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PALEOMONSOONS OF CHINA OVER THE LAST 130,000 YEARS*

——PALEOMONSOON VARIATION

AN ZHI-SHENG (安芷生),
(*Xi'an Laboratory of Loess and Quaternary Geology, Academia Sinica, Xi'an* 710061, *PRC*)

WU XI-HAO (吴锡浩),
(*Institute of Geomechanics, Ministry of Geology and Mineral Resources, Beijing* 100081, *PRC*)

WANG PIN-XIAN (汪品先),
(*Marine Geology Department, Tongji University, Shanghai* 200092, *PRC*)

WANG SU-MIN (王苏民),
(*Nanjing Institute of Geography & Limnology, Academia Sinica, Nanjing* 210008, *PRC*)

DONG GUANG-RONG (董光荣),
(*Institute of Desert Research, Academia Sinica, Lanzhou* 730000, *PRC*)

SUN XIANG-JUN (孙湘君),
(*Institute of Botany, Academia Sinica, Beijing* 100044, *PRC*)

ZHANG DE-ER (张德二),
(*State Bureau of Meteorology, Beijing* 100081, *PRC*)

LU YAN-CHOU (卢演俦),
(*Institute of Geology, State Seismological Bureau, Beijing* 100029, *PRC*)

ZHENG SHAO-HUA (郑绍华)
(*Institute of Vertebrate Paleontology and Paleoanthropology, Academia Sinica, Beijing* 100044, *PRC*)

AND ZHAO SONG-LING (赵松龄)
(*Institute of Oceanology, Academia Sinica, Qingdao* 266071, *PRC*)

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ABSTRACT

Based upon the effect of land-sea interaction on the paleomonsoon variation and the time series of climatic proxy-indicators, the historical Asian monsoon variation over the last 130,000 and 18,000 years has been reconstructed with an emphasis on the basic characteristics of summer monsoon circulation. The monsoon-climatic cycles and associated model of environmental development over the central and eastern China are proposed and the mechanism of

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paleomonsoon variation of China preliminarily discussed. The variation of East Asian monsoon circulation should be regarded as a regional result of both solar-radiation changes and the global glacial-interglacial cycles. The episodic uplifting of the Qinghai-Xizang Plateau since the late Miocene has to a large extent controlled the forming and evolution of the paleo-monsoon circulation of China.

Keywords: paleomonsoon, solar-radiation change, land-sea interaction, uplifting of Qinghai-Xizang Plateau, environmental model.

I. Paleomonsoon Climate

Monsoon climate as a basic issue always attracts great attention of meteorologists and climatologists[1-4]. Geographers and geologists have done some special work on the paleomonsoon circulation of China and the humid-dry alternation of Quaternary climate[5-7]. But up to now the paleomonsoon study has not yet got wide attention. In the recent years, both Chinese and foreign scientists put too much emphasis on the paleomonsoon study[8-12], suggesting that the variation of paleomonsoon circulation is a response to the solar-radiation variation on the earth's surface as a result of the earth's orbital change and to the seasonal cycles. Meanwhile, it is suggested that this variation is related to the conditions of underlying surface in glacial and interglacial periods.

Quaternary paleomonsoon records are diversified and abundant in China, of which the loess deposits have to a considerable extent preserved the historical changes of East Asian monsoons in the past 2,500,000 years. In Luochuan, the paleosols or paleosol complex were well developed. For instance, WS3 complex, S13, S5 and S1 paleosols reveal a pronounced effect characteristic of summer monsoon environment, while WL2 complex, L15, L9, L6, L5, L2 and L1 loess layers reveal an effect characteristic of extremely cold-dry winter monsoon environment. The Pilocene Red Clay Formation underlying the loess sediments contains a considerable quantity of eolian silt and rodent fossils. Many layers of paleosols with illuvial carbonte concretions are located in the upper part of the formation, while in the low part are often densely distributed many carbonate concretion layers resulting from eluvial-illuvial processes. All these indicate that this Pliocene formation was formed under the monsoon climate with distinctive seasonal changes. A further study should reveal the history of paleomonsoon climatic changes during Pliocene, possibly also during the late Miocene (Baode Period), when alternatively dominated the environmental effects of summer monsoon and winter monsoon. From the lacustrine sediments of Lower Sanmen Group in southern Loess Plateau, the changes of pollen ratio between herbal and arboreous components had already revealed dry-humid alternations characteristic of the paleomonsoon climates[13].

