north-easterly regions. *Ailuropoda* and *Stegodon* fauna were distributed in the north regions of the Yangtze River, which overlapped with the fauna of *Coelodonta antiquitatis* and *mammuthus* in the Epipleistocene period. *Stegodon* moved northward into the Shanxi province. *Stegodon* overlapped with *mammuthus* fauna for ~800 km. The most northern boundary of semitropical flora reached to the north-west of the Loess Plateau and to south Tibet. *Carya* grew to 47°N in the early Quaternary and then moved southward. They grow on the southern slopes of Tianmu Mountain, which is 30°N, and then it receded southward ~17° (Zhisheng and Xihao 1990). *Hipprion* and *Equus sanmeniensis* migrated to 30–40°N between the late Tertiary and early Quaternary. During this period, paleoclimate, paleogeography and paleoenvironments were the same in vast areas from Xinjiang, Yunnan-Guizhou Plateau to the North China plain. The eco-environment of the Quaternary in China did not undergo a tremendous transition until the late Pleistocene, along with global climatological change and Qinghai-Tibet Plateau' uplift.

References

Baofu W (1987) The Pliocene series and Quaternary of Qinghai-Tibet Plateau. In: Tingdong L (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 3. Geological Publishing House, P.R. China, pp 395–296

Bingyuan L, Baofu L (1983) Tibet Quaternary geology. Science Publication House, P.R. China, pp 67–82

CAS (Qinghai-Tibet Plateau Synthesis Science Expedition) (1981) The problem of age and amplitude and formation problem of Qinghai-Tibet Plateau uplift. Science Publishing House, P.R. China, pp 54–89

CAS (Qinghai-Tibet Plateau Synthesis Science Expedition) (1986) Tibet glacier. Science Publishing House, P.R. China, pp 37–45

CAS (Qinghai-Tibet Plateau Synthesis Science Expedition) (1983) Tibet geomorphology. Science Publishing House, P.R. China, pp 12–56

CAS (Qinghai–Tibet Plateau Synthesis Science Expedition) (1983) Tibet Quaternary geology. Science Publishing House, P.R. China, pp 103–152

Dianqing S, Xihao W (1986) Preliminary study on construction-climate cycle of Chinese Quaternary. J China Quat Study 7(2):1–9

Duzheng Y (1955) The influence of Qinghai-Tibet Plateau on Asia atmospheric circulation and China weather. Sci Bull, P.R. China, 6(6):29–33

Duzheng Y, Youxi G (1979) Aerography of Qinghai–Tibet Plateau. Science Publishing House, P.R. China, pp 34–78

Du Z, Qinye Y (1985) Some problems of vertical natural zones of the south mountainous region in Qinghai-Tibet Plateau. Geogr J, P.R. China, 40(1):60–69

Guangrong D, Jiong J (1990) The process of desert and its cause of Chinese land ecosystem since early Epipleistocene. In: Zhisheng A, Xihao W (eds) Loess-Quaternary geology – global change, vol 2. Science Publishing House, P.R. China, pp 91–101

Guangrong D, Shangyu G, Jong J (1988) Problem of formation, evolution and formation cause of the Maowusu Desert. Chin Sci, P.R. China B(6):633–642

Huairen Y (1985) Climatic change in Quaternary. In: Tingdong L. Contribution to the Quaternary glaciology and Quaternary geology, vol 2. Geological Publishing House, P.R. China, pp 135–144

Huairen Y, Xiqing C (1988) The paleo-environmental character and affected factors of Late Quaternary in China. In: Tingdong L (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 5. Geological Publishing House, P.R. China, pp 14–21

Huairen Y, Xin X (1985) Environmental evolution of the eastern China in the Quaternary. In: Tingdong L (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 2. Geological Publishing House, P.R. China, pp 104–125

Huairen Y, Xin X (1985) The influence of Quaternary climate on Chinese loess and desert. In: Tingdong L (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 2. Geological Publishing House, P.R. China, pp 126–134

Jiaqi L (1995) China Quaternary study and global change in resent years. J China Quat Study 2:150–153

Jianzhong S, Jingbo Z (1991) Loess Plateau Quaternary. Science Publication House, P.R. China, pp 123–156

Kutzbach JE, Guetter PJ (1989) Sensitivity of climate to Late Cenozoic uplift in southern Asia and the American west: numerical experiments. J Geophys Res 94(D15):18393–18407

Qingyu P, Xia C, Ming C (1988) The basic character and study status of the Paleoenvironment in the Late Quaternary in China. In: Qingyu P (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 5. Geological Publishing House, P.R. China, pp 1–13

Ruddiman WF, Kutzbach JE (1989) Forcing of Late Cenozoic northern hemisphere climate by plateau uplift in southern Asia and the American west. J Geophys Res 94(D15):18409–18427

Ruddiman WF, Prell WL (1989) Late Cenozoic uplift in southern Asia and the American west: rational for general circulation modeling experiments. J Geophys Res 94(D15):18379–18391

Tingdong L (1995) The relationship of East Asia monsoon and Quaternary glacier in the regions of the middle and low Yangtse River. In: Tingdong L (ed) Contribution to the Quaternary glaciology and Quaternary geology, vol 8. Geological Publishing House, P.R. China, pp 154–163

Tingru Z (1983) The difference of paleogeographic environment in the Chinese Quaternary. Geography Science, P.R. China 3(3):192–205

Xihao W (1991) The height and phases of Qinghai-Tibet Plateau' uplift in Late Cenozoic, In: Zhisheng A (ed). Loess-Quaternary geology – global change, vol 3. Science Publishing House, P.R. China, pp 1–13

Xihao W, Zhisheng A (1991) Quaternary geology and environment of China. In: Zhisheng A (ed) Loess-Quaternary geology – global change, vol 3. Science Publishing House, P.R. China, pp 31–37

Xihao W, Yongzhao L (1990) Drift sheet and environment of Qinghai-Tibet Plateau. J China Quat Study 2:146–158

Xudong G (1984) Preliminary study on climate and environment of Chinese Quaternary. J Glacier Frozen Earth, P.R. China 6(1):49–59

Yafeng S, Zhijiu C, Jijun L (1989) Problem of Quaternary glacier and environment in the eastern China. Science Publishing House, P.R. China, pp 351–374

Zaoyu Z, Zhongli D (1994) The Quaternary palaeoclimate and recent tectonics evolvement in China Loess Plateau. Geological Publication House, P.R. China, pp 87–92

Zhenyao L, Yunzhi M, Jijun L (1981) The climate status before and after Qinghai-Tibet plateau uplift. In: Zhenyao L, Yunzhi M, Jijun L (eds) The problem of age and amplitude and form of Qinghai-Tibet plateau uplift. Science Publication House, P.R. China, pp 51–121

Zhisheng A, Xihao W (1990) Preliminary study on the Chinese palaeoenvironment transition in resent twenty thousand years. In: Zhisheng A, Xihao W (eds) Loess-Quaternary geology – global change, vol 2. Science Publishing House, P.R. China, pp 1–26

Zhisheng A, Xihao W, Pinxian W (1991) Chinese ancient monsoon and environment transition since last glacial epoch. In: Zhisheng A, Xihao W (eds) Loess-Quaternary geology – global change, vol 3. Science Publishing House, P.R. China, pp 14–30