The evidence of fossil carbon isotopes of the climatic event at the beginning of Quaternary

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Abstract Tooth enamel of mammalian fossils can efficiently preserve the original carbon isotopic composition when they lived. The ungulate fossils, especially equids in the early Early Pleistocene Bajiazui fauna from Qingyang, Gansu are studied. According to the enriched relation of carbon isotopes between mammalian tooth enamel and grass diets, the fractions of C_3 and C_4 plants in this region at that time are reconstructed, which indicates that C_3 grass occupied a dominant position. Because C_3 grass adapts itself to cold and damp climates, our analytic results show that the time of the Bajiazui fauna was in a critical state between a glacial stage beginning and a summer monsoon retreat, and it was a reflection to the turning cold event of the global climate at the beginning of the Quaternary.

Keywords: **climatic event, Quaternary, ungulate, carbon isotope.**

IN recent years, researches into paleoclimate reconstructions using carbon stable isotopes have been developing. In China, some achievements were got on analyses of $\delta^{13}C$ values to carbonate and organic carbon in loess and paleosol[1,2]. However, those carbon isotopes are evidently affected by diagenesis so that the paleoclimate reconstructions have obvious deviations. Tooth enamel of mammalian fossils can better preserve original carbon isotopes in diagenesis[3], and moreover, $\delta^{13}C$ is enriched in teeth and bones of ungulates with a regular rate[4]. As a result, we are able to recognize the plant isotopic composition and photosynthetic pathways during geological times in order to reconstruct paleoclimates.

1 Materials and methods

The studied fossils come from the early Early Pleistocene Bajiazui fauna in Qingyang, Gansu, which was contemporary with the Nihewan fauna. The beds of the Bajiazui fauna are fluviolacustrine deposits overlying loess correspondent with the Wucheng Loess[5]. Therefore, the earliest age of the Bajiazui fauna is about 2.5 Ma BP. We analyzed the ungulate isotopic composition in the Bajiazui fauna, in which equidae is predominant, including *Equus* sp., *Hipparion* sp., *Cervus* sp., *Gazella* sp. The samples come mainly from tooth enamel, as comparison, a few samples come from the bones and whole teeth of the genus *Equus* as well as the deposits. Tooth enamel is composed of about 95% hydroxyapatite, mainly $Ca_3(PO_4)_2$ which characteristically contains up to 1% structural carbonate. The carbon stable isotopes enter $Ca_{10}(PO_4,CO_3)_6(OH,CO_3)_2$ during the tooth development.

Enamel samples are first steeped in acetone to dissolve organic matter. Then, they were ground into powder in an agate mortar and pestle. The powder was allowed to react in 5% solution of sodium hypocholorite for 12 h to eliminate bacterial proteins and humates. The inorganic powder was pretreated with 0.6% acetic acid for 12 h under vacuum to remove diagenetic carbonates. CO_2 was produced by reaction of the hydroxyapatite enamel samples with 100% phosphoric acid, purified[6]. Carbon and oxygen isotopes were measured on a Finnigan MAT-251 mass spectrometer. The isotopic ratios were reported in the standard notation relative to PDB. The analytical precision is better than 0.1‰ (table 1).

Table 1 Carbon and oxygen isotopic composition of fossils and deposits in Bajiazui fauna

Specimen	Material	$\delta^{13}C$(‰)	$\delta^{18}O$(‰)
E-1	*Equus* sp.	−10.2	−9.9
E-2	*Equus* sp.	−11.9	−12.5
E-3	*Equus* sp.	−10.8	−10.8
E-4	*Equus* sp.	−8.7	−11.0
E-5	*Equus* sp.	−8.0	−9.0
E-6	*Equus* sp.	−9.8	−10.1
E-7	*Equus* sp.	−10.4	−10.4
E-8	*Equus* sp.	−11.1	−9.5
E-9	*Equus* sp.	−9.7	−9.1
E-10 a)	*Equus* sp.	−10.2	−7.4
E-11 a)	*Equus* sp.	−8.9	−5.9
E-12 b)	*Equus* sp.	−10.0	−6.7
E-13 b)	*Equus* sp.	−8.8	−9.0
H-1	*Hipparion* sp.	−9.8	−7.5
H-2	*Hipparion* sp.	−10.4	−6.8
C-1	*Cervus* sp.	−9.8	−5.8
C-2	*Cervus* sp.	−11.4	−8.9
G-1	*Gazella* sp.	−10.5	−10.1
S-1	sandy clay	−6.3	−7.6
S-2	sandy clay	−6.2	−7.5

$\delta^{13}C$ and $\delta^{18}O$ are relative to PDB. a) Whole tooth samples; b) bone samples.

