Climatic variations in the past 140 ka recorded in core RM, east Qinghai-Xizang Plateau *

WU Jinglu (吴敬禄), WANG Sumin (王苏民), PAN Hongxi (潘红玺) and XIA Weilan (夏威岚)

(Nanjiang Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China)

Received October 28, 1996

Abstract The sequences of climatic evolution are reconstructed by the analyses of $\delta^{13}C$ and $\delta^{18}O$ of carbonate from core RM in the Zoigê Basin since 140 kaB. P. During the Last Glaciation there existed at least seven warm climatic fluctuations and five cold events correlated with the records of ice core and deep sea, and during the preceding last interglacial period there were two cold climatic variations coinciding with the record of ice core GRIP. These results depict climatic instability in east Qinghai-Xizang Plateau over the last interglacial period. In addition, the environmental proxies of the carbonate content and pigments indicate the similar results to the stable isotope record from core RM.

Keywords: **Zoigê Basin, oxygen isotope, climatic variation.**

The hole RM, the deepest fully obtained core in the Qinghai-Xizang Plateau, is situated in the depocenter of the Zoigê Basin (33°57′N; 102°21′E) in the northeastern Qinghai-Xizang Plateau with a depth of 310.46 m. From ^{14}C dating and paleomagnetic stratigraphic study, the core RM reaches 900 kaB. P. Here we only discuss preferably the paleoclimatic record by $\delta^{13}C$ and $\delta^{18}O$ of authicarbonate from core RM in the past 140 ka.

1 Experimental methods

The carbonate consists of calcite by the microscope examination1), and there is obvious difference in the grain size between terrestrial detrial and authigenic carbonates. Thus the samples were first proceeded by the mechanical sorting method to remove the detriatal carbonates. Then, the pretreated samples were dissolved in 100% H_3PO_4 at 25℃ for 6—8 h. The released CO_2 was separated and purified by liquid nitrogen, and then $\delta^{18}O$ and $\delta^{13}C$ were measured in a Finigen Model-251 mass-spectrometer expressed in the conventional δ‰ with the standard PDB. The analytical precision of the $\delta^{18}O$ and $\delta^{13}C$ for carbonate samples is ±0.2‰ and ±0.1‰ respectively.

2 Experimental results and paleoclimatic analyses

2.1 The chronological sequence establishment

Based on the consolidation model of lake sediment[1], together with ^{14}C dating and paleomagnetic stratigraphy (table 1), the ages of each stage and responsible sample depth have been

* Project supported by the Chinese Climbing Project (85-029-02-01).

1) Wang Yunfei, Features of mineral and climate significant in core RM of Zoigê Basin over the past 150 ka, in *Proceedings of Qinghai-Xizang Plateau* 1996, in the press.

obtained (figure 1).

Table 1 Dating ages of various layers in core RM

Depth/m	Ages/aB.P.	Dating methods
2.6	3 324 ± 145	^{14}C
2.8	3 428 ± 124	^{14}C
4.1	6 167 ± 155	^{14}C
6.3	21 600 ± 1 500	^{14}C
8.2	33 140 ± 2 350	^{14}C
25	110 000(Blake Event)	paleomagnetic