II. Influence of Land-Sea Interaction

According to many research reports, it is concluded that, during the past 130,000 years, three major large-scale marine transgressions (125,000—70,000, 40,000—25,000 and 11,000—6000 a B.P.) and two major regressions (50,000—45,000 and

18,000—15,000 a B.P.) took place in the coastal areas of eastern China and southern China as well as in their adjacent continental shelf[14-18], resulting in repeated changes of the inland-sea distance. The isotherms and isohyets in the modern eastern China and the eastern part of western China approximately run parallel to the general trend of the mainland coast, indicating that the air temperature and precipitation in these areas are closely related to their distance to the seas. The area from Yinchuan to Baotou, for example, is now located in the transitional zone between arid or semiarid and semi-humid climates, about 1100 km long in distance to the east coast of the Huanghai (Yellow) Sea. During 6000—7000 a B.P., the distance was about 900—1000 km (Fig. 1). While during 15,000—18,000

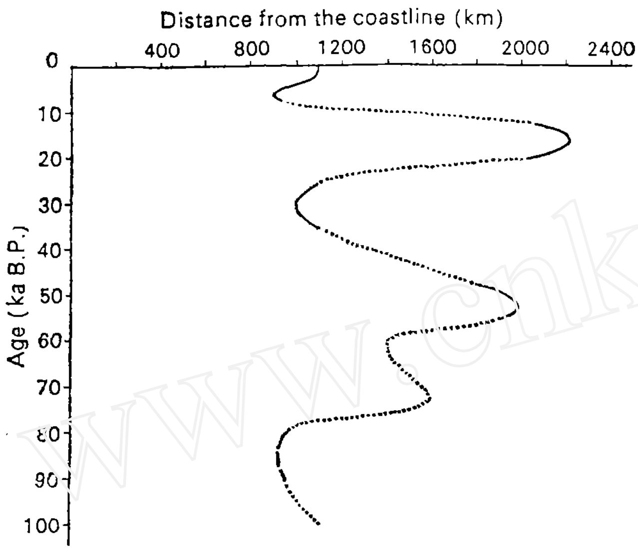

Fig. 1 Distances of Yinchuan-Baotou zone from the coastline of the Huanghai Sea and the East China Sea.

