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PALEOMONSOONS OF CHINA OVER THE LAST 130,000 YEARS*

——PALEOMONSOON RECORDS

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ABSTRACT

The characteristics of the modern monsoon climate of China may be used as clues for recognizing the records of paleomonsoon climate. The present paper deals primarily with the various paleomonsoon records of the last 130,000 years in the southeast monsoon area. These records mainly come from the following three fields: (i) the historical, (ii) the geological, including loess-paleosol sequence, deserts, lakes, snowlines, timberlines, the phenomena of

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continental desertization and so on, and (iii) the biological, presented by vegetation and mammals. Among these records, the loess-paleosol sequence in the Loess Plateau reflects a climatic history characterized by alternation of two different climatic periods when the Asian winter monsoon and summer monsoon showed pronounced effects on environment, respectively.

Keywords: paleomonsoon, paleoenvironment, loess, global change.

I. Introduction

The modern climate over China's mainland is mainly controlled by the polar continental air-mass or modified polar continental air-mass in winter. The by-north winter monsoon, carrying cold-dry air from mid-high latitude area, is prevalent in the lower layer of troposphere; in summer, most parts of the mainland are under the control of tropical to subtropical marine air-mass and tropical continental air-mass. The by-south summer monsoon with warm-humid air from the lower latitudes is prevalent in the lower layer to troposphere[1]. Generally, the monsoon climate of China shows the following characteristics. The change of prevalent wind from winter to summer is distinctive. As the advance and retreat of monsoon, precipitation and surface air temperature show a distinctive seasonal variation. Hot summers get a plenty of rainfall, while cold winters have a dry climate. The shift of monsoon from one type to another coincides with the seasonal changes, etc. These characteristics indicative of the monsoon climate of China may be used as clues for recognizing the geological, biological and historical paleomonsoon records.

II. Historical Records

The start of rainy season from the south to the north of East China is clearly in response to the process of northward movement of rain belt, i.e. the northward movement of the summer monsoon. The rain spell and dry spell appeared alternatively in the Changjiang River basin during the recent 800 years, with the major dry spells concentrated in 1200—1264, 1523—1590 and 1920 to the present. The yearly variation of precipitation in rainy season shows quasi-cyclic changes with periods of about 2—3 years, 5 years and 20 years[2], obviously a result of quasi-periodic variations of the monsoon circulation. The reconstructed climatic sequence of plum rains in the 18th century has provided certain details about the advance and retreat of the southeast monsoon[3]. The plum rains in the 18th century averagely started on June 15 and ended on July 6, with a mean length of about 20 days. Meanwhile, it showed 2—3, 5—6 and 34-year quasi-periodic changes, also reflecting the oscillations of summer monsoon circulation.

The winter monsoon of China is mainly characterized by the activity of the cold waves or cold air-mass. In the past 500 years, for example, the periods 1440—1520, 1620—1720 and 1810—1900 AD experienced strong activities of cold air-mass[4]. The route of cold waves varies with the alternation of cold and warm periods, which was determined by the prevalent wintertime circulation regime in each climatic period.

III. Geological Records

1. *Loess-Paleosol Sequence*

The Holocene black loam and cinnamon on the Loess Plateau are zonal soils developed under monsoon climate[5]. The loessial paleosols of accumulational type possess obvious claying horizon and illuvial carbonate horizon (carbonate concretions). The snail fossils, dominantly *Metodontia*, as well as herbal and hard wood pollen in such paleosols suggest that the paleosols of the cinnamon family were formed under steppe to forest steppe environment[6], where dry and wet seasons are distinctive, high-temperature concurrent with the rich rainfall in summer. In other words, this type of paleosols developed in periods with pronounced summer monsoon effects on environment. The material composition and texture of silty loess containing rich carbonate as well as snail fossils (dominantly *Cathaica*) and herbal pollen assemblage, reflected a steppe to desert steppe landscape and a cold-dry climate under which the loess developed and accumulated. Malan Loess (L1) of the late Pleistocene gradually becomes smaller in its grain size from the northwest to the southeast, indicating the direction of wind that transports dust to its depositional area. In northern China, the historical and modern dust storms and dust-falling events mostly took place in the winter half-year when air temperature was lower and climate drier. Meanwhile, these events were often related to a strong by-north wind. All the evidence suggests that the loess-forming stage, characterized by accelerated dust accumulation and very weak pedogenic processes, is a climatic period dominated by the winter monsoon environmental effect.

