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THE SAND WEDGE AND MIRABILITE OF THE LAST ICE AGE AND THEIR PALEOCLIMATIC SIGNIFICANCE IN HEXI CORRIDOR

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ABSTRACT: The sand wedges in Hexi Corridor occur in the alluvial gravel stratum of bajada and high terraces. The ^{14}C ages of eolian sand in sand wedges prove that they formed during the Last Ice Age, with the mean annual air temperature about – 5.6℃. The common ^{14}C and AMS ^{14}C dating ages of terrestrial branch relicts in Huahai clay-mirabilite interlayer are (11 600 ± 280) a B. P. and (1118 ± 54) a B. P. respectively, proving that the mirabilite formed at the cold episode of the Last Glacial Maximum (LGM) and Younger Dryers (YD) in Huahai Lake. It is pointed out that the mean annual air temperature in Hexi Corridor during LGM was about – 3℃ – – 7℃, 11℃ – 15℃ lower than that of present, and that during YD was about 0℃ – 2℃, 6℃ – 8℃ lower than at present. This decreasing temperature values are generally coincident with those inferred by pollen, sand wedge and ice core in the northern China, and also with the research on temperature-falling amplitude of middle and high latitude on the Northern Hemisphere recently.

KEY WORDS: sand wedge; Last Ice Age; Hexi Corridor; paleoclimate

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Sand wedge is formed under the conditions of cold climate, and is an important basis for reconstructing paleoenvironment (LI *et al.*, 1990; WANG, 1991). It has been reported constantly over the last 20 years in the Qinghai-Xizang (Tibet) Plateau (GUO, 1979; CUI, 1983; XU *et al.*, 1984; LIANG *et al.*,, 1984; PAN *et al.*, 199) and North China (YANG *et al.*, 1983; DONG *et al.*, 1985) and Northeast China (GUO *et al.*, 1981). We also found fossil sand wedge groups formed in the end of the Late Pleistocene (Fig. 1) recently in Jiuquan, Anxi, Dunhuang etc of Hexi Corridor. Hexi Corridor is located in the transition zone of monsoon-westerly, and in an important position for its ecological fragility and climatic sensitivity in past global change research. The first found of sand wedges in this region provides the immediate proof for distributing the permafrost of the Late Pleistocene in northern China, also presents significant basic data for reconstructing paleoclimate in the transition zone of monsoon-westerly. Now, the preliminary research results are reported as follows.

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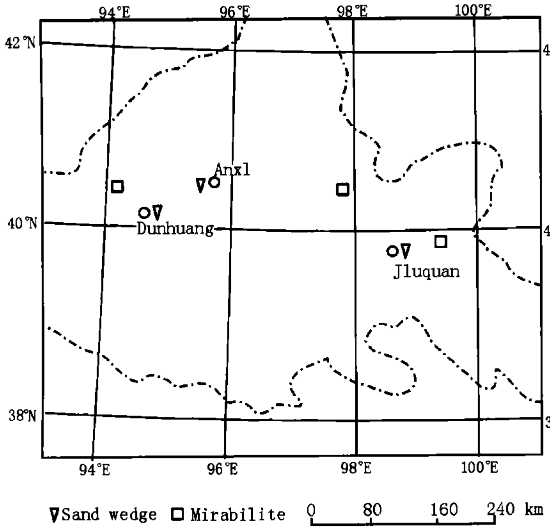

Fig. 1 Distribution of sand wedges in Hexi Corridor during the Last Ice Age

1 CHARACTERISTICS AND FORMING ERA OF SAND WEDGES

When making research on sand wedge, the distinctions between sand wedge and other fissures (e. g. sun crack, ground crack, gypsum wedge etc.) are often based on the lithology and tectonics of country rock. The sand wedges in Hexi Corridor mainly developed within the gravel stratum of bajada and piedmont alluvial plains. Based on the field incomplete statistics, the top-width of them is usually 12 – 30cm, the depth 17 – 70cm, and the mean ratio of width to depth is 1 : 1. 61. The morphometric appears bottom-cuspated wedge which is both deep and narrow. The wedge bottom is mostly single cusp; that having more than one cusp is very seldom. Eolian sand is filled in all wedge body, and the highest in granulometric composition of the two sample groups is fine sand, the particle size of which is 0. 25 – 0. 125mm; the second is very fine sand of 0. 125 – 0. 063mm; median diameter is 0. 166mm; the physical clay, less than 0. 002mm, is not up to 3%, The top of the sand-wedge groups is overlaid by the thin layer of grail or loess of the Holocene, the thickness of which is about 10 – 20cm. The fine sand filled in wedges is at the bottom and near the wall of the wedges with sporadically clipped little gravel, the diameter of which is 2 – 3cm, and there is compressional deformation formed from frost-heave in wedge wall.