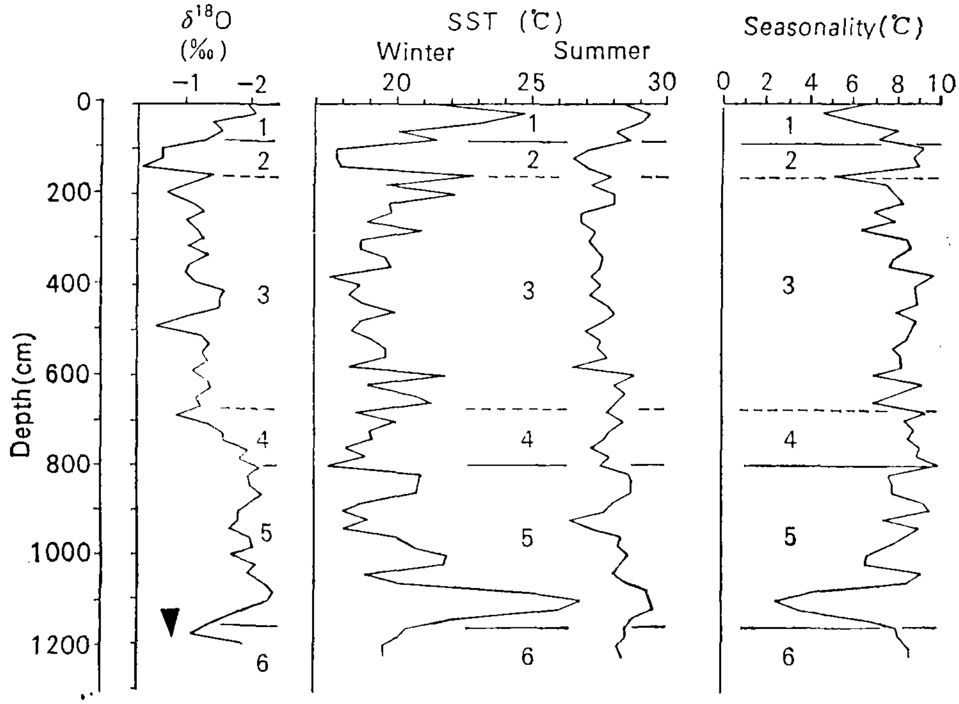

Fig. 2. The curves of sea surface temperatures from V36-06-3 in northern continental slope of the South China Sea.

a B.P. of the Last Glacial Maximum (LGM), when the sea level at least dropped by 130 m[17], the distance was about 2100—2200 km, twice as great as the present one. This increase of distance had further reduced the effect of the weak summer monsoon in LGM and hence greatly decreased the amount of summer precipitation in this area.

During LGM, the exposure of continental shelf as a result of sea level drop decreased about 2/3 area of the Huanghai Sea (including Bohai Bay) north of the Taiwan Strait and about 1/5 area of the South China Sea. Whereas the areal reduction of the West Pacific was very small, with an indistinctive fall of water temperature[19]. Therefore, the marine heating sources of the modern East Asian monsoon are located in two areas, i.e. the West Pacific and the South China Sea. During the glacial period, the heating sources mainly concentrate to the West Pacific alone. The planktonic foraminifera fossil assemblage in core V36-06-3 (19°00.5′N, 116°05.6′E, water depth 2809 m) from the low part of steep continental slope of the northern South China Sea, numerically analyzed by using the transfer function, has provided a changing history of annual range of sea surface temperature (SST) over the last 130,000 years (Fig. 2).

Fig. 2 shows that the annual range of SST of the interglacial period was smaller than that of the present in the South China Sea. In the adjacent Pacific area the SST differences between the two periods are similar, though with a less amplitude[20]. This evidence indicates that the changes of summer SST obviously influence the forming of summer monsoon, whereas the large amplitude drop of SST in the glacial period was probably connected to the winter monsoon from the continent and to drift current from the northern ocean.

Warm-water benthonic foraminifera *Asterorotalia* and *Pseudorotalia* in the West Pacific are regarded as an indication of mordern Kuroshio Current[21]. During the so-called "*Asterorotalia* Transgression" (100—70 ka B.P.) and "*Pseudorotalia* Transgression" (30 ka B.P.)[16], these two species extended to the Bohai Bay, indicating that a branch of Kuroshio had ever moved northwestwards, hence strengthened the summer monsoon of northern China and increased the precipitation in the area. ***Buccella frigida*** (Cushman), indicative of cold water mass, was found to live in the outer fringe of the East China Sea around LGM[22], suggesting that the notable eastward shift of Kuroshio had a remarkable role in weakening the summer monsoon of eastern China.

