

Analysis of Carbon Isotope Composition Characteristics of Topsoil on the Southwestern Margin of the Tarim Basin (Postprint)

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Abstract

Soil carbon isotopes can reflect the isotopic composition of growing vegetation, thereby providing insights into contemporaneous vegetation types and climatic conditions. Previous studies have demonstrated significant regional variations in the relationship between carbon isotopes and climatic factors; thus, conducting regional correlation analyses between soil carbon isotopes and climatic factors is essential for paleoclimate reconstruction. By collecting surface soil sediments from the Pamir region on the western margin of the Tarim Basin and from Cele County in the Hotan region on the southern margin of the basin, we analyzed their organic carbon isotopes and performed correlation analyses between these surface soil organic carbon isotope data and climatic factors to investigate the compositional characteristics of organic carbon isotopes in the study area and their potential climatic significance. The results reveal distinct differences in how surface soil carbon isotope variations respond to climatic factors between the Pamir and Cele regions. Regarding temperature, the Pamir region exhibits a positive correlation, with the strongest correlation observed for cold-season temperature ($r=0.598$, $P<0.01$); conversely, the Cele region shows a negative correlation, with the strongest correlation for warm-season temperature ($r=-0.684$, $P<0.01$). For precipitation, the Pamir region shows no significant correlation with precipitation amounts; the Cele region demonstrates a weak negative correlation with annual mean precipitation, a weak positive correlation with warm-season precipitation, and a significant negative correlation with cold-season precipitation ($r=-0.632$, $P<0.01$). These findings indicate that regional differences must be fully considered when reconstructing paleoclimate from sediment organic carbon isotopes.

Full Text

Composition Characteristics of Surface Soil $\delta^{13}\text{C}_{\text{org}}$ in the Southwest Margin of Tarim Basin

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Abstract

Soil organic carbon isotopes ($\delta^{13}\text{C}_{\text{org}}$) can reflect the isotopic composition of growing vegetation, thereby providing insights into vegetation types and associated climatic conditions. Previous studies have demonstrated significant regional differences in the relationship between $\delta^{13}\text{C}_{\text{org}}$ and climate factors, underscoring the importance of analyzing these correlations across different regions for robust paleoclimate reconstruction. This study investigates the carbon isotopic composition of surface soils from two key areas in the core arid region of Central Asia: the Pamir Plateau on the western margin of the Tarim Basin and Qira County on the southern margin. Through systematic sampling and analysis, we examined the characteristics of surface soil $\delta^{13}\text{C}_{\text{org}}$ and its relationships with modern climate factors to establish a scientific foundation for paleoclimate reconstruction.

We collected and analyzed 50 topsoil samples (25 from each region) to determine their organic carbon isotopic composition. The results reveal distinct differences in how surface soil $\delta^{13}\text{C}_{\text{org}}$ responds to climate factors between the two regions. Regarding temperature, the Pamir region shows significant positive correlations with annual mean temperature ($r = 0.594$, $P < 0.01$), warm-season temperature ($r = 0.593$, $P < 0.01$), and cold-season temperature ($r = 0.598$, $P < 0.01$). In contrast, Qira County exhibits significant negative correlations with annual mean temperature ($r = -0.675$, $P < 0.01$), warm-season temperature ($r = -0.684$, $P < 0.01$), and cold-season temperature ($r = -0.646$, $P < 0.01$). For precipitation, the Pamir region shows no significant correlation, while Qira County displays a weak negative correlation with annual precipitation ($r = -0.485$, $P < 0.05$), a weak positive correlation with warm-season precipitation ($r = 0.483$, $P < 0.05$), and a significant negative correlation with cold-season precipitation ($r = -0.632$, $P < 0.01$).

Mechanistic analysis indicates that $\delta^{13}\text{C}_{\text{org}}$ variations in both regions are primarily controlled by temperature, but the opposing correlation patterns likely

stem from differences in water sources (glacier meltwater in the Pamir versus precipitation in Qira) and vegetation types. The weak correlation with precipitation in both regions probably reflects the extreme aridity, with annual precipitation below 80 mm. These findings emphasize that paleoclimate reconstructions based on sedimentary organic carbon isotopes must carefully consider regional differences and local environmental contexts.

Keywords: surface soil $\delta^{13}\text{C}_{\text{org}}$; temperature; precipitation; correlation analysis; arid region

1. Study Area Overview

The western margin of the Tarim Basin connects with the Pamir Plateau [Figure 1: see original paper]. The Pamir Plateau spans southwestern Xinjiang in China, northeastern Afghanistan, and southeastern Tajikistan, with its eastern portion located primarily within Kizilsu Kirghiz Autonomous Prefecture and Kashgar Prefecture in Xinjiang (73°40'–96°18' E, 34°25'–40°10' N). The plateau exhibits a severe continental alpine climate, particularly pronounced in the eastern Pamir, with a mean annual temperature around -2°C . Blocked by high mountains from westerly moisture, the region receives only 75–100 mm of annual precipitation, predominantly supplied by glacier meltwater.

