Great Basin Calcite Vein and the Pleistocene Time Scale

Isaac J. Winograd *et al.* (*1*) challenge the conventional Pleistocene time scale, which is based on deep-sea-core oxygen-isotope ratios and stratigraphy (*2*, *3*). Their well-dated oxygen-isotope profile from a calcite vein (DH 2) deposited by Great Basin ground water 21 meters below the water table in Devils Hole, southeastern Nevada, covers an interval from 50 to 280 ka (thousand years ago). They list possible effects that could influence the DH 2 isotope ratios and conclude that, because the oxygen-18 ($\delta^{18}O$) (*1*, p. 1276) in worldwide precipitation correlates with surface air temperatures, the peaks in the DH 2 profile are therefore associated with maxima in mean annual surface-air temperatures corresponding to interglacial and interstadial warm climates. The DH 2 profile bears a resemblance to that typically found in carbonate microfossils in deep-sea sediments, although critical data for the last glacial extreme 18 ka is missing. However, the positive $\delta^{18}O$ peaks occur substantially earlier than the interglacial peaks in deep-sea cores, the difference being about 15,000 and 20,000 years, respectively, for the DH 2 "interglacial peaks," which have an amplitude of as much as 2 per mil and precede glacial terminations II and III in the deep-sea-core record.

Alternative causes for the DH 2 data peaks are consistent with the conventional time scale and with the climatological record. We replotted the DH 2 data on a time scale (Fig. 1) that incorporates the 16,000-year ground-water residence time suggested by Winograd *et al.* We found that the two broad positive $\delta^{18}O$ peaks then closely coincide not with peaks, but rather with major minima of the deep-sea-core $\delta^{18}O$ record. These features correspond to the Illinoian glaciation of 150 ka and to the next earlier major glaciation, which occurred about 270 ka. The results of this replotting lead to the question, "What factors might have caused positive isotope-ratio peaks at the DH 2 site during such glaciations?"

A major factor in the isotope ratios is the ^{18}O enrichment of the source water vapor reaching the DH 2 site from the ocean. At glacial extremes the average ocean $\delta^{18}O$ was about 1.3 per mil more positive, as noted by Winograd *et al.*, and this difference would surely have contributed directly to the DH 2 peaks. In addition, three other positive effects are associated with a lower-latitude moisture source. At the last glacial extreme, the source vapor for the southwestern United States was drawn from lower latitude ocean surface water, as indicated by paleoclimate model results reported by the Cooperative Holocene Mapping Project group. (*4*). They show that, under the domination of the maximum continental ice sheet, the jet-stream trajectory marking the path of more prevalent winter storms into the southwestern United States 18 ka crossed the coast west of the DH 2 area at 30° to 35°. This is in contrast with the modern path, which crosses much farther north in southern Canada at about 50°N. The lower latitude ocean source during glacial times would therefore have supplied (i) vapor from water which had a $\delta^{18}O$ that was about 1.4 per mil more positive due to the lower latitude surface water composition difference (*5*); (ii) vapor with a $\delta^{18}O$ value that was 0.7 to 1.6 per mil more positive because of evaporation at the warmer temperatures (3° to 7°C) of low latitudes (*6*, figure 1; *7*); and (iii) vapor which experienced less ^{18}O depletion by fractionation because of a shorter path to the DH 2 site over lower altitude land. All these factors could have significantly enriched the Great Basin precipitation in ^{18}O at glacial extremes, perhaps by as much as 4 per mil.

On the other hand, the interpretation of Winograd *et al.* would be supported by the effects of the atmospheric absolute humidity that influence the temperature required to initiate condensation of precipitation. The lower humidity during desiccated interglacials like the present (*4*, *8*) in the U.S. Southwest would result in lower condensation temperatures and a tendency toward more positive $\delta^{18}O$ precipitation values. However, measurements of deuterium isotopes from wood recovered from Holocene lake sediments in the San Juan Mountains in southern Colorado by Friedman *et al.* show a strong *negative* trend in the δD values (which generally follow $\delta^{18}O$ relations) from 9.5 ka to the present. This change, during an interval of increasing desiccation, is attributed to a probable change in moisture source, not atmospheric temperature (*9*).

We conclude that several hypotheses could explain the Devils Hole data beyond the single proposal offered by Winograd *et al.* We favor the factors enumerated above: moisture derived from relatively warm, low-latitude Pacific Ocean waters already enriched in ^{18}O, with a short travel distance of air masses to Devils Hole driven by the course of the displaced jet stream, and without the isotope fractionation that occurs today due to a longer land path and strong lifting over the western mountains. This interpretation, combined with the 16,000-year shift in the time scale to account for the ground-water residence time, would permit our revised mirror-image $\delta^{18}O$ profile for Devils Hole (Fig. 1) to support rather than oppose the chronology from deep-sea cores.

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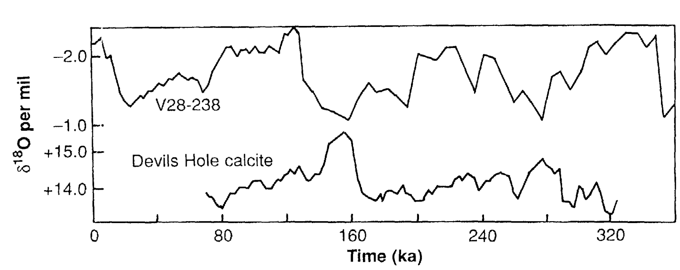

Fig. 1. Comparison of oxygen-isotope ratios from uniformly deposited tropical deep-sea core V28-238 (*10*) with those of Devils Hole (DH 2) calcite reported in (*1*). The calcite values have been displaced backwards 16,000 years on the time scale to compensate for ground-water residence time.

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Response: Johnson and Wright present an imaginative attempt to reconcile the discrepancy in the timing of glacial termination II in the Devils Hole (DH 2) and marine oxygen-18 ($\delta^{18}O$) curves. First, the prepon-