III. Time Series of Proxy-Indicators

The magnetic susceptibility curves of the three sections in Fig. 3 from Beiyuan, Lingxia, Gansu (35°37′N, 103°12′E); Heimugou, Luochuan, Shaanxi (35°45′N, 109°25′E); and Baimapu, Lantian, Shaanxi (34°10′N, 109°19′E) are obtained through the following procedures: (i) determining the bottom age (128,000 a B.P.) and the top age (71,000 a B.P.) of S1 based on the equivalent ages of the Oxygen Isotope Stage 5[23], (ii) using 10,000 a B.P. (the beginning of Holocene) as the bottom age of S0 and (iii) using the susceptibility time scale to determine the ages of individual layers within the sections.

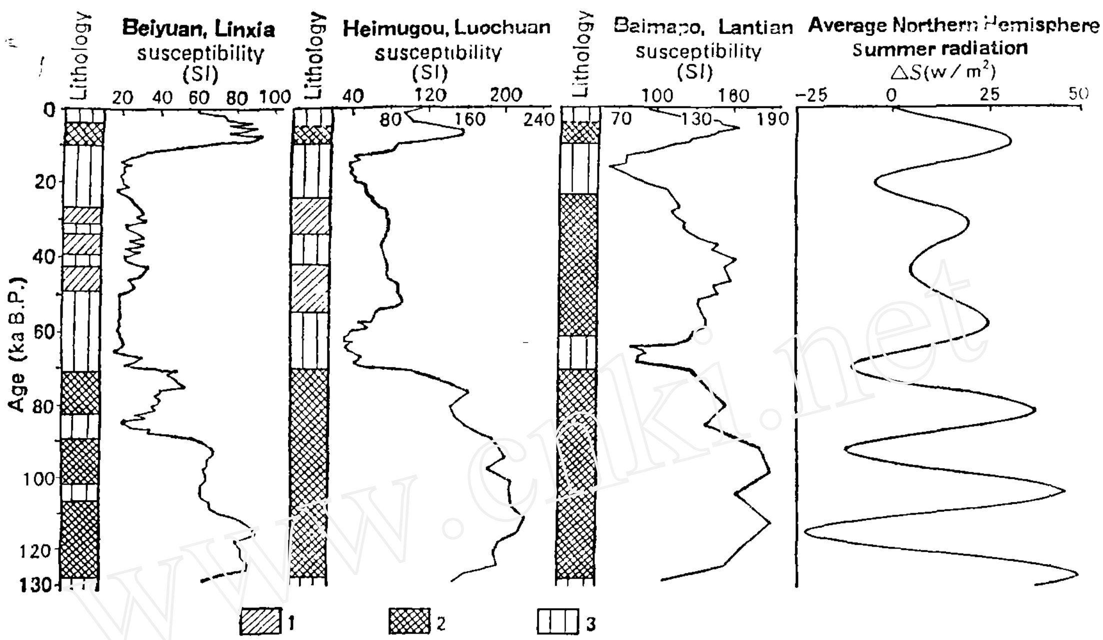

Fig. 3. Susceptibility curves of the three loess-paleosol sequences in Lingxia, Luochuan and Lantian and their correlation with the average Northern Hemisphere summer solar radiation during the last 130,000 years.

1, Weakly developed paleosols; 2, paleosols; 3, loess;
ΔS, Average Northern Hemisphere summer solar-radiation increment.