$CaCO_3$ content and grain size in loess and paleosol, dust flux[7] as well as magnetic susceptibility, etc. may be adopted as proxy-indicators for determining the

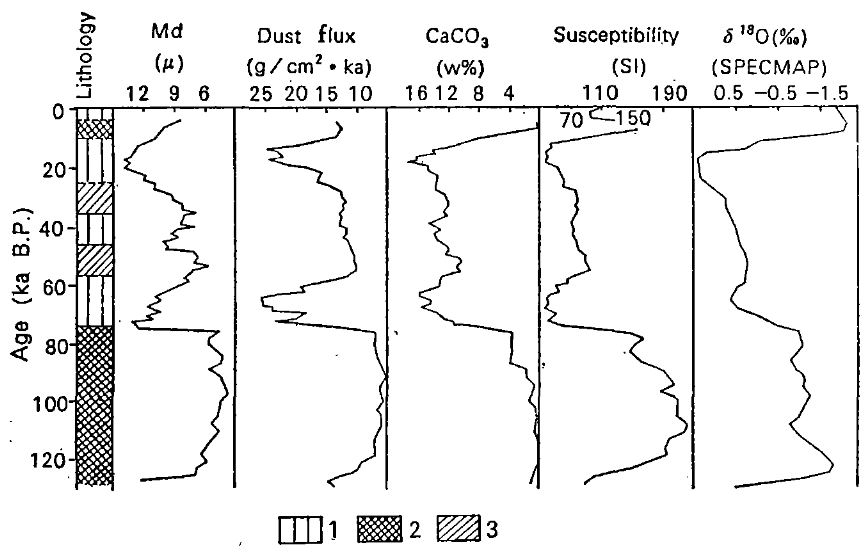

Fig. 1. The curve of grain size, eolian flux, $CaCO_3$ content and susceptibility from Heimugou, Luochuan during the last 130,000 years.

1, Loess; 2, paleosol; 3, immature soil.

strength of winter monsoon or summer monsoon environmental effect. High value of magnetic susceptibility, small grain size, lower dust flux and lower $CaCO_3$ content indicate a comparatively strong pedogenic process and a low rate of dust sedimentation, showing relatively rich precipitation, higher soil moisture and greater coverage of vegetation, and representing an environment with a prevalent summer monsoon. The opposite case therefore indicates a higher rate of dust deposition and a pronounced winter monsoon effect on environment (Fig. 1).

2. *Deserts*

The extent of summer monsoon protrusion to the inland directly influences the arid intensity and advance/retreat of the desert areas. Hence, the deserts of China may be generally divided into three areas (Fig.2). The eastern desert area presents a landscape of semi-arid dry steppe to arid desert-steppe, experiencing the by-north cold-dry monsoon effects in winter and the by-south temperate-humid monsoon effects in summer. The annual precipitation there varies from 200 to 400 mm. The sand dunes there are mainly semi-stablized and stabilized ones. The western desert area shows a dry to extremely dry desert landscape with its climate controlled by cold-dry winds from anticyclones originated on the Mongolia Plateau. In this desert the annual precipitation is generally lower than 100 mm because the moist summer monsoon from the ocean can hardly reach there. Consequently, the sand dunes are mostly active ones. The northern Xinjiang desert area, north of the Tianshan Mountains, also has a dry desert landscape. However, because of the effect of westerly current and the Arctic air-mass, the annual precipitation there may reach up to 100—200 mm and shows a relatively uniform distribution within each year.

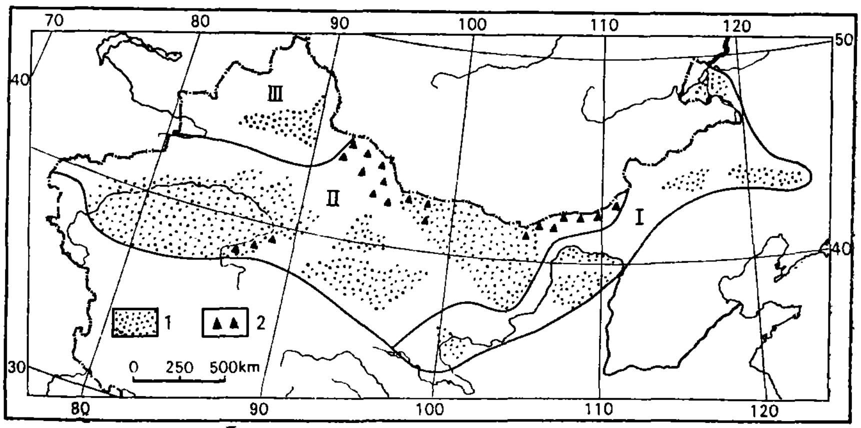

Fig. 2. Subdivision of desert areas in northern China.
1, Desert and sandy land; 2, Gobi Desert; I, eastern desert area;
II, western desert area; III, desert area in northern Xinjiang.