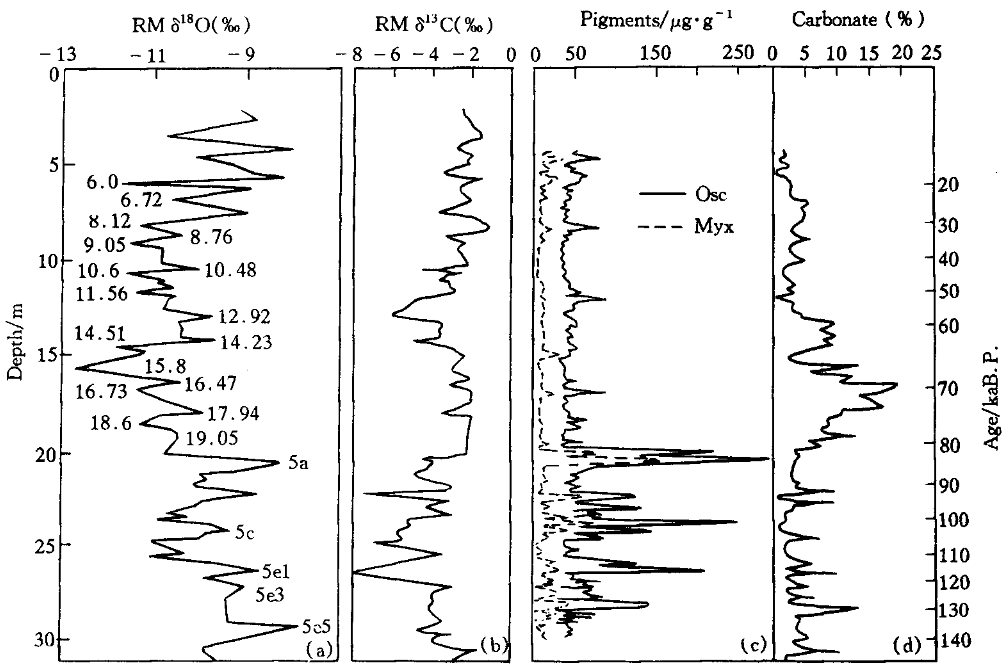

Fig. 1. The curves of $\delta^{18}O$ ((a) numbers represent responsible depth) and $\delta^{13}C$ (b) of authicarbonate, carbonate content (d) and pigments (OSC, MYX)(c) from core RM.

2.2 Experimental results

In the interval of 0—30 m in the core RM, the $\delta^{18}O$ and $\delta^{13}C$ of authicarbonate were analyzed for 247 samples at 10-cm interval. The average resolution is about 500 a/sample (some samples with few carbonate content fail to be determined at the top of the core). Correspondingly, the pigments and carbonate contents were synchronously determined to compare each other (fig. 1). Fig. 1 shows that $\delta^{18}O$ values of carbonate in the past 140 ka changed from −7.7‰ to −12.8‰ with the maximum magnitude of 5‰, and the subordinate fluctuations are very obvious. All these basically reflect the characteristics of paleotemperature change. The general trend of the curve of $\delta^{18}O$ is consistent with the carbon isotope, the carbonate contents, both pigments of oscillaxanthin (OSC) and myxoxanthophyll (MYX), showing that the main fluctuations of these curves are controlled by climate factors, but there exist some differences in details because of the response ways and sensible degrees of the proxies for climate variations (figure 1).

2.3 $\delta^{18}O$, $\delta^{13}C$ composition and climatic analyses

The oxygen isotope of lake carbonate is an ideal proxy for paleotemperature[2,3]. But in some conditions, the isotope composition of lake water in which the carbonate was deposited has an evident effect on it, for instance, when the lake water is enriched in heavy oxygen isotope due to intensive evaporation, consequently, the $\delta^{18}O$ value of carbonate happens to change. However, the information of the paleotemperature contained by oxygen isotope proxy can still be qualitatively obtained referring to the analyses of the carbon isotope of carbonate.

The changes of the ^{13}C values in lake carbonate are mainly governed by the hardness of lake water, and it is enriched in heavy carbon isotope with respect to the high hardness of lake water[4]. When the lake is evolving at the stage, in which only carbonate is deposited, the variations in the hardness of lake water indicate the degree of the condensation of water body. Therefore, the high salinity is in response to the high values of carbon isotope and has an advantage of enrichment of the heavy oxygen. The changes in $\delta^{18}O$ are thus mainly controlled by water temperature responsibly if the $\delta^{18}O$ values correlate negatively with $\delta^{13}C$, namely, the higher $\delta^{18}O$ value responding to Thermochron, on the contrary, the lower $\delta^{18}O$ value to Kryochron. In this study, there is a negative correlation between $\delta^{18}O$ and $\delta^{13}C$ of authicarbonate in core RM in the past 140 ka, showing that the change of $\delta^{18}O$ values is mainly relative to the water temperature. Moreover, in response to the sections of high values of oxygen isotope, the values of carbon isotope fluctuate intensively, indicating that the factors controlling the carbon isotope are more complicated in the warm periods. About 30 kaB.P., the Zoigê paleolake was captured by the Yellow River and lacustrine sediment was gradually replaced by fluvial sediments[5]. After 20 kaB.P. it was fully occupied by fluvial sediment. With respect to these, the change in $\delta^{18}O$ and $\delta^{13}C$ of authicarbonate became identical, suggesting the transformation of water environment.