Qira County, located on the southern margin of the Tarim Basin (80°03'–82°10' E, 35°18'–39°30' N), borders the Kunlun Mountains to the south and the Taklamakan Desert to the north, with topography sloping from high in the south to low in the north [Figure 1: see original paper]. The county experiences an extreme continental arid desert climate, with a mean annual temperature of 12.2°C , mean annual precipitation of 43.5 mm, warm-season monthly precipitation of 6.2 mm, and cold-season monthly precipitation of 0.7 mm. Unlike the Pamir region, Qira's water supply depends mainly on natural precipitation.

Vegetation also differs markedly between the two regions. The Pamir Plateau displays clear vertical zonation, including meadows below 3,500 m, alpine steppe between 3,500–4,500 m, and alpine sparse vegetation above 4,500 m. In contrast, Qira County is dominated by desert vegetation, with halophytic grasses as the predominant community. Both regions represent ecologically fragile areas sensitive to climate change, yet systematic climate studies remain limited.

2. Materials and Methods

Surface soil sampling was conducted in 2019. At each site, we collected approximately 500 g of topsoil (0–5 cm depth) from areas with minimal gravel using a shovel. Samples were sealed in zip-lock bags, transported to the laboratory, and stored at low temperature. In the lab, samples were air-dried at room temperature, ground, and passed through a 100-mesh sieve. Carbonate was removed

using 1 M HCl, followed by rinsing with deionized water until neutral pH was achieved. Samples were then dried at room temperature.

For isotopic analysis, 9–11 mg of each pretreated sample was sealed in a tin capsule. $\delta^{13}\text{C}_{\text{org}}$ measurements were performed at the Climate and Environmental Change Laboratory, College of Earth and Atmospheric Sciences, University of at Albany, State University of New York. The samples were combusted at 900°C in a temperature combustion of organic carbon to CO_2 , ionization, magnetic separation, and detection of isotopic abundances. Measurement precision was better than $\pm 0.2\%$, with one standard sample analyzed after every ten unknown samples to ensure accuracy.

Climate data (monthly temperature and precipitation) for all sampling sites were extracted from WorldClim (<http://www.worldclim.org/>) using ArcGIS, covering 1970–2000 at 10-minute spatial resolution. Warm season refers to May–September, and cold season to October–April.

3. Results

3.1 Characteristics of Surface Soil $\delta^{13}\text{C}_{\text{org}}$ Composition The $\delta^{13}\text{C}_{\text{org}}$ values of surface soils from both regions are summarized in and [Figure 2: see original paper]. In the Pamir region, $\delta^{13}\text{C}_{\text{org}}$ ranges from -26.5% to -20.4% , averaging -23.5% , with the most frequent values around -23.5% . In Qira County, $\delta^{13}\text{C}_{\text{org}}$ ranges from -24.6% to -21.5% , averaging -23.6% , with the most frequent values around -23.5% . The Pamir $\delta^{13}\text{C}_{\text{org}}$ values are more depleted, indicating C_3 -dominated vegetation, while Qira's values suggest nearly pure vegetation as well, though with a narrower range.

3.2 Correlation Between Surface Soil $\delta^{13}\text{C}_{\text{org}}$ and Altitude [Figure 3: see original paper] illustrates the relationship between $\delta^{13}\text{C}_{\text{org}}$ and altitude for both regions. In the Pamir region, $\delta^{13}\text{C}_{\text{org}}$ shows a significant negative correlation with altitude ($r = -0.494$, $P < 0.01$), becoming more depleted with increasing elevation:

$$y = -5.96 \times 10^{-5}x - 22.644 \quad (\text{where } y \text{ is } \delta^{13}\text{C}_{\text{org}} \text{ and } x \text{ is altitude}).$$

In Qira County, $\delta^{13}\text{C}_{\text{org}}$ shows a significant positive correlation with altitude ($r = 0.732$, $P < 0.01$), becoming more enriched with increasing elevation:

$$y = 1.15 \times 10^{-4}x - 27.644.$$

These opposing trends suggest different environmental controls operating in the two regions.

3.3 Correlation Between Surface Soil $\delta^{13}\text{C}_{\text{org}}$ and Temperature [Figure 4: see original paper] presents correlations between $\delta^{13}\text{C}_{\text{org}}$ and temperature parameters. The Pamir region shows significant positive correlations with annual mean temperature ($r = 0.594$, $P < 0.01$), warm-season temperature ($r = 0.593$, $P < 0.01$), and cold-season temperature ($r = 0.598$, $P < 0.01$). Qira County exhibits significant negative correlations with annual mean temperature

($r = -0.675$, $P < 0.01$), warm-season temperature ($r = -0.684$, $P < 0.01$), and cold-season temperature ($r = -0.646$, $P < 0.01$).

The correlation coefficients indicate that temperature exerts a stronger influence on $\delta^{13}\text{C}_{\text{org}}$ in Qira County than in the Pamir region, though both areas show temperature as a dominant control.

