Analysis of carbon isotope in phytoliths from C3 and C4 plants and modern soils

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Abstract The analysis of carbon isotope in phytoliths from modern plants and surface soils in China shows that the values of carbon isotope are consistent with those from C3 and C4 plants, and the processes of photosynthesis of the original plants can be clearly identified by carbon isotope in phytoliths. The value of carbon isotope varied from –23.8‰ to –28‰, with the maximum distributed in the latitude zone from 34°N to 40°N in North China and East China areas, and the minimum in the Northeast China and South China regions. The values of carbon of phytoliths tend to increase from low to high and then reduce to low value again as the latitude increases. In the same latitude zone, the carbon isotope in phytoliths from grassland soil under the trees is obviously lower than that from grassland soil without any trees with the difference of 1‰ — 2‰.

Keywords: C3 and C4 plants, phytoliths, carbon isotope.

The analysis of stable carbon isotope ($\delta^{13}C$) has been widely used to reconstruct the evolution of vegetation and the history of climate changes in the Quaternary period[1—4]. However, carbon isotope can be greatly influenced by epigenesis in sediments formed in different environments. Scientists have been trying to find the test materials that can represent the coetaneous climate and environment without any influence from epigenesis. Phytolith is the siliceous cell formed during the growing process of plants. In the nucleus and bioplasm of the siliceous cells there is enclosed carbon that is free from the epigenesis of deposition. As a result, phytoliths are selected as the perfect materials for the study of stable carbon isotope. Furthermore, the test materials of carbon isotope used for paleo-environmental analysis must meet the following requirements: (i) the isotopic compositions of the materials for measurement are only related to the formation environment, without any exchange with the surrounding materials during the epigenesis of sedimentation. (ii) The $^{13}C/^{12}C$ ratios in the test materials are controlled mainly by the contribution of C3 and C4 plants[5,6]. As a matter of fact, the sources of organic material in sediments are complex. The climatic environmental signals of carbon isotopes can be interfered seriously by the growth of plants, bioturbation and microbiological reaffection on organic material in sediments. While carbon isotope analysis using phytoliths in the strata can avoid this kind of interference to certain extent. As a result, this method has become a new means in the study of paleoclimate in recent years. This is not only because a part of organic carbon within the original plant cells is occluded in phytoliths, which is free from the contamination and being intermixed by extra-carbon, but also because phytoliths can be preserved in great amount in the strata, hence high-resolution isotopic records can be obtained by continuous sampling[8—10]. However, whether carbon isotope in phytoliths from different plants can accurately reflect the characteristics of the photosynthesis of C3 and C4 plants and whether the changes of carbon isotope in phytoliths from modern soils are firmly connected with modern vegetation types and climate changes are still little known. This study provides the basic evidence for the above problems by the carbon isotopic analysis on phytoliths from modern plants and soils.

1 Materials and methods

10 mg phytoliths were extracted from each of 15 species of modern plants using the methods introduced by Wang Yongji and Lü Houyuan[11]. The CO_2 samples for carbon isotopic measurement were made using the method introduced by Mulholland and Prior[12]. 18 soil samples were selected from modern soils in different climate zones ranging from Heilongjiang Province in the north to Guangdong Province in the south in eastern China. Phytoliths were extracted using a heavy liquid (SG>2.35) separation procedure. The samples were treated with 30% H_2O_2 for 24 h before and after extraction, in order to eliminate organic matter, and then identified under a microscope. Phytolith content in the specimen is generally 60%—80%, and the rest are a little amount of relics of organic matter and detritus. CO_2 specimens of the phytoliths in soil samples were made using the same method as for phytoliths from modern plants. Then, carbon isotopic composition was measured by an MAT-252 mass spectrograph with the PDB standard and precision < 0.02%. The preparation of carbon isotopic samples and the measurements of carbon isotope in phytoliths were respectively made in Lanzhou Institute of Geology, the Chinese Academy of Sciences (CAS) and Lanzhou Institute of Glaciology and Geocryology of CAS.

2 Results and discussion

Carbon isotopic values of phytoliths of 15 species of modern plants phytoliths and the related ways of photosynthesis are listed in table 1[13—15]. The carbon isotopic values of phytoliths from the 10 species of C3 plants vary from –24‰ to –31‰, with the average of –27.467‰, while the values of that from the 5 species of C4 plants are just in the range of –15‰ — –20‰, with the average of –17.524‰. It is reported that $\delta^{13}C$ values for C3 and C4 plants vary from –22‰ to –34‰ and from –9‰ to –19‰ respectively[5]. Obviously, carbon isotopic values of different phytoliths correspond well

Table 1 The values of carbon isotope in phytoliths from 15 species of modern plants