Paleo-eolian sand dunes, sand layers and loess horizons in the sedimentary sequence of deserts are generally regarded as the indicators of winter monsoon-predominated climate. The prevalent wind direction of that time may be identified according to the lee slope of dunes and the occurrence of bedding. The buried and relic paleosols in the eolian dunes result from a grass-growing pedogenic process, reflecting the reversal of desertization process and transformation from active sand dunes to stable, semi-stable ones, indicating the landward movement and the presence of summer monsoon with relatively rich moisture. Therefore, the historical change of summer monsoon can be reconstructed based on the alternations of sedimentary sequence between eolian sands and paleosol in the desert area, between eolian sands, loess and paleosol in the transitional zone from desert to loess area[8]. For instance, based on ^{14}C dating of organic material within paleosols, five horizons of paleosols have been identified in sedimentary sections of the eastern desert area, with their ages around 25,000, 9000, 7000, 6000 and 5000 a B.P., respectively. These horizons recorded an intensified summer monsoon at those times[9].

3. *Lakes*

Daihai Lake (112°40′E, 40°40′N), an interior lake, is located in the transitional zone between semi-humid and semi-arid areas. According to the lake terraces, lacustrine deposits, biological and geochemical analysis as well as ^{210}Pb dating, the lowest lake level in the Last Glacial Maximum (LGM) was found to occur at about 14,000 a B.P., coincident with the present stand (Fig. 3), whereas the high level lasted from 8500 to 4500 a B.P., corresponding to the Holocene Climatic Optimum. The lake area then was 4 times as large as the present one. At about 10,500 a B.P., an abrupt drop of the water level took place, followed by a rapid rise, which possibly corresponded to the record of Younger Dryas[10]. The water level changes of Daihai Lake have presented a historical picture of rise and decline of summer monsoon during the last 25,000 years.

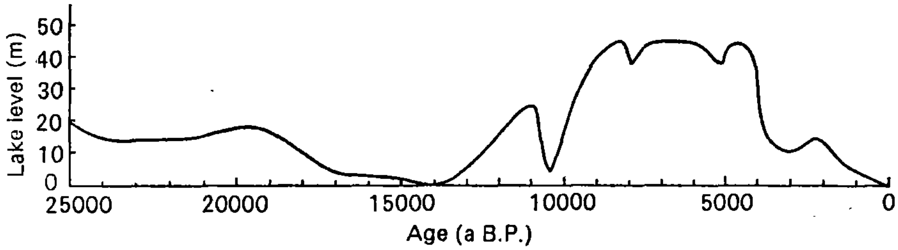

Fig. 3. The water table changes of Daihai Lake, Inner Mongolia during the last 25,000 years.

In the same monsoon area, lake levels in different temperature zones and humidity zones have shown a distinctive synchronism in their fluctuation on the time scale of 10^4 years. However, on the scale of 10^3 years still existed a notable difference. For example, after 4500 a B.P., when Daihai Lake rapidly decreased its areal extent under the New Glacial cold-dry climate, the big lakes in the mid-lower Changjiang River basin, such as the Poyang Lake, Dongting Lake and Taihu Lake, were under the forming and expansion[11], which was possibly attributed to the southward shift of the southeast monsoon front. Between different monsoon areas, climatic fluctuation on the time scale of 10^4 years seems to show a striking difference. For instance, during the Last Glaciation the water level was lower in Daihai Lake, the southeast monsoon area, while it was higher in both the Dianchi Lake and the West Lake, Yunnan. Worth noting is that the Qinghai Lake, on which the southwest and southeast monsoons exerted dual effects, did not show any indication of low water level during 5000—4000 a B.P. Hence, no single model is acceptable to represent the different combinations of cold, warm, dry and humid climates.

4. *Snowlines and Treelines*

The modern topographic and climatic snowlines are determined in their spatial distribution by the water and heat balance of solid precipitation and summer (July) temperature[12]. Its spatial configuration, inconsistent with the law of the global latitudinal zonality, was mainly attributed to the monsoon climate and the climatic effect of Qinghai-Xizang Plateau. The forests near treeline are primarily composed of the cold-resistant coniferous species as *Picea*, *Abies* and *Larix*. *Tsuga* often grows in the frigid mountainous coniferous forest south of the Qinling Mountains, whereas it is absent in the forest north of the mountains. This difference is attributed to a distinct decrease of annual temperature range from north to south. The spatial location of treeline, while requiring an annual precipitation more than 400—500 mm, is also strictly controlled by the annual range of temperature and growing season temperature[13]. For a given location in monsoon areas, the fluctuation of annual temperature range reflected by the historical changes of flora in different periods also indicates the climatic difference between the summer monsoon area and the winter monsoon area.

