

## C and O stable isotope compositions of Cenozoic Earth-surface carbonates of all sorts, Part II

The plot on Part I of this pair shows ranges of C and O stable isotope data from an arbitrary selection of Cenozoic, and largely Quaternary, carbonate materials that formed at Earth's surface. Some things to note are that . . .

- 1) The overall range of data is huge: about 38‰ in  $\delta^{18}\text{O}$  and 32‰ in  $\delta^{13}\text{C}$ .
- 2) Continental carbonates (lacustrine carbonates, pedogenic carbonates, tufas, travertines, and speleothems) collectively have a huge range of data and commonly have large ranges within one set of data. This presumably reflects the variability of continental environments across small spaces (for examples, edge to center of a lake basin, top to bottom of a soil profile and location in a soil catena, drip-site to wall of a cave) and through relatively short periods of time (for example, seasonal to millennial climate change).
- 3) Marine carbonates, in contrast, have a comparatively small range of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ . This reflects the extent to which the oceans are a well-mixed mass because of their circulation (largely their deep thermohaline circulation) and a large mass that responds comparatively little to global climate change, compared to the swings in data from continental carbonates. Marine carbonates record the behavior of the difficult-to-disturb dog; continental carbonates record, or simply are, the tail that wags widely.
- 4) Data from non-travertine continental carbonates collectively, and commonly within sets of data, have a greater  $\delta^{13}\text{C}$  than of  $\delta^{18}\text{O}$ . This is because there are multiples sources of carbon to these carbonates, ranging in  $\delta^{13}\text{C}$  from very small values generated by respiration and decay of C3 plants to large values in atmospheric  $\text{CO}_2$ .
- 5) Data from continental carbonates collectively, and within sets of data, show a broad correlation of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . This is largely because wetter settings allow more input of plant-mediated  $\text{CO}_2$  and less evaporation of  $\text{H}_2\text{O}$ , giving smaller values of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . On the other hand, drier settings commonly allow less input of plant-mediated  $\text{CO}_2$  and more evaporation of  $\text{H}_2\text{O}$ , giving greater values of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ .
- 6) Among continental carbonates, material from high altitudes and/or high latitudes commonly has low values of  $\delta^{18}\text{O}$ , presumably because of rain-out effects in the transport of water vapor.

7) Carbonates precipitated at high temperatures typically have small values of  $\delta^{18}\text{O}$  because of the lessened fractionation between water and mineral. Travertines thus commonly have small values of  $\delta^{18}\text{O}$ .

8) Comments 6 and 7 combine to mean that carbonate deposits from hot springs in mountains at higher latitudes have very low values of  $\delta^{18}\text{O}$ , and the travertines from Mammoth Hot Springs at Yellowstone therefore fall far to the left on the plot.

9) Travertines and tufas occupy areas on the plot that overlap to some extent, but travertines generally have lesser values of  $\delta^{18}\text{O}$  and greater values of  $\delta^{13}\text{C}$  than tufas. The former can be explained by the higher temperatures at which travertines form, and the latter can be explained by the lesser involvement, or at least engulfment, of plants in the formation of travertines.

10) Marine carbonates have a small range of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  compared to continental carbonates, but there are predictable variations within marine data sets:

10a)  $\delta^{18}\text{O}$  values in planktic carbonates are typically less than those in abyssal benthic carbonates because surface waters are variably warm but deep waters are invariably cold. Even within those sets of data,  $\delta^{18}\text{O}$  values are greater through time in glacial phases and less in interglacials (the "GM" and "IG" on the plot).

10b) Values of  $\delta^{13}\text{C}$  also vary from planktic to benthic, because photosynthetic removal of  $^{12}\text{C}$  from surface water typical gives greater  $\delta^{13}\text{C}$  in planktic carbonates, whereas oxidation of organic matter at depths gives lesser  $\delta^{13}\text{C}$  in benthic carbonates.

10c)  $\delta^{13}\text{C}$  of benthic carbonates also varies from the Atlantic to the Pacific, because younger deep water in the Atlantic has had less time to accumulate low- $\delta^{13}\text{C}$   $\text{CO}_2$  from oxidation of sinking organic matter, but older deep water in the Pacific has had time to accumulate such  $\text{CO}_2$  and thus gives benthic foraminiferal carbonate with lesser values of  $\delta^{13}\text{C}$ .

11) The range of  $\delta^{18}\text{O}$  values in marine carbonates would be even smaller were it not for the peculiarities of Quaternary glaciation. Both near-freezing bottom-water temperatures and glacial storage of  $^{16}\text{O}$  push the  $\delta^{18}\text{O}$  of benthic forams during glacial maxima to values more than +4 that would not be attained otherwise.