Plant	$\delta^{13}C$ (‰)	Ways of photosynthesis	Plant	$\delta^{13}C$ (‰)	Ways of photosynthesis
Carex bodinieri	−31.190	C3	*Phyllostachy arcana*	−24.776	C3
Cyperus sp	−29.173	C3	*Gahnia tristis*	−24.504	C3
Roegneria kamoji	−28.456	C3	*Buchloe dactyoides*	−20.101	C4
Pleioblastus amarus	−28.414	C3	*Imperata cylindrca*	−18.892	C4
Oryza sativa	−28.163	C3	*Setaria viridis*	−17.199	C4
Triticum aestivum	−28.156	C3	*Chloris virgata*	−16.285	C4
Scirpus trigueter	−26.322	C3	*Zea mays*	−15.144	C4
Indocalamus latifolius	−25.518	C3			

to the carbon isotope from modern C3 and C4 plants, so, the ways of photosynthesis of the original plants can be distinguished clearly by carbon isotope in phytoliths.

The sampling sites, vegetation types and values of carbon isotope in phytoliths of the 18 samples of modern surface soils are listed in table 2. The values of carbon isotope vary from −24‰ to −28‰,

Table 2 The values of carbon isotope in phytoliths from modern surface layers of soil

Site	Latitude & Longitude	$\delta^{13}C$ (‰)	Topography and vegetation types	Mean annual temperature/℃[a)]	Mean annual rainfall/mm[a)]
Yushan, Guangzhou	23.1°N 113.2°E	-27.795	meadow under woods	21.8	1712
Qingcheng Mount	30.9°N 103.5°E	-26.955	meadow under woods at the elevation of 1 207 m	16.0	1053
Manzhouli	49.6°N 117.4°E	-26.884	prairie	−1.6	348
Daqingliangzi	27.9°N 102.3°E	-26.243	grasslands at the elevation of 2 800 m	13.6	1021
Taishan Mount	36.4°N 117.2°E	-26.118	meadow under woods at the elevation of 405 m	13.4	663
Meng Temple	35.4°N 116.9°E	-25.789	meadow under the woods of cypress	13.7	800
Changlin Tomb	40.2°N 116.2°E	-25.768	meadow under woods on top of a fortress	10.9	551
Lingshan	40°N 115.3°E	-25.645	meadow under woods at the elevation of 1 650 m	10.1	508
Dinglin Tomb	40.2°N 116.2°E	-25.408	meadow under the woods of cypress on top of a fortress	10.9	551
Konglin	35.6°N 116.9°E	-25.364	meadow under the woods of cypress	13.4	663
Grassland Station	44°N 116.1°E	-25.063	prairie	2.0	310
Tailin Houshan	40.3°N 116.2°E	-24.968	grassland on hillside	10.9	551
Qingdao 2	36°N 120.3°E	-24.925	grassland on the northern hillside	12.4	708
Summer Palace	39.9°N 116.4°E	-24.808	grassland on hillside	10.9	551
Qingdao 1	36°N 120.3°E	-24.718	grassland on the southern hillside	12.4	708
Chengde	40.9°N 117.9°E	-24.660	grassland	8.3	501
Luanchuan County	33.7°N 115.5°E	-24.355	grassland	14.4	828
Miaofeng Mount	40°N 116°E	-23.814	piedmont grassland on the southern hillside	10.9	551

a) The data of mean annual temperature and rainfall are based on the meteorological data from the State Meteorology Administration of the People's Republic of China.

with the maximums distributed in the North China and East China regions in the latitude zone of 34°N — 40°N and the minimums in the Northeast China and South China regions. Carbon isotope values change with a low-high-low tendency as latitude increases (fig. 1).

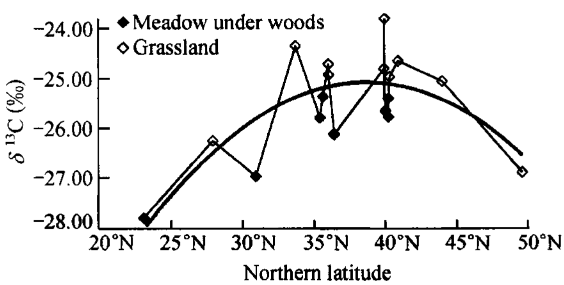

Fig. 1. The distribution trend of carbon isotope in phytoliths from the soil in eastern China .

In similar latitude zones, the carbon isotope values in phytoliths from meadow soil under woods are obviously lower than those from grassland soil without trees, the difference between them is in the range of 1‰—2‰. A great amount of work has been carried out on the study of the ways of photosynthesis for different C3 and C4 plants in China[13,14]. Because both cold and rainy environments are unsuitable for the growth of C4 plant, the content of C4 plants in the vegetation of a certain region increases as the mean annual temperature rises. C4 plants in China are mostly distributed in the mid-subtropical zone with the maximum of 61.1% of the total in the country and about 13.3%—14.3% of C4 plants are distributed in the northern Temperate Zone, while to the south of the mid-subtropical zone, C4 plants decrease southwards because of the increasing rainfall[13]. Changes of carbon isotopic values in phytoliths from modern soils correspond well to the distribution of C3 and C4 plants in China. In addition, to a great extent, it is due to the contribution of woody plants, which belong to C3 plants, that the values of carbon isotope in the phytoliths from woody soils are lower than those from grassland soils in the same latitude zone.