By comparing the snowline distribution of the Last Glaciation, marked by paleo-cirques, with that of climatic snowline, it is found that the snowline has declined about 900—1300 m in the southeast monsoon area, 800—1200 m in the southwest monsoon area, 700—1200 m within the transitional zone between the formers, 300—800 m on the southern fringe of the Qinghai-Xizang Plateau and only 200—400 m or less in its interior part. As for the decline of treeline, it may be inferred from the assemblage of coniferous forest in the frigid mountainous zone. It follows that the treeline declined about 2000 m during 60,000—47,000 a B.P. near Riyue Tan, Taiwan[14], more than 1200 m during 30,000—20,000 a B.P. in Northeast China[15], more than 2300 m in the Weihe River Valley[16] and about 1200 m during 20,000—15,000 a B.P. in Weining, Guizhou, the transitional zone of the two monsoon areas[17]. In the Jianchuan Basin of western Yunnan Province, belonging to the southwest monsoon area, *Picea-Abies* forest still is distributed in the early Postglacial. It is therefore inferred that in LGM the treeline had declined about 1700 m. These data suggest that the decline of treelines, though existed considerable difference, all exceeds that of snowlines during the Last Glaciation. In the interstadial of the Last Glaciation, when *Picea* and *Abies* flora near the treeline north of the Qinling Mountains and south of the Yanshan Mountains descended to the level of piedmont and plains, the components adapted to a temperate climate as *Tsuga* in the flora indicate a decreased range of annual temperature. Due to a remarkable shrinkage of the summer monsoon in the glacial period of eastern

China, the drop of July temperature was greater than that of January temperature, resulting in a decrease of annual temperature range. Therefore, the continentality became smaller in the glacial period, which should be a character of the monsoon climate with a pronounced winter monsoon effect on the environment.

5. *Phenomena of Continental Shelf Desertization*

During LGM, when a large amplitude drop of sea level resulted in an eastward marine regression, the present continental shelf of eastern China became a part of the Asian continent, a source area with large amounts of sand and silt within the range of wind-drift process. The eolian sand deposits, as thick as 8 m and about 75 m high in elevation, developed in the north and south slopes of Chengsi, Zhoushan Archipelago in the continental shelf area. On the Shidao Island, Xisha Archipelago developed eolian limestone[18]. Meanwhile, paleo-eolian sand dunes were found in many places such as the coastal areas of Fujian and Shandong Peninsula as well as Changli in the northwest of Bohai Bay. The shallow stratigraphic profiles on the shelf detected by the geophysical method have revealed the desertizational deposits and the buried dunes formed in LGM. An example is the profile near the "Ancient Wind Channel" of Yellow Sea Trough (Fig. 4). These facts indicate that, during the cold-dry LGM, the desertization phenomena occurred in the continental shelf area of East China. Hence, the eolian loess on its coastal areas and islands, Miaodao Archipelago, for example, is perhaps a derivative of wind-drift sand action. The above evidence indicates the shrinkage of summer monsoons and a certain decrease of winter monsoon strength during LGM. At the same time, it suggests a notable effect of winter monsoon on the environment.