3.4 Correlation Between Surface Soil $\delta^{13}\text{C}_{\text{org}}$ and Precipitation

[Figure 5: see original paper] shows the relationships between $\delta^{13}\text{C}_{\text{org}}$ and precipitation. In the Pamir region, $\delta^{13}\text{C}_{\text{org}}$ shows no significant correlation with annual precipitation ($r = -0.145$, $P > 0.05$), warm-season precipitation ($r = -0.02$, $P > 0.05$), or cold-season precipitation ($r = 0.127$, $P > 0.05$). In Qira County, $\delta^{13}\text{C}_{\text{org}}$ shows a weak negative correlation with annual precipitation ($r = -0.485$, $P < 0.05$), a weak positive correlation with warm-season precipitation ($r = 0.483$, $P < 0.05$), and a significant negative correlation with cold-season precipitation ($r = -0.632$, $P < 0.01$).

These results demonstrate that precipitation plays a minor role in $\delta^{13}\text{C}_{\text{org}}$ variation in both regions, likely due to the extreme aridity (annual precipitation < 80 mm).

4. Discussion

4.1 Influence of Altitude on $\delta^{13}\text{C}_{\text{org}}$ Variation

In Xinjiang, water availability is the dominant factor controlling plant growth and $\delta^{13}\text{C}_{\text{org}}$ variation. In the Pamir region, increasing altitude brings lower temperatures and higher precipitation, and plants at higher elevations. This leads to more depleted $\delta^{13}\text{C}_{\text{org}}$ values with increasing altitude, consistent with patterns observed in northern Xinjiang and the Yulong Snow Mountains on the southeastern Tibetan Plateau.

In Qira County, however, $\delta^{13}\text{C}_{\text{org}}$ becomes more enriched with altitude despite decreasing temperatures. This 反常 pattern likely reflects severe water stress at higher elevations, where reduced precipitation and increased evaporation limit plant growth. Unlike the Pamir region, which receives glacier meltwater supplementation, Qira's higher altitude zones experience more arid conditions, causing $\delta^{13}\text{C}_{\text{org}}$ to respond positively to altitude.

4.2 Influence of Temperature on $\delta^{13}\text{C}_{\text{org}}$ Variation

Temperature affects $\delta^{13}\text{C}_{\text{org}}$ through multiple mechanisms: influencing enzyme activity and stomatal conductance during photosynthesis, altering water vapor pressure gradients between air and leaves, affecting dark respiration, and modifying soil moisture through evaporation. Previous studies show that $\delta^{13}\text{C}_{\text{org}}$ generally correlates positively with temperature across northern China, particularly in Xinjiang.

The Pamir region follows this general pattern, with $\delta^{13}\text{C}_{\text{org}}$ increasing with temperature. Higher temperatures likely enhance enzymatic activity and photosynthetic rates, reducing carbon isotope fractionation and leading to enriched $\delta^{13}\text{C}_{\text{org}}$ values. In contrast, Qira County shows a negative $\delta^{13}\text{C}_{\text{org}}$ -temperature relationship, similar to patterns in southern China. This may result from temperature-induced enzyme inhibition and stomatal closure to conserve water, combined effects that reduce photosynthetic efficiency and lead to more depleted $\delta^{13}\text{C}_{\text{org}}$ values.

The contrasting water sources—glacier meltwater in the Pamir versus precipitation in Qira—and distinct vegetation types likely contribute to these divergent temperature responses.

4.3 Influence of Precipitation on $\delta^{13}\text{C}_{\text{org}}$ Variation Increased precipitation generally enhances stomatal conductance, leading to more depleted $\delta^{13}\text{C}_{\text{org}}$ values. However, in the Pamir region, $\delta^{13}\text{C}_{\text{org}}$ shows no significant correlation with precipitation, probably because glacier meltwater, rather than direct precipitation, dominates the water supply for vegetation. In Qira County, the significant negative correlation with cold-season precipitation aligns with previous studies in arid regions, where winter moisture is critical for plant survival.

The overall weak $\delta^{13}\text{C}_{\text{org}}$ -precipitation relationship in both regions likely reflects the extreme aridity. With annual precipitation below 80 mm, water availability is too low to exert a strong selective pressure on vegetation isotopic composition, making temperature the primary controlling factor.

5. Conclusions

Our analysis of surface soil $\delta^{13}\text{C}_{\text{org}}$ from the Pamir region and Qira County reveals significant regional differences in environmental controls. Altitude effects differ markedly: $\delta^{13}\text{C}_{\text{org}}$ becomes more depleted with increasing elevation in the Pamir region but more enriched in Qira County, reflecting different water availability patterns. Temperature emerges as the dominant control in both regions, but with opposite correlation directions—positive in the Pamir region and negative in Qira County. These contrasting patterns likely arise from differences in water sources (glacier meltwater vs. precipitation) and vegetation types. Precipitation shows weak correlations with $\delta^{13}\text{C}_{\text{org}}$ in both regions, probably due to extreme aridity limiting its influence.

These findings demonstrate that the relationship between $\delta^{13}\text{C}_{\text{org}}$ and climate factors varies significantly across the southwest margin of the Tarim Basin. When applying $\delta^{13}\text{C}_{\text{org}}$ for paleoclimate reconstruction, it is crucial to consider these regional differences and validate the relationships within specific study areas. The divergent responses highlight the importance of local environmental context in interpreting carbon isotopic records from arid regions.

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