On the other aspect, the results of this study can provide the evidence for the cause of changes of organic carbon isotope in stratigraphic layers and for the reconstruction of paleoclimates. If a low carbon isotopic value (with lighter carbon isotope) indicates a cold climate stage on the Loess Plateau[1], the contrary trend may occur in the south of China, which means that the light carbon isotope in the sediment from South China may reflect a relatively warm climate. More work is needed to further study this kind of relations in detail.

3 Conclusions

Relatively pure phytoliths can be obtained from modern plants and surface soils by the method introduced in this note. 10 mg pure phytoliths are enough to meet the requirements for measurement. $\delta^{13}C$ in phytoliths can be measured with an MAT-252 mass spectroscope.

The values of carbon isotope in phytoliths from modern plants correspond well to those in modern C3 and C4 plants. As a result, different ways of plant photosynthesis can be clearly distinguished by means of the analysis of carbon isotope in phytoliths.

Carbon isotopic values in phytoliths from surface soils vary in the low-high-low tendency as the latitude increases, which is consistent with the trend of distribution of C3 and C4 plants in China, indicating that the changes of carbon isotopic values in phytoliths are related to temperature and rainfall.

The results of this study provide a new interpretation for the relation between the carbon isotope in the stratigraphic layers in both the north and the south area and the climatic changes, i.e. a low value of carbon isotope may represent a cold climate stage in the north area, while it might represent a warm and humid climate stage in the south area. This conclusion needs to be tested by further research.

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References

1. Lin, B. H., An, Z. S., Liu, R. M., Stable isotopic evidence of monsoon variation on Chinese Loess Plateau during the last 600 ka, Loess, Quaternary Geology and Global Change, Part III (in Chinese), Beijing: Science Press, 1992, 51—54.
2. Nordt, L. C., Boutton, T. W., Hallmark, C. T. et al., Late Quaternary vegetation and climate change in central Texas based on the isotopic composition of organic carbon, Quaternary Research, 1994, 41: 109.

3. Humphrey, J. D., Ferring, C. R., Stable isotopic evidence for latest Pleistocene and Holocene climate change in north central Texas, Quaternary Research, 1994, 41: 200.
4. Han, J. M., Jiang, W. Y., Liu, D. S. et al., Carbonate isotopic records of paleoclimate changes in Chinese loess (in Chinese), Science in China, Ser. D, 1996, 39(5): 460.
5. Boutton, T. W., Archer, S. R., Nordt, L. C., Climate, CO_2 and plant abundance, Nature, 1994, 372: 625.
6. Deines, P., The isotopic composition of reduced organic carbon, Handbook of Environmental Isotope Geochemistry (eds. Fritz, P., Fontes, J. C. H.), Amsterdam: Elsevier Scientific Publishing Company, 1980, 329—406.
7. Chen, T. M., Progress loess problems in Quaternary dating, Quaternary Sciences (in Chinese with English abstract), 1995(2): 182.
8. Kelly, E. F., Amundson, R. G., Marino, B. D. et al., Stable isotope rations of carbon in phytoliths as a quantitative method of monitoring vegetation and climate change, Quaternary Research, 1991, 35: 222.
9. Fredlund, G. G., Tieszen, L. L., Phytolith and carbon isotope evidence for late Quaternary vegetation and climate change in the Southern Black Hills, South Dakota, Quaternary Research, 1997, 47: 206.
10. Wang, Y. J., Lü, H. Y., AMS^{14}C dating and isotope analysis in phytoliths, Marine Science Bulletin (in Chinese), 1997, 16 (3): 49.
11. Wang, Y. J., Lü, H. Y., The Study of Phytolith and Its Application (in Chinese), Beijing: China Ocean Press, 1993, 1—228.
12. Mulholland, S. C., Prior, C., Processing of phytoliths for radiocarbon dating by AMS, The Phytolitharien News Letter, 1992, 7(2): 7.
13. Yin, L. J., Li, M. R., A study on the geographic distribution and ecology of C4 plant in China, Acta Ecologica Sinica (in Chinese with English abstract), 1997, 17: 350.
14. Yin, L. J., Wang, P., Distribution of C3 and C4 photosynthetic pathways of plants on the steppe of Northeastern China, Acta Ecologica Sinica (in Chinese with English abstract), 1997, 17: 113.
15. Wu, N. Q., Lü, H. Y., Nie, G. Z. et al., The study of phytoliths in C3 and C4 grasses and its paleoecological significance, Quaternary Sciences (in Chinese with English abstract), 1992, 240—251.

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