The wedge body above mentioned only appears in part of the phase, which means it had not penetrated the whole stratum or made the same stratum similarly deformed. It is impossible apparently for the wedge body to be the crack formed by tectonic swell or earthquake. Meanwhile, the wedge body is mostly situated in relatively flat area of high terrace or on the beam, and in particular, there is no hydrogenic stratification or tectonics in the filled matter. Therefore, it is clearly different from the morphotypes of gully and groove filled with eolian sand or loess after temporary flows erode slope. Besides, its country rock is normal calcite cementation, so it is different from the gypsum wedge in the Gobi of the Taklimakan Desert's outer margin. Based on above analysis, we presume that the wedge body founded in Hexi Corridor in recent years is the result of deformation made by long-term seasonal freeze-thaw procession on the surface of tundra. Now the seasonal frozen depth of plain areas in Hexi Corridor is 86 – 144cm, but the forming wedge-veins is not found, and miniature polygonal mesh is found only at altitudes above 2800m in the Qilian Mountains. Hence, the sand wedges in gravel stratum in Hexi Corridor can form only in permafrost largely different from the modern seasonal tundra. Research has shown that since the Late Pleistocene the permafrost in the Northern Hemisphere has advanced apparently many times, of which the permafrost in the end of the Late Pleistocene extended to about 36°N (ZHANG, 1993) in north of our country, 10 latitudes souther than the south boundary of modern permafrost. However, the geographical latitude of Hexi Corridor lies in 37° – 40° N, which just settles in the permafrost areas of the Late Pleistocene, so it is utterly possible to develop sand wedge here.

The observations on profile show that most of the sand wedges slightly appear shallow red brown in weathering state and have calcite cementation indicating weak eluviations after its formation. The content of $CaCO_3$ in the wedge-body silty sand collected from Guazhou town, Anxi, is 16. 4%, and the ^{14}C ages of the eluvial $CaCO_3$ through test are (22 500 ± 190) and (19100 ± 125) a B. P. (Fig. 2), which correspond to the Last Ice Age. As much as what we have seen in field, the sand wedges in north of Huaimao town, Jiuquan, are distributed in the trailing edge of terrace T_2 or the gravel stratum of terrace T_3 of Beida River, and the ^{14}C age of the clayey in the upper sediments of terrace T_2 is less than 12 000a B. P. (CAO, 1989), which indirectly proves that the age of the gravel stratum including sand wedges should belong to the end of the Late Pleistocene. While the sand wedges in Guazhou town, Anxi, are distributed in alluvial gravel stratum that is contemporaneous difference facies with alluvia of terrace T_2 in Shule River, and its age is also the Late Pleistocene (WANG, 1989) Therefore, the evidences of ^{14}C ages, stratigraphy and geomorphology all illuminate that the sand wedges in this region were formed in the Last Ice Age, which is in agreement with the age forming paleo-eolian sands and fossil ice margins founded by Dong Guangrong *et al.* (DONG *et al.*, 1985) in nearby the Erdos Plateau and its southeast loess-hill areas, and is also synchronous with paleo-eolian sand of the Last Pleistocene founded in Lanzhou Area by Chen Fahu *et al.* (CHEN *et al.*, 1990).