2.4 Characteristics of climatic evolution in the past 140 ka

According to the changes of the paleoclimatic proxies, several evolutionary stages in the past 140 ka may be classified as:

Unit 1, 31—20 m (140—80 kaB.P.). The sediments mainly consist of muddy silts containing organic remains and shell, with horizontal and wavy bedding. High $\delta^{18}O$ with an average of $-9.8‰$ and low $\delta^{13}C$ with the average of $-4.52‰$ indicate a warm climate. But there are internally obvious subordinate fluctuations of $\delta^{18}O$ and $\delta^{13}C$, reflecting an unstable climate. Low carbonate content, high pigments and lower $\delta^{13}C$ show the stronger exchange of CO_2 between lake water and atmosphere, abundant biomass and intensive organic geochemical process. Therefore, the stage has an optimum heating and moisture association representing the warm and humid climate. According to the dating age and characters of environment criteria, this period corresponds to deep-sea oxygen isotope stage 5, among which substage 5a has a high $\delta^{18}O$, low $\delta^{13}C$, and the peak values of MYX, OSC often are interpreted as being proportional to the primary productivity of the lake controlled by water temperature, lightness and nutrient state[6]. Thus this substage was of the best moisture and heat conditions. And during substages 5b and 5d, the low $\delta^{18}O$ suggests the cold or cool conditions, while 5c represents a relatively weak warm period. Especially, during substage 5e, the highest value of $\delta^{18}O$ reflects the warmest climate period, in which the curves of $\delta^{18}O$ have two dales, representing two rapid cooling events. Correspondingly, the climate proxies, such as pigments (OSC, MYX), carbonate content and $\delta^{13}C$, display the similar fluctuation to the $\delta^{18}O$ record.

Unit 2, 20—14 m(80—60 kaB.P.). The gray muddy silts are predominant, alternating with silty mud, occasionally siderite nodules and patches. The lowest $\delta^{18}O$(− 11.8‰) and highest $\delta^{13}C$ of the section suggest the cold climate and the peak content of carbonate reflects high hardness of the lake water, implying a cold and dry climatic period, in which there exist four positive fluctuations of $\delta^{18}O$ at 76 kaB.P.(19.05 m), 73 kaB.P.(17.94 m), 68 kaB.P.(16.47 m), 61 kaB.P.(14.23 m) and five negative ones at 79.8 kaB.P.(19.9 m), 74.5 kaB.P.(18.6 m), 69 kaB.P.(16.73 m), 66 kaB.P.(15.8 m), 60.5 kaB.P.(14.51 m) respectively. The maximum amplitude of $\delta^{18}O$ variation is over 3‰(66 kaB.P.). Appropriately the contents of carbonate and pigments manifest evident fluctuations under the background of the high and low value respectively.

Unit 3, 14—8 m (60—30 kaB.P.). The sediments mainly consist of muddy silt, silt, silty mud with thin peat layers and fossil gastropod shell. The value of $\delta^{18}O$ has an increasing trend, reflecting that the temperature began to rise. The low content of carbonate, low $\delta^{13}C$ and higher organic matter content show a temperate and wet climatic condition. During the stage there is a dramatic oscillation of $\delta^{18}O$ at 55 kaB.P.(12.92 m), 43 kaB.P.(10.48 m), 35 kaB.P.(8.76 m), 48 kaB.P.(11.56 m), 45 kaB.P.(10.6 m), 38 kaB.P.(9.05 m), 33 kaB.P.(8.12 m) respectively.

Unit 4, 8—6 m(30—20 kaB.P.). The sediment is largely composed of grey silts, with a lot of organic bands, constituting centimeter-millimeter horizontal and oblique beddings. $\delta^{18}O$ value is obviously increasing, suggesting a warmer climate in this period. $\delta^{13}C$ keeps a negative correlation to $\delta^{18}O$ but the general trend rises, indicating a transitional water environment from lacustrine to fluvial. The paleolake Zoigê disappears gradually. Similarly, the obvious trough value of $\delta^{18}O$ occurs at 25 kaB.P.(6.72 m) and 20 kaB.P.(6.05 m).

Unit 5, 6—0m(20—1kaB.P.). The sediments are mainly yellow, grayish yellow thick-layered sands with some lenticular bedding, a scour surface and disturbing structure at the bottom, showing that the large filling sediments were carried by rivers. Because of the dominate fluvial sediments, $\delta^{18}O$ and $\delta^{13}C$ of carbonate were positively correlated with each other. The information about paleoclimate failed to be drawn clearly from it. As the core was located in the first terrace of the Heihe River, the sediment over the past 1 ka was lack.

