East Asian winter monsoon intensity in the Pleistocene based on seasonal land snail shell stable isotope ratios

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Monsoon climates are characterized by strong seasonal oscillations between a very wet season and very dry conditions. The study of ancient variation in monsoon climate strength and its impact on regional environments is difficult because geological materials rarely record individual seasons. It is difficult to infer seasonal change through time when working with oxygen isotope records that average multiple years or centuries. One solution is to use high-resolution sampling of land snail shells as monitors of wet-season and dry-season differences. Although land snail fossils are often rare, in many cases they are well preserved and widely distributed across the planet. We subsampled shells along the spiral growth axis, producing 15 to 35 samples per shell to document maximum and minimum oxygen and carbon stable isotope ratios. The most robust signal in land snail shell oxygen isotope records is connected to evaporation. The arid dry-season leads to significant evaporation in the land snail body water, which elevates the δ18O values recorded in the shell. Wet-season oxygen isotope ratios are more negative and can be tied roughly to the δ18O of wet season precipitation and summer temperatures. Carbon isotope ratios are tied to the diet of the animals, and reveal the proportion of C3 and C4 plants in the landscape.

Larger land snail (> 1.5 cm diameter) taxa have behaviors that can lead to significant evaporation of body water, as they are willing to range away from local water sources. Modern samples show that the total amplitude in oxygen isotope variation in a shell can be related to the intensity and duration of the dry season. This suggests that amplitudes in ancient shells are indicators of the winter monsoon strength. Although under extremely arid conditions snail growth occurs only when surface water is available and d18O amplitudes collapse in desert conditions. The most negative δ18O values are not correlated with the intensity of the summer monsoon, suggesting that δ18O values are not good indicators of summer monsoon strength.

Data from one genus of land snail (*Cathaica* species) living on the Chinese loess plateau throughout the late Pleistocene allow us to make some generalizations about monsoon climate in this region. In general, the oxygen isotope amplitude in shells from glacial periods are larger than those from the interglacial periods. This suggests that the East Asian Winter Monsoon was strongest during glacial intervals on the Loess Plateau. The largest δ18O amplitude observed was 19.2 ‰. Marine Isotope Stages 2, 6, and 8 have the largest amplitudes and, by inference, the strongest winter monsoons in our record. Older glacial intervals seem to have weaker winter monsoons. However, glacial amplitudes were not always larger, just as climate undergoes significant short-term variation in glacial intervals (such as D-O cycles and Heinrich events) oxygen isotope amplitudes show large amounts of variability in glacial times. In contrast, interglacial intervals tend to have smaller δ18O amplitudes, pointing to warmer and wetter winters in interglacial times. But like the glacial data, some interglacial amplitudes are larger than some glacial records. These data show that the differences in high frequency climate variability is as large as the differences between glacial and interglacial climates.

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