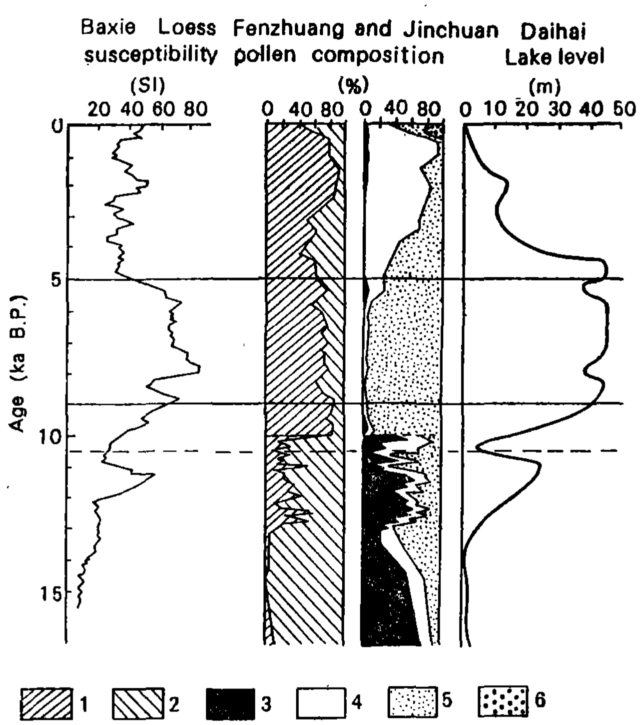

Fig. 4. Correlation of geological-biological records reflecting the climatic changes during the past 18,000 years.

1, Arbor; 2, bush and herb; 3, *Picea* and *Abies*; 4, *Pinus*;
5, deciduous broad-leaved trees; 6, *Butula*.

The magnetic susceptibility peaks around 125—110, 98—90, 80—75 and 9—5 ka B.P. as well as the corresponding paleosol horizons indicate four climatic stages with strong summer monsoons and rich precipitation, which basically coincides with the research results of the Indian and African monsoons by Prell and Kutzbach[11], and also concurrent with the remarkable reduction of global ice-volume. The two peaks around 55 ka B.P. and 30 ka B.P. correspond to the stages of intensified summer monsoons within the last glacial period, while the two valleys at 65 ka B.P. and 18 ka B.P. indicate that the summer monsoon then had a very small effect on the Loess Plateau, hence the winter monsoon effect on the environment became more prominent and the loess sedimentation more rapid. The four stages with strong summer monsoon are in general consistent with the maximum summer solar radiation in the Northern Hemisphere[11] (Fig. 3), suggesting that the changes of summer solar radiation to the Northern Hemisphere were basically consistent with that of summer monsoon circulation. However, the geological records of monsoon show an obvious time lag.

The variation of East Asian monsoon since LGM may be generally reflected in the following aspects: (i) the susceptibility curve obtained from the loess-paleosol sequence in Baxie, Dongxiang, Gansu (36°42′N, 103°24′E)[24], (ii) the lacustrine sediments (16,500—10,000 a B.P.) in Fangshan, Beijing (39°33′N, 115°50′E)[24], (iii) the pollen curve from peat sediments since 10,000 a B.P. in Jinchuan, Jilin (46°12′N, 126°29′E) and (iv) the water table change of Daihai Lake, Inner Mongolia (Fig. 4).

During 18,000—14,000 a B.P. of LGM, the rate of dust accumulation in northern China was found to be relatively great. The sparse vegetation then was dominantly composed of drought-enduring herbs, and the enclosed inland lakes were characterized by their low water level, showing a great decrease of precipitation, a notable weakening of summer monsoon and a pronounced winter monsoon effect on the environment. Around 12,000 a B.P., paleosols developed in western Loess Plateau. Ligneous components increased in the vegetation of northern China. Steppes were inlaid with patches of sparse *Picea-Abies* trees. The lake level rose. All these indicate an episodic strengthening of summer monsoon. At about 11,000 a B.P., eolian dust deposited rapidly and herbal pollen increased again in proportion, which was accompanied by the extinction of *Abies* and *Picea* trees and a rapid fall of lake level. This abrupt change toward a cold-dry climate probably lasted only several hundred years, reflecting a short and abrupt retreat of East Asian summer monsoon, possibly corresponding to the Younger Dryas in Europe. To the period about 9000—5000 a B.P., the paleosol complex developed on the Loess Plateau, with a notable increase in proportion of wood pollen. Meanwhile, deciduous broad-leaf forest grew in North China and southern Northeast China. The lake level reached their maximum stand, indicative of a climatic period with rich precipitation and strong summer monsoon. Since the beginning of the New Glacial (about 5000 a B.P.) the summer monsoon has shown a general declining tendency.