2 Results and characteristics

All $\delta^{13}C$ values of these fossil samples are rather similar because their variation coefficient (ratio of standard deviation and average value) is smaller than 0.1, which shows that the drift degrees of these values are very small. They are obviously different from the $\delta^{13}C$ values of the strata, which indicates that the carbon isotopic composition of the fossils are not influenced by diagenesis of deposits. On the other hand, the $\delta^{18}O$ values of the fossils are rather dispersal, whose variation coefficient is larger than 0.2. Some $\delta^{18}O$ values are similar to and have overlaps with those of the strata, therefore, $\delta^{18}O$ values are easily influenced by diagenesis and cannot reflect the oxygen isotopic composition when mammals lived, which has also been proved by some experimental results[3].

The $\delta^{13}C$ value scope of the fossil samples in the Bajiazui fauna is normal as a fauna lived in the same region and time, whose precision is very identical with that of the modern ungulates in North America ($\delta^{13}C$ values of −15.9‰— −12.7‰)[6], the Samos fauna in Greece at 7 Ma BP ($\delta^{13}C$ values of −13.0‰— −9.6‰)[7], the Equidae in South Dakota at 32 Ma BP ($\delta^{13}C$ values of −14.1‰— −10.0‰)[8].

3 Discussion and conclusions

Plants photosynthesize carbon through one of three different metabolic processes. The CAM cycle is very rare in nature and CAM plants are not important in most ecosystems. The dominant photosynthetic pathways for terrestrial plants are the Calvin-Beson cycle and the Hatch-Slack cycle, the former exists in C_3 plants among which there are grass living in high latitudes and high elevations with cold or cool and damp climates; the latter exists in C_4 plants which include tropical and subtropical grass living strong dry and seasonal climates[6].

C_3 plants characteristically have $\delta^{13}C$ values ranging from $-23‰$ to $-34‰$ with a mean of about $-27‰$; C_4 plants characteristically have $\delta^{13}C$ values ranging from $-9‰$ to $-17‰$ with a mean of about $-13‰$. When mammals feed on plant foodstuffs, there is a further enrichment of $\delta^{13}C$ in their skeletal tissues by some 12‰—15‰. Therefore, the hydroxyapatite derived from a mammal with pure C_3 diet has a $\delta^{13}C$ of $-15‰$—$-12‰$ with a mean of about $-13‰$ while that derived from pure C_4 diet has a value of $-1‰$—$+2‰$ with a mean of about $+1‰$[4]. According to this pattern, we can calculate the grass $\delta^{13}C$ values when the Bajiazui fauna lived. The results indicate that C_3 plants occupied a dominant position, about 4/5 while C_4 plants were rare, about 1/5 (figure 1).

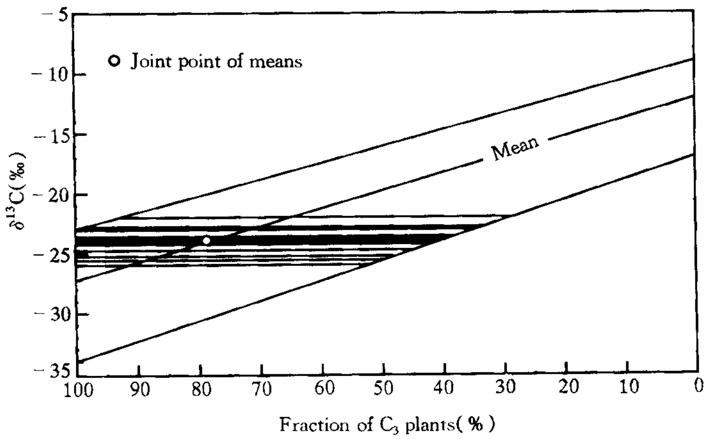

Fig. 1. $\delta^{13}C$ values of the early Early Pleistocene grass in Bajiazui, Qingyang.

Qingyang is located in the climatic susceptible belt in northwestern China, and its latitude is 36°N. Today, there are predominantly C_4 plants in latitudes 36° of the Northern and Southern Hemispheres, such as the Great Plains in the Untied States and Pampas in Argentina. On the other hand, there are predominantly C_3 plants in the latitudes higher than 50°, such as the Grassland in Canada[6]. Therefore, the early Early Pleistocene environment that Bajiazui fauna lived was much different from the present one.

C_3 plants can grow in high elevation regions, for example, in montane grass communities from Kenya there are all C_3 species above 3 000 m, mixed C_3 and C_4 species among 3 000—2 000 m, and all C_4 species below 2 000 m. If the dominant C_3 plants in Bajiazui had been determined by elevation, the elevation of Qingyang would have been over 2 500 m at that time. However, the highest elevation of the Northern Shaanxi Plateau where Qingyang is located is only 1 200 m today, therefore, the elevation of this region did not reach 2 500 m in the early Early Pleistocene.

C_3 plants can grow at high latitudes. In the Northern Hemisphere, the south boundary of C_3 plants distributions to the north of Qingyang is located near the south of the Baykal in Russia and the Selenga valley in Mongolia, whose latitude differs from Qingyang by about 15°. However, the latitude of Qingyang in the early Early Pleistocene did not have an obvious difference from the present one, therefore, the dominant position of C_3 plants in the time of the Bajiazui fauna was not caused by latitudes either.