3 Conclusion and discussion

The results of stable isotope of carbonate in the past 140 ka suggest that at 140—80 kaB.P., the climate condition was warm and wet, with obvious subordinate fluctuations. In this period, the condition of heat and moisture was optimum, causing the high lake productively. The five internal climate oscillations in the period are equivalent to substages 5a—5e described in the deep-sea oxygen isotope stage 5, in which substage 5e is the warmest one, while 5a is an optimum episode of moisture and heat, 5c is a relatively weak warmer period, and, in both substages 5b and 5d, 5b is colder. Further, in substage 5e the two rapid cooling events are also found, thus there are five climate fluctuations in it, namely 5e5—5e1, among which 5e5 is the warmest climate period, while 5e1 is an optimum episode of moisture and heat (fig. 2). During 80—30 kaB.P., equivalent to a fully subglacial cycle, the oxygen isotope from core RM recorded at least seven obvious warm and five cold climatic fluctuations, in which the warm fluctuations at 73 kaB.P., 68 kaB.P., 61 kaB.P., 55 kaB.P., 45 kaB.P. correspond to IS20, IS19, IS17, IS14, IS8 in the ice core GRIP[7] and four cold events at 66 kaB.P., 48 kaB.P., 38 kaB.P., 25 kaB.P. are equivalent to H6, H5, H4, H3 events reported in deep-sea sediment[8]. The period at 30—20 kaB.P. was a transition from lake to fluvial sedimentation. Besides the effect of the temperature, the $\delta^{18}O$ in carbonate was also influenced by the oxygen isotope in river water. The cold event at 20 kaB.P. (6.05 m) corresponds to H2 event. As the chronological sequence in the paper is built by using the lake sediment consolation model which is independent of the dating age of ice core and deep-sea sediment, there is the difference between the age of beginning and ending event recorded in $\delta^{18}O$ of core RM and that of other records. But, the fluctuated features of $\delta^{18}O$ of core RM are well comparable with that of ice core and deep sea. Since 20 kaB.P., the paleolake disappeared and the lacustrine sediments were replaced by fluvial sediments. Meanwhile, the climatic significance of oxygen isotope became indistinct, just reflecting the rapid environmental shift with the lake disappearance.

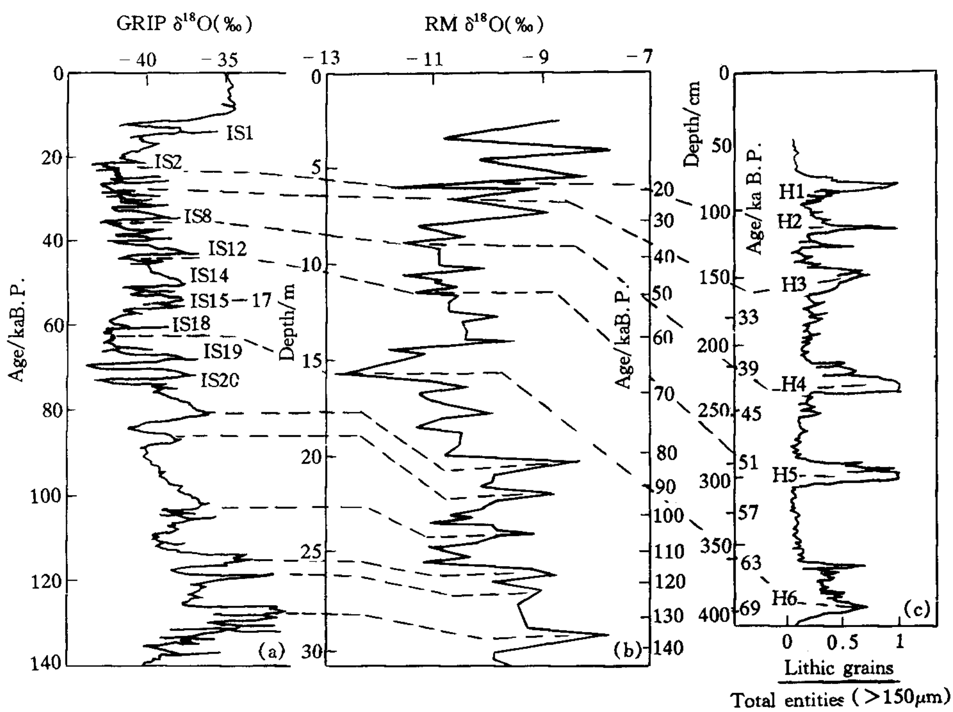

Fig. 2. Comparison of the records of oxygen isotope from core RM(b), the records from the Northern Atlantic Ocean[8] (lithic grains>150 μm) (c) and GRIP[7] ice core (a).