IV. Variation Model

Paleomonsoon records of the past 130,000 years have revealed a history in which the two climatic periods occurred alternately. The East Asia summer monsoon (by-

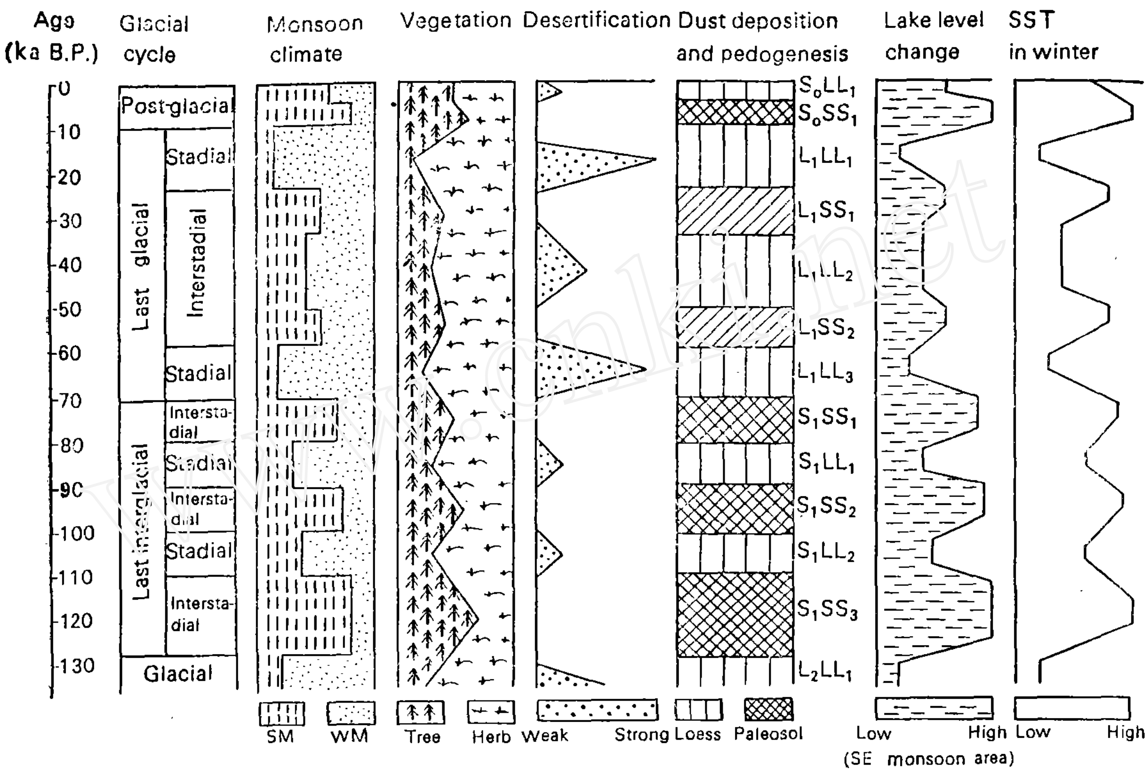

Fig. 5. The monsoon climate cycles in central and eastern China during the last 130,000 years and the model about the paleoenvironmental processes.

south wind from the ocean) and winter monsoon (by-north wind from the mid-high latitude continent) were respectively characteristic of the two climatic periods and have pronounced effects on environment.

The conceptual model of monsoon-climatic cycles and the associated enironmental processes (Fig. 5) indicate that (i) during interglacial periods and the interstadial within the the glacial period, the summer monsoon was generally strong and exerted a prominent effect on environment. The component of arbor plants increased in vegetation; desertization process weakened or even disappeared, whereas the pedogenic process strengthened; water table rose in the enclosed inland lakes in the southeast monsoon area; the winter SST became higer; (ii) during glacial periods and glacial stades within interglacial period, the summer monsoon declined. The winter monsoon effect on environment was reinforced; herbal component increased in vegetation; desertization process intensified; dust deposition accelerated; lake level fell and winter SST notably declined.

