C4 Expansion in the Central Inner Mongolia during the Latest Miocene and Early Pliocene

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Introduction

The expansion of C4 grasses has been widely documented around the world. However, the timing and driving mechanism of C4 expansion remain a contentious issue. Here we report a stable carbon and oxygen isotope study of fossil and modern mammalian (from the Late Oligocene at ~26 Ma to the present) tooth enamels from the central Inner Mongolia (~1000 m above sea level).

Results and Discussion

The $\delta^{13}C$ values of tooth enamel samples from fossil herbivores in central Inner Mongolia display significant temporal variations in $\delta^{13}C$ values reflecting changes in the diets of herbivores. From 26 Ma to ~8 Ma, the $\delta^{13}C$ values of enamel range from -7.6‰ to -13.0‰, with a mean of -9.8 ± 1.2‰ (n = 87, all means reported ± 1 standard deviation), indicating a pure C3 diet. From ~8 Ma to ~3.6 Ma, the $\delta^{13}C$ values display a large range of variation (-2.4‰ to -12.6‰), and 12 out of 30 tooth enamel samples have $\delta^{13}C$ values greater than -8.0‰, indicating that C4 plants were a significant component in the diets of some fossil mammals (up to ~76%C4) and thus possibly a significant component of local ecosystems during the latest Miocene and Pliocene. Bulk enamel samples from two modern horses and one modern cow yield $\delta^{13}C$ values of -8.2 to -12.7‰, indicating a C3-based diet for these modern herbivores, consistent with present C3 dominance in the area. The C4 expansion in central Inner Mongolia occurred much earlier than in the Linxia Basin and in the Chinese Loess Plateau (CLP), both of which are located to the southwest of our study area. In the CLP, C4 first expanded at ~2.9-2.7 Ma (An et al., 2005). Farther west in the Linxia Basin, C4 grasses became an important component of local ecosystems only after ~2.5 Ma (Wang and Deng, 2005). And in both the CLP and the Linxia Basin, C4 plants remain a significant component of the local ecosystem today. We suggest that with the further progressive and significant growth/uplift of the Tibetan Plateau, the East Asian summer monsoon was strengthened and the dominant monsoon wind direction shifted slightly toward the CLP and away from the central Inner Mongolia area, thus diverting moisture away from central Inner Mongolia and to the CLP and later also to the Linxia Basin, resulting in the retreat of C4 plants from the central Inner Mongolia area due to a lack of sufficient growing season precipitation and the subsequent expansion of C4 plants in the CLP and later the Linxia Basin.

Conclusions

Stable carbon and oxygen isotope analyses reveal significant vegetation and climate change in the central Inner Mongolia area: from pure or nearly pure C3 vegetation prior to ~8 Ma, to a mixed C3 and C4 ecosystem between ~8 to ~3.6 Ma, and to the modern day C3-dominated ecosystem. The retreat of C4 plants from this area can be explained by the further progressive and significant uplift of the Tibetan Plateau, which strengthened the East Asian summer monsoon and diverting the moisture away from the study area to the CLP and later to the Linxia Basin.