The record from the core of the Northern Atlantic Ocean and Greenland[7,8] ice core demonstrated that during the last glacial there existed a series of rapid and great magnitude cooling events. Broecker[9] thought that these events occurred in global extent. According to the record from the proxy of grain size in Luochuan loess profile, Porter and An[10] proved that the events mentioned above also existed in China, and pointed out that they had the original relation with the Heinrich events deduced from the Northern Atlantic Ocean. The results of climate-model simulations of full-glacial conditions point to enhanced atmospheric circulation and to latitudinal displacement of surface storm tracks; these tracks passed to the south of the North American ice sheets and then across the North Atlantic IRD zone, southern Europe, and Central Asia towards the Loess Plateau[10]. Although some possible explanations about abrupt event have been put forward now, the further research on the reason still should be improved. The oxygen isotope records from core RM demonstrated that the abrupt cooling events also existed in eastern Qinghai-Xizang Plateau. Our results may support the hypotheses given by Porter and An that there is an original relation to the Heinrich event. But, which role did the Plateau play in the events, passive response or active driving? It would be discussed. Moreover, we also found that the cooling events similar to Heinrich events existed in the last interglacial early period, coincidental with GRIP records and different from deep-sea records. Compared to Loess Plateau record, substage 5e1 deduced from core RM, which was a warm and wet stage, was equivalent to the substage 5e from Loess Plateau record[11], yet 5e3 and 5e5, warm and dry substages in the record of RM core, were not discovered in Loess Plateau. Therefore, during the early Last Interglacial, the climate in Loess Plateau was stable or the instability of climate failed to be recorded. In fact, it has been reported that the climate variations of substage 5e were recorded in Lanzhou loess profile[12]. Therefore, whether the cold events recorded in core RM during the last interglacial period were originally similar to Heinrich events or not and what the driving force of the global climate events is remain to be studied.

Acknowledgement We express our thanks to Prof. Shi Yafeng for reading and commenting on the manuscript; to Wang Yunfei, Ji Lei, Shen Caiming, Zhang Pingzhong, Xue Bin for their help in the field work.

References

1 Kashiwaya, K., Yamamoto, A., Fukuyana, K., Statistical analysis of grain size distribution in Pleistocene sediments from Lake Biwa, *Japan*, *Quat. Res.*, 1988, 30: 12.
2 Burcharott, B., Fritz, P., Environmental isotopes as environmental and climatological indicators, *Handbook of Environmental Isotope Geochemistry* (eds. Fritz, P., Fontes, J. C.), Part I, Amsterdam: Elsevier, 1980, 478—1504.
3 Abell, P.Z., Oxygen isotope ratios in modern African gastropod shells: a data base for paleoclimatology, *Chem. Geol., Isotope Geosci.*, 1985, 58: 183.
4 Emrich, K., Ehhalt, D.H., Vogel, J.C., Carbon isotope fractionation during the precipitation of calcium carbonate, *Earth Planet. Sci. Letts.*, 1970, 83: 63.
5 Wang Yunfei, Wang Sumin, Xue Bin *et al.*, Sedimentological evidence of the piracy of fossil Zoige lake by the Yellow River, *Chinese Science Bulletin*, 1995, 40(18): 1539.
6 Swain, E.B., Measurement and interpretation of sedimentary pigments, *Freshwater Biology*, 1985, 15: 53.
7 GRIP members, Climate instability during the last interglacial period recorded in the GRIP ice core, *Nature*, 1993, 364: 203.
8 Bond, G., Heinrich, H., Broecker, W.S., Evidence for massive discharges of icebergs into the North Atlantic ocean during the last glacial period, *Nature*, 1992, 360: 245.
9 Broecker, W.S., Massive iceberg discharges as triggers for global climate change, *Nature*, 1994, 372: 421.
10 Porter, S.C., An, Z.S., Correlation between climate events in the North Atlantic and China during the Last Glaciation, *Nature*, 1995, 375: 305.
11 Li Jijun, *Uplift of Qinghai-Xizang (Tibet) Plateau and Global Change*, Lanzhou: Lanzhou University Press, 1995, 130—180.
12 Lu Houyuan, Guo Zhengtang, Wu Naiqin, Paleomonsoon evolution and Heinrich events: evidence from the Loess Plateau and the south China sea, *Quaternary Sciences*, 1996, (1): 9.