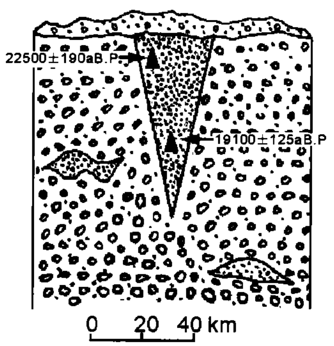

Fig. 2 The section of sand wedge in Guazhou town, Anxi

2 RECONSTRUCTION OF PALEOCLIMATE DURING LAST ICE AGE

The formation of sand wedge which acts as the product of permafrost, depends on temperature, humidity, earthiness and surficial conditions (e. g. perpetual snow, vegetation etc.), of which temperature is in leading role, that is its cooled degree is enough to lead to the dehiscence of the earth's surface. At present, there are distributions of fossil sand wedges in Siberia, Antarctic dry-valley and the Xizang (Tibet) Plateau. Among them the area of modern permafrost in the Xizang Plateau is about 160km^2 (SHI *et al.*, 1997) and the peripheral limit of the distributions of sand wedges is concordant with the area with mean annual air temperature $-2 - -3$°C (XU *et al.*, 1984) Romanovskiy (ROMANOVSKY, 1978) not only noticed the difference in temperature in the formation of different wedge structures (e. g. the mean ground temperature required by the forming of sand wedge is at least $-3 - -5$°C, while that of ice wedge is $-5 - -7$°C), he also realized the difference in geothermal conditions of differently lithologic country-rock forming polygonal wedge-body. The sand wedges we have found in Hexi Corridor all occurred in gravel stratum; considering that this region was probably near the southern margin of continuous permafrost at the Last Ice Age, -3°C that is in $-3 - -5$°C, the mean annual ground temperature required to develop sand wedge in gravel stratum, can be taken as the mean annual ground temperature in this region during the Last Ice Age, and its corresponding mean annual air temperature was about -5.6°C. Based on these, the temperature difference between the Last Ice Age and present can be predicated to be 12.9 – 14.9°C (Table 1). Because of the little tectonic rise over the late 2 millions yr. in Hexi Corridor, it is unnecessary to take into account the expurgations of height in the falling value of air temperature during the Last Ice Age in Table 1.

Those of which can be used as proof is that many mirabilite sedimentary layers came into being in many lakes of Hexi Corridor when sand wedges were developing in this region during the Last Ice Age. Based on our exploratory research in Suwushan Yanchi, Minqin, the thickness of the mirabilite layer in this area is about 1.5m, and its buried depth is 1.38 – 1.73m or so. The ^{14}C age of its upper lacustrine deposits is 7760 ± 150a B. P. in depth of 0.67m, 9520 ± 170 a B. P. in depth of 1.17m, hence it indicates that the mirabilite

Table 1 The decreasing value of the temperature in the formation of sand wedges at the Last Ice Age as compared to the present in Hexi Corridor

The district of distribution	Elevation (m)	Country rock	Weather-station nearby and elevation (m)	Mean annual air temperature (°C)	Mean annual ground temperature (°C)	The temperature lower than that of present during Last Ice Age (°C)
Huaimao town, Jiuquan	1424	gravel statum	Jiuquan(1477.2)	7.3	9.5	12.9
Guazhou town, Anxi	1167	gravel statum	Anxi (1170. 8)	8.8	11.3	14.4
Wudun town, Dunhuang	1120	gravel statum	Dunhuang(1138.7)	9.3	12.3	14.9
Mengjiaqiao town, Dunhuang	1097	gravel statum	Dunhuang(1138.7)	9.3	2.2	14.9

layer is the deposits in the end of the Late Pleistocene. While the mirabilite in Huahai, Yumen, shaped in the cold episode of the Last Glacial Maximum(LGM) and Younger Dryes (YD). There are branch relicts in clay interlayer in the upper part of mirabilite layer which corresponds to the warm period of the Bolling-Allerod interglacial stage; its normal ^{14}C age is 11 600 ± 280 a B. P. and its AMS ^{14}C age is 11 181 ± 54 a B. P.. In addition, the sedimentary era of mirabilite layer in Gaotai Yanchi and Halanuo'er, Dunhuang, is also the Last Ice Age. Mirabilite is the marker of cold-dry environment; the lower the lake water's temperature is, the easier it crystallizes. ZHENG Mian-ping *et al.* (1998) pointed out that stable mirabilite layer occurs in arid or semiarid climate regions of the frigid zone、subpolar zone and midtemperate zone, the mean air temperature in which it occurs in January is −30 − −16°C or even less , in July 8 − 18°C, the mean annual air temperature is −3 − −7°C; the unstable mirabilite layer forms when the mean annual air temperature is 0 − 2°C and there are more than 7 months a year in which the mean monthly temperature is less than and equal to 0°C. The observations show that the thickness of the mirabilite layer formed in Huahai during LGM is stable and continuous, and its water temperature should correspond to the temperature that the mean annual air temperature is −3 − −7°C; the upper part of the mirabilite layer formed in YD appears solution structure that is perfectly round, ore formation is unstable, and its corresponding mean annual air temperature is 0 − 2°C. Now, the annual precipitation in Huahai Basin is about 56mm, the mean annual air temperature is 8°C, and there is no modern mirabilite layer. It can be concluded through the above two contrast that the temperature-falling amplitude in this region is 11 − 15°C during LGM in comparison with that of today, 6 − 8°C during YD, which is basically consistent with the estimation through the sand wedges. The modern sand wedges in Antarctic appear in the area with annual precipitation of about 160mm. The annual precipitation in the Xizang Plateau where soil wedges are developing is 100 − 200mm, and now, it is also 100 − 200mm (ZHOU *et al.*, 1982) in Alaska where there are ice wedges developed. In comparison, the distributions of sand wedges in Siberia have more annual precipitation which is about 300 − 400mm, and it is up to 400 − 500 mm in modern permafrost of Northeast Plain of our country. If only considering from the precipitation developing fossil sand wedges that is its low limit of precipitation is 100 − 200mm, the annual precipitation of the Last Ice Age in Hexi Corridor adds to about 100mm as compared with the present. This result coincides with the conclusion drawn by YANG Xiao-ping(CHEN *et al.*, 2000) about the relative moist during the Last Ice Age in the Badanjilin Desert and also with the simmulated result of climate at 21ka B. P. in China by CHEN Xing *et al.* However, whether the conclusion is definitive needs to further test(SHI, 2000).