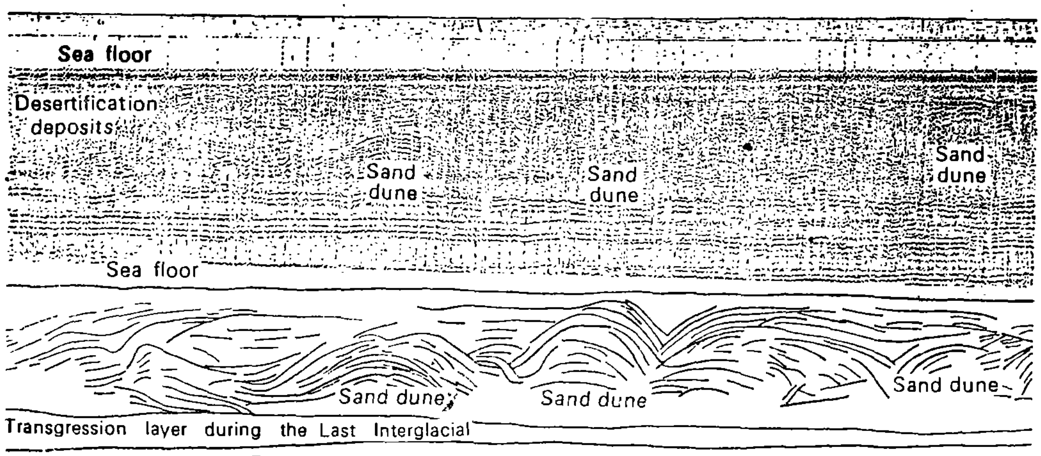

Fig. 4. Shallow stratigraphic profile and the interpreted buried dunes near the "Ancient Wind Channel" of Yellow Sea Trough.

IV. Biological Records

1. *Vegetation*

In the northwestern arid area, to which the summer monsoon is hardly accessible, the pollen spectrum from surface soil shows that the xerophyte components are absolutely predominant, especially abundant being those as *Artemisia* and Chenopodiaceae, followed by ***Ephedra***, Gramineae, *Nitraria*, *Tamarix* and Cyperaceae. In the humid area considerably influenced by the summer monsoon also dominates the component of arbor pollen. For example, it is as high as 70—90% under the forest of the Changbai Mountain where the herbal pollen is complicated in types with many hydrophytes and semihydrophytes.

During 40,000—24,000 a B.P., steppe vegetation with sparse trees of *Tsuga*, *Picea* and *Abies* developed in the vast expanse of area north of the Changjiang River[16,19], while the evergreen broad-leaf forest containing deciduous broad-leaved trees was distributed in areas south of the Nanling Mountains. The temperate species *Tsuga* and cold species *Picea-Abies* coexisted in the glacial flora north of the Huanghe (Yellow) River, indicating a decreased annual range of air temperature. In LGM (20,000—15,000 a B.P.), the vegetational zones shifted southeastwards on a large spatial scale, resulting in a replacement of needle-broad-leaved mixed forest by evergreen forest, reflecting a weak activity of summer monsoon. To the period 9000—5000 a B.P., the summer monsoon was reinforced again, when the deserts retreated to the area west of the Qinghai Lake, while temperate deciduous broad-leaved forest occupied the Northeast and North China plains. The subtropical components *Myrica* and *Ceratoperis* also existed in the plain forest, reflecting an increase of summer temperature and of annual temperature range.

2. *Mammals*

Species like *Hyaena*, *Acinonyx*, *Tapirus Rhinoceros*, *Elephas*, *Paguma*, *Hapalomys* and *Chiropodomys*, presently living in the southwest monsoon area as members of India-Malaysian Fauna, had once held a very important position in the mid-Pleistocene *Ailuropoda* (Melanoleuca Milne-Wdwards)-*Stegodan* Fauna in the South China and Southwest China, suggesting that these areas possess certain climatic characteristics similar to those of the modern southwest monsoon area. Some cold-dry-enduring rodents now belonging to the Paleo-Northern Kingdom covering Eurasia and other lands north of Tropic of Cancer, as *Cricetulus*, *Clenthrionomys* and *Microtus*, may have extended southwards into the area of subtropical fauna in the glacial periods when the summer monsoon shrank, reflecting a strengthened winter monsoon effect.

In the last interglacial or interstadial, *Elephas* lived not only in Zhejiang, south of the Changjiang River[20], but also ever extended to Qianxian, Shanxi[21], Hetai, Inner Mongolia[22], and Zhoukoudian, Beijing[23], indicating that the northwestward movement of summer monsoon carried more precipitation to these areas. When the warm climate of Holocene approached, *Elephas* again appeared in Zhoukoudian[24] and lasted to the Shang Dynasty (before 1100 B.C.)[25], which also indicates the strengthening of summer monsoon. In LGM, however, no evidence is available for their existence. On the contrary, large cold-enduring fossils of *Mammuthus*, a kind of herbivorous mammal, was found in the deposits developed during 30,000—20,000 a B.P. and 15,000—11,000 a B.P., when *Mammuthus* migrated southwards and eastwards to the Huanghe River basin and the continental shelf area. However, this mammal was not found in sediments around 18,000 a B.P., suggesting that *Mammuthus*, while adapted to a cold climate with pronounced winter monsoon environmental effect, also needed a proper amount of precipitation brought by summer monsoon so as to get enough quantity of plant foods. After 1000 a B.P., *Mammuthus* had to retreat northwards and finally became extinct within the territory of China due to the approaching postglacial climate and the great protrusion of strong summer monsoon into the inland.

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