Evidently, the climate in the early Early Pleistocene differed greatly from the recent one. C_3 plants adapt themselves to cold and damp climates, as a result, the dominant position of modern C_3 plants at the same latitude with Qingyang exists only in a few winter rainfall regions, which reflects a state of low temperature and high humidity, such as the Aegean coasts of Greece, Oregon of the United States[4], southern Victoria of Australia, and the west seashore of South Africa[9]. There is no winter rainfall climate in the east part of Eurasia, so the cold and damp state in the time of the Bajiazui fauna must be caused by other reasons.

In the early Early Pleistocene at 2.5 Ma BP, the first important aggregation of global ice took place, the Chinese loess began to accumulate, the genus *Equus* disperse into Eurasia through the Bering land-bridge, which are identical with the characteristics of the Bajiazui fauna. The loess-paleosol sequence represented relatively strong or weak variations of the East-Asian monsoon: loess reflected a cold and dry climate while paleosol reflected a warm and damp one. According to the research of the East-Asian monsoon variation, glacial stages corresponded to the cold and dry winter monsoons while interglacial stages corresponded to warm and damp summer ones[10]. However, the climate of the Bajiazui fauna, which is identical with neither the cold and dry of loess and glacial stages nor the warm and damp of paleosol and interglacial stages, represented a cold and damp climate. Obviously, it exactly is a transition between a warm and damp climate and a cold and dry climate, and it is a result of climatic changes.

In the light of the horizon and age of the Bajiazui fauna, it lived at the beginning of the Quaternary at about 2.5 Ma BP. The climatic changes at about 2.5 Ma BP in the Chinese continent were identical with the global changes of glacial climates, at the same time, high latitudinal continental glaciers in the Northern Hemisphere began to expand. But, the climatic features of the Bajiazui fauna imply that it did not live in the grandest glacial stage. Glacial stages corresponded to cold and dry climates, however, the dominant C_3 grass in the time of the Bajiazui fauna indicated that the temperature is low while the humidity is still high. Therefore, the Bajiazui fauna just lived at the beginning of a glacial climate, meanwhile, the East-Asian monsoon climate is just in a transition from a strong summer monsoon stage to a strong winter monsoon stage, and aqueous vapor brought by summer monsoon still influenced this region. The above-mentioned facts prove that a joint function of high latitudinal continental glaciers and East-Asian summer monsoons to the Chinese climatic susceptible belt, in which Qingyang is located, was in an important turning point, namely in a critical state between a glacial stage beginning and a summer monsoon retreat. Conclusively, the cold and damp state of dominant C_3 grass, reflected by the carbon isotopic composition of the Bajiazui fauna, represented the transition from the Pliocene warm and damp climate to the Pleistocene cold and dry climate, which is new evidence for the turning cold event of the global climate at the beginning of the Quaternary.

References

1 Gu Zhaoyan, The carbonate isotopic composition of the loess-paleosol sequence and its implication of paleoclimatic change, *Chinese Science Bulletin*, 1991(36): 1979.

2 Lin Benhai, Liu Rongmo, The stable isotopic evidence of the summer monsoon variation in the Loess Plateau over the last 800 ka, *Chinese Science Bulletin*, 1992(37): 1691.

3 Wang, Y., Cerling, T.E., A model of fossil tooth enamel and bone diagenesis: implications for paleodiet reconstruction from stable isotopes, *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 1994, 107: 281.

4 MacFadden, B.J., Cerling, T.E., Fossil horeses, carbon isotopes and global change, *Trends in Ecology and Evolution*, 1994, 9: 481.

5 Wang Yongyan, Xue Xiangxu, He Ruchang *et al.*, Division of the Quaternary strata in the loess district of north Shaanxi and east Gansu, *Acta Geologica Sinica* (in Chinese), 1966,46(1): 102.

6 Wang, Y., Cerling, T.E., MacFadden, B.J., Fossil horses and carbon isotopes: new evidence for Cenozoic dietary, habitat, and ecosystem changes in North America, *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 1994, 107: 269.

7 Quade, J., Solounias, N., Cerling, T.E., Stable isotopic evidence from paleosol carbonates and fossil teeth in Greece for forest or woodlands over the pass 11 Ma, *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 1994, 108: 41.

8 Heady, H.F., *Terrestrial Vegetation of California* (eds. Barbour, M.G. *et al.*), New York: Wiley, 1977, 491—514.

9 Rutherford, M.C., *Components of Productivity of Mediterranean-climate Regions*: *Basic and Applied Aspects* (eds. Margaris, N.S. *et al.*), The Hague: Junk, 1981, 135—147.

10 An Zhisheng, Wu Xihao, Wang Pinxian *et al.*, Palaeomonsoon of China over the last 130 ka, *Science in China*, Ser. B, 1991(34): 1016.

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