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Quaternary research in China and global change

Quaternary deposits of various kinds are well developed in China and provide records of almost all Quaternary geological events. With increasing interest in environmental problems, Quaternary research in China focuses mainly on understanding past environmental change. As the most important terrestrial deposit, loess has been intensively studied in recent years. Some climatic proxies (magnetic susceptibility, grain size, carbonate content, ^{10}Be and isotopes of carbon and oxygen) show climatic fluctuation during the Quaternary. Thirty-seven cycles and 110 substages have been recognized. Depth curves of these climatic proxies are well correlated with the deep-sea isotopic records, indicating their global significance. Other environmental information carriers, such as lake deposits, speleothems and sea-level change, are also dealt with in this short review. Uplift of the Qinghai-Xizang (Tibet) Plateau, and its effect on monsoon circulation in East Asia, is briefly summarized and the main discoveries of paleoanthropological relics are also mentioned.

coast and some other localities (Zhang and Shao, 1991). Figure 1 is a sketch map of Quaternary sediments in China.

Main research areas

Loess

Quaternary sediments are useful tools for reconstructing Quaternary environmental history. Among them, loess is in all senses the most important carrier of environmental information in China. Loess, of tremendous thickness and in an almost complete sequence covering all the Quaternary, occupies an area of 450 000 km² mainly concentrated in the loess plateau. Palaeomagnetic dating has revealed that the Matuyama/Gauss boundary is quite near the boundary of loess and Red Clay (Heller and Liu, 1982). This strongly supports the suggestion to set the Quaternary and Tertiary (Q/T) boundary at about 2.5 Ma. Loesses alternating with palaeosols reflect multiple climatic changes. Thirty-seven pairs of loess and palaeosol indicate the same number of climate cycles, in each of which a cold dry episode of loess accumulation is followed by a warm wet period of palaeosol development (Ding and Liu, 1989; Liu and Ding, 1990). Depth curves of some proxies of climate changes such as magnetic susceptibility, grain size, carbonate content and isotopes with cosmic origin (^{10}Be) indicate very well the climatic fluctuations during the Quaternary (Liu et al., 1985; Shen et al., 1992), which can also be well correlated with those of the oxygen isotopic stages of deep-sea deposits (Figure 2). From palaeosol S0 to S26, or in time series from the present to 1.6 Ma BP, all the highs and lows of these curves clearly have their correspondents on the isotopic curve (from stage 1 to stage 61, Rutter, 1992). The depth-age conversion curve, obtained by Liu et al. (1994) from the Weinan loess section using effective dating methods, corresponds well with that derived from SPECMAP stratigraphy (Imbrie et al., 1984).

The distribution of loess is closely related to that of deserts. Loess is usually situated on the outside of the deserts, especially at places in the path of winds prevailing in winter and early spring. The loess-desert transition belt is fragile and sensitive to environment change. Expansion and reduction of the deserts is well recorded in this region. Apparent desert expansion took place in the last glacial maximum and is characterized by the interbedded coarse sandy layer in the loess section in Yulin (Sun, 1994). The flux of dust is positively correlated with the total area of the deserts. Major deserts in north-west China formed in different episodes during the Quaternary (Zhu and Wang, 1992) and played an important role in the formation of loess.

Lakes

Lakes are another source of information on environmental change. Besides many freshwater lakes, there are a great number of saline lakes distributed mainly in some closed basins in the north-west with elevations from 155 to 4900 m. On the basis of chemical composition, three categories of salt lakes can be recognized: carbonate, sulphate and chloride (Chen and Xu, 1991). In the Qarhan salt lakes large amounts of halite began to precipitate at 25 Ka and potash sedimentation at 15 Ka. These two salt layers are generally seen in lake records in west China and indicate relatively dry climatic events (Chen and Xu, 1991). The fluctuation of lake levels is another indi-

Introduction

Environmental change was extensive during the Quaternary. China, with its vast territory covering the north temperate to subtropical and tropical zones, has multiple geomorphologic features, including huge plateaux, vast basins and great plains; a multiplicity of biotas, and complex geological and tectonic backgrounds. There are well-developed and widespread (nationwide) Quaternary deposits of many different kinds which carry records of almost all events in global environmental evolution. Quaternary terrestrial sediments in China are well known in the world. In the west, moraines and molasse facies with the thickness up to several thousand metres are seen on the Qinghai-Xizang (Tibet) plateau and surrounding areas and in front of large mountain ranges. Coarse residual deposits occur in the rocky and sand deserts, while detrital lake sediments and chemical deposits accumulated in arid regions. A special kind of earthy deposit—loess, delivered from eolian dusts, has mantled a vast area, forming the famous loess plateau in the north-central part of China. In the east there are well-developed fluvial deposits more or less mixed with lacustrine deposits in extensive plains. Lava flows and volcanic deposits are sometimes discovered in the north-east and coastal areas. Laterite and terra rossa formed in situ by deep weathering and other red soils with more complex origins are widespread in south China. Cave deposits are scattered everywhere but mainly concentrated in south-west China. Apart from the above-mentioned deposits, terrestrial detrital facies occur in some marine environments on the continental shelves and several sets of marine deposits with foraminifera of different ages are found in some onshore drill cores in the east. The latter are several tens to hundreds of kilometres from the present-day coast line indicating major coastline changes during the Quaternary. Holocene marine series are well developed along the

Figure 1 Sketch map of Quaternary deposits in China.
1 Loess; 2 Loess-like deposit; 3 Desert; 4 Gobi (rocky desert); 5 Alluvial deposit; 6 Marine deposit; 7 Volcanic; 8 Karst; 9 Glacifluvial-glacial; 10 Bedrock.