The environmental stratigraphic system of the last 130,000 years has been preliminarily established and incorporated into the conceptual model. A detailed stratigraphic subdivision has been made for L0, L1, and S1.

V. Preliminary Discussion of Variation Mechanism

The four stages (125—110, 98—90, 80—75 and 9—5 ka B.P.) with remarkably strengthened summer monsoon circulation, reflected by the curve of loessic magnetic susceptibility, indicate that the increased summer solar radiation over the Northern Hemisphere and the land-sea thermal capacity difference facilitated the creation of greater ocean-continent gradient of atmospheric pressure, consequently strengthening the East Asian summer monsoon circulation. Meanwhile, the six stages of strong summer monsoon (Fig. 3) just correspond to the periods with increased summer solar radiation over the Norhern Hemisphere and show periodic changes about 20,000 and 40,000 years. This shows that the change of solar radiation amount received at the earth's surface is in response to the variation of the earth's orbital parameters, such as precession of the equinoxes (with period about 20,000 years) and obliquity of the elliptic (period about 40,000 years), which had to a great extent controlled the strength of the East Asian summer monsoon and the movement of the front. The Holocence Climatic Optimum came into existence at 9000 a B.P. and lasted to 5000 a B.P., when the summer monsoon was strong. The latitudinally averaged maximum amplitude of seasonal variation of solar radiation occurred at 9000 a B.P. in the Northern Hemisphere. So it is the increased seasonal difference that intensified the normal monsoon circulation, hence further strengthened the East Asian summer monsoon. Nevertheless, the geological records of this intensified summer monsoon seem to show a time lag. By 18,000 a B.P., when the seasonal changes of solar radiation reached the minimum value in amplitude[10], the winter monsoon circulation over the Northern Hemisphere continents as a whole should become weaker due to an areal expansion of ice-snow coverage at high latitudes and the resultant strong continental air-mass. However, the winter by-north wind over the China's mainland was still prevalent and stronger than today, which was possibly attributed to the persistent prevailing of winter monsoon over the China's mainland in the glacial period. The primary cause for such a pronounced winter monsoon effect on the environment is to a considerable extent attributed to a significant shrinking of the summer monsoon during glacial periods or stages. Hence, the annual mean humidity and vegetation coverage became much smaller and land albedo greater, which consequently augmented and pretruded the cold-dry winter monsoon effect on environment. For the same reason, during the interglacials or interstadials with strong summer monsoon, the annual ground surface humidity increased greatly due to the increased precipitation brought by the summer monsoon. Therefore, even though the winter monsoon in the interglacial or interstadial reached the strength equal to the summer monsoon, it was still unable to produce a prominent environmental effect. Besides, the sea level fluctuation in response to glacial-interglacial climatic changes had greatly changed the distance from the central and eastern China to the sea and the coastal land area. Accordingly, it had also changed the extent of summer monsoon influence on the mainland of China. For instance, at 18,000 a B.P., the east coast of China shifted eastwards about 1000 km. At the same time, the heating sources of summer monsoon concentrated to the West Pacific alone. All these changes further weakened the influence of summer monsoon on the mainland of China.

During the glacial periods, the Qinghai-Xizang Plateau became more prominent in its role as a heating source. The low-pressure over the plateau further enhanced the land-sea air pressure gradient, which facilitated the reinforcement of the East

Asian summer monsoon. On the contrary, during the glacial periods, such a heating role became much weaker and further exacerbating the attenuation of the Asian summer monsoon. Since the late Cenozoic Era, the uplifting of Qinghai-Xizang Plateau and the resultant thermal effect as well as its role in blocking and branching the mid-lower layer Westerly Circulation have to a great extent controlled the formation, development and variation of the paleomonsoon circulation of China.

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