3 RESULTS AND DISCUSSIONS

The found of the sand wedges and mirabilites formed in the Last Ice Age in Hexi Corridor undoubtedly provides immediate proof for the determination of the climatic rate-of-change and the southern margin of permafrost during the Late Quaternary in northwest of our country. The paleotemperature-falling value reconstructed in terms of them is approximate to the reported temperature-falling value (Table 2) of the same period in most regions of our country's north, and also coincide with the conclusion that the mean annual temperature is 11 – 15℃ lower than at present when sand wedges were forming during the Wisconsin Glacial Epoch in intermountain basin of Wyoming, America(YU *et al.*, 2000) As for the disparity in the estimated value of temperature-falling amplitude in different sites, it mainly should be the result of different computed method and time scale. For example, the falling value of air temperature predicated by phytolith during LGM in Weinan region is less than that in other sites, and the main reason is that the type of the plant silicates reflecting cold climatic environment is relative small, difficult to preserve, which lead to the more absence of information, so the predicated difference is caused . In fact, the estimation of the temperature-falling amplitude during the global ice ages is mostly much larger than before. For example, The air temperature during LGM, which was predicated from N isotope and CH_4 in the air bubbles of the Greenland ice bore by K. M. CUFFEY *et al.*, (YANG, 2000) is 20℃ lower than at present, and that of YD is 14 ± 3℃ lower than that of present. After the measurement of the O isotope composition in the paleogroundwater of Lake Agassiz` s south thick-bedded clay during the Last Ice Age, V. H. Remenda *et al.* came to the conclusion that the temperature difference in this region located in 48° – 45°N between the Last Ice Age and present is up to 10℃.

Table 2 The annual temperature lower than at present in Northern China during the Last Ice Age

District	Time	Temperature-falling amplitude (℃)	Estimated basis	Data origin
Beijing	LGM	8 – 13.6	pollen and fossil ice margin	AN Zhi-sheng *et al.* (1990)
Datong basin	<26 kaB. P.	14 – 15	fossil sand wedge	YANG Jing-chun *et al.* (1983)
Northwestern Shanxi	27 – 10 kaB. P.	9. 6 – 15. 5	fossil sand wedge	SU Zhi-zhu *et al.* (1997)
Weinan	27 – 18 kaB. P.	10 – 12	pollen	SUN Xiang-jun(1989)
Weinan	23 – 14 kaB. P.	7 – 9	vegetation silicate	WU Nai-qin(1994)
Erdos Plateau	< 25 kaB. P.	12 – 16	fossil sand wedge	DONG Guang-rong *et al.* (1985)
Hexi Corridor	LGM and YD	13 – 15 and 6 – 8	fossil sand wedge and mirabilite	this paper
Xizang Plateau	LGM	9 – 11	Guliya ice core	LIU Dong-sheng *et al.* (1999)
Xizang Plateau	LGM	6 – 9	pollen , sand wedge etc	SHI Ya-feng(1997)
Qaidam basin	21 – 15 kaB. P.	6 – 7	mineral inclusion isotope	ZHANG Bao-zhen *et al.* (1995)
WesternKunlun Mountains	LGM and YD	12	Guliya ice core	YAO Tan-dong (1999)

The Ice Age was just the most rigorous period of the Northern Hemisphere in climate since the Late Pleistocene, the temperature-falling amplitude being so big that it is inevitable to lead to the general atmosphere circulation situation different from today's. The results (ZHANG *et al.*, 1995; YAO, 1999) of the Global General Atmosphere Circulation Model simulating the paleoclimate of 21 ka B. P. (lunar calendar, corresponding to LGM) showed that the ice stream on the western Eurasia of the Northern Hemisphere during LGM was developing more strongly on high latitude, which forced westerly moving towards south; the permafrost on the high latitude of the eastern Eurasia was both deep and thick with tundra spreading to south, which resulted in the stronger westerly. Meanwhile, the East Asian summer monsoon retreated; the westerly could not only move towards south but also be strong all over the year. This circulation situations resulted in the differences both in precipitation and temperature between the west and east of China(LIU *et al.*, 1995) which probably provided the tundra-desert environment with low temperature and increasing effective precipitation in favor of the formation of sand wedges in this region.

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