Figure 2 Correlation between the records of loess and those of deep-sea sediments.

cator of climate change. High lake level, with a relatively low salinity, is usually equivalent to the optimum climate with high precipitation. Holocene high levels appeared at 10–9 Ka in the Daihai Lake, Inner Mongolia and at 7.5–5.5 Ka in the Ebinur Lake, west Xinjiang. Based on carbon and oxygen isotopic compositions and MgO/CaO ratios in lake sediments, the 12 Ka climate record from Siling Lake in Xizang (Tibet) shows the terminal Pleistocene (12–10 Ka) cold and dry period (Younger Dryas?), an early–middle Holocene (10–4.2 Ka) warm-wet period (relatively high lake level) and a late Holocene (post 4.2 Ka) wavy drying (and/or cooling) trend (Gu et al., 1993). We are not quite sure why there is a time difference in the appearance of high lake levels in different places. High levels at 3.5 Ka is widely recorded in most of the lake records. Wang and Wang (1992) suggested that it might coincide with a warm period of the Subboreal phase.

Karst

The dissolution and reprecipitation of carbonate in the carbon cycle, reflecting the complex interactions between hydrosphere, atmosphere, biosphere and geosphere, formed the karst landscape (Figure 3), which contains a large part of the global carbon dioxide reservoir and which, in turn has a great effect on the global carbon cycle (Yuan, 1993). China is one of the countries in the world where karst limestone, ranging in age from Proterozoic to Quaternary is very well developed. In south-west China the karst landscapes have been greatly affected by both climatic change in the Quaternary and by tectonic uplift. Great potential exists in this area for obtaining datable sequences of cave deposits to determine and illustrate Quaternary changes (Sweeting, 1991).

Sea level

China has benefited greatly from its vast expanse of sea and long coast line in the study of eustatic sea level change and climate fluctuation. In Qingfeng and Xiyuan, north of Jiangsu, some sections have yielded good records of Holocene environmental history. Seven warm episodes separated by six cold episodes have been dis-

Figure 3 Karst landscape in south-west China.

cerned with each warm episode correlated with a high sea level. The highest sea level in the Holocene occurred at 6.5–4 Ka, 1.5–3m higher than at present (Zhao and Wang, 1992)

Neotectonism

In China the framework of Quaternary environment change is greatly influenced by neotectonism, especially the uplift of the Qinghai-Xizang plateau (Figure 4). The uplift of the plateau during the Quaternary is estimated to be about 3000 m or more with an average rate of 1–1.5 mm/year (Xu, 1981). Zhang et al. (1991) found that uplift of the whole plateau is still going on, based on data from repeated precise geodetic leveling surveys in 1960 and 1980 respectively. The rate of vertical crustal deformation in the south of the plateau is about 8.9 mm/year. The appearance of such a huge plateau splits the westerly winds into two rapid flows. One passes north of the plateau and the other, south causing anticyclones to appear above the plateau in the early summer and making north China draughty. Furthermore, this huge plateau directly influences the location and intensity of Siberian high pressure. From numerical experiments, Manabe and Terpstra (1974) concluded that this high pressure will

Figure 4 Mount Qomolangma (Everest).

become stronger and locate near 45°N if the plateau continues to exist, otherwise it will be weak and locate near 30°N. The high pressure is fundamental to the existence of the East Asia monsoon and of great significance in the formation and transport of dust material.

The continental glaciers developed on the Qinghai–Xizang plateau and surrounding area have provided high-resolution records of climate change in the late Quaternary. A megathermal maximum at 7.2–6.1 Ka and other Holocene climatic fluctuations have been found in the Dundee ice core in the Qilian Mountains (Yao et al., 1992).

Palaeoanthropology

China is not only a country where the complexity of Quaternary deposits has provided a great amount of information about paleoenvironmental changes but also a country rich in palaeoanthropological relics. Representative fossils of almost every stage in the development of mankind have been unearthed so far (Wu, 1992). Important fossils localities are Yuanmou, Lantian, Zhoukoudian (Beijing Man), Hexian, Yunxian and Yunxi (*Homo erectus*), Dali, Jinjushan, Dingcun Xujiayao, Maba, Changyang and Tongzi (Early *Homo sapiens*), Liujian, Ziyang, Zhoukoudian (Upper Cave Man), etc. (Late *Homo sapiens*), and Lufeng (fossil apes).

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