

Last interglacial in Devils Hole

SIR — Broecker in *News and Views*¹ confessed himself confused by the apparent contradiction between the chronologies for the last interglacial presented by the Devils Hole (Nevada) calcite vein² and that generally accepted by adherents to the Milankovitch theory³. I suggest that the discrepancy arises from an unforeseen consequence of dating this unusual deposit by measuring the growth of ²³⁰Th from its parent ²³⁴U.

The oxygen-isotope record from core DH11 (ref. 4), obtained from a calcite crust in the Devils Hole, provides an apparently amazing confirmation of the global validity of the continuous marine $\delta^{18}\text{O}$ records as a description of the first order pattern of the ice ages. Almost every detail in the SPECMAP stacked $\delta^{18}\text{O}$ record³ can be recognized in this precisely dated core which is only 36 cm long (Fig. 3 of ref. 4). The one apparent discrepancy that leads these authors² eloquently to disagree with the authors of the SPECMAP paper³ is a seemingly crucial disagreement in the timing of the onset of the last interglacial.

The Devils Hole is a water-filled fault fissure about 1.2 m wide lined with a thick layer of calcite; it is this layer of calcite that was sampled. The calcite and associated uranium has been deposited from the water. Ages are estimated from the ingrowth of ²³⁰Th in apparently technically ideal conditions². The average accumulation rate is about 0.6 mm per kyr, although over the critical interval of interest 5.5 mm accumulated between 149.8 and 131.9 kyr, a rate of about 0.3 mm per kyr. If we envisage the water from half the width of the fissure contributing to the calcite on each side, then out of the 0.6 m thick layer of water, calcite was deposited at a rate of 0.8×10^{-4} g cm⁻² of surface per year. The calcite contains about 0.5 p.p.m. uranium (Table 1 of ref. 5) so that uranium is deposited at a mean rate of 0.4×10^{-10} g cm⁻² of surface per year.

An important difference between the Devils Hole situation and the cave speleothems that have usually been dated by this method (reviewed in ref. 6) is that the vein is continuously in water. This difference is important because one must consider the fate of the ²³⁰Th that

is produced by decay of dissolved ²³⁴U in the water. A layer of water 0.6 m thick and containing 3 p.p.b. uranium (ref. 7 and I. J. Winograd, personal communication) represents 0.18×10^{-6} g of uranium per cm² of the fissure face, and thus will generate in one year a quantity of ²³⁰Th about 4.5×10^5 times the amount generated by the decay of the uranium in one year's accumulation on the vein. Because thorium is very insoluble, this ²³⁰Th will immediately attach to the surfaces of the cavern, so that even though the ²³²Th concentration of the calcite is negligible, zero-age calcite could have an apparent age of the order of 5×10^3 yr if age is estimated on the assumption that freshly deposited calcite contains no ²³⁰Th. Although this ²³⁰Th excess will decay with time, its contribution to the apparent age remains a constant number of years. Moreover, the initial age error would vary inversely with the growth rate; it would be difficult to interpret the apparent 60 kyr age obtained for the outer part of the calcite where calcite accumulation must have slowed towards zero with an ever increasing "initial age", although the excellent ²³⁴U/²³⁸U data provide a valuable constraint.

I conclude that rather than being a thorn in our flesh, the record generated by Winograd and colleagues⁴ is both the most impressive record of the ice ages from the American continent, and a remarkable demonstration of the ubiquity of the characteristic record that has been so widely documented in the sediments of the deep ocean. The general validity of the timescale currently in use is strongly supported by the impressive ²³⁴U chronology², but despite the technical excellence of the ²³⁰Th measurements, I suggest that the potentially large contribution from unsupported ²³⁰Th precludes their use to refine our best estimate for the age of the last interglacial.

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LUDWIG *ET AL.* REPLY — Our disagreement with SPECMAP and with the Milankovitch hypothesis stems not only from the "timing of the onset of the last interglacial", as claimed by Shackleton, but also from the following features of the Devils Hole record: the 20-kyr duration of the interglacial climates; an increasing duration of the quasi-100-kyr cycle as we come forward in time; and the occurrence of a well-developed glacial cycle at 350–450 kyr when the insolation theory indicates none should occur⁴.

With regard to the ²³⁰Th excess issue,

properly raised by Shackleton, we note that: (1) groundwater flow in Devils Hole is laminar, whereas turbulent flow would be required to efficiently transfer water-generated ²³⁰Th to the cavern walls; (2) particulate scavenging of ²³⁰Th, followed by gravitational settling, is strongly suggested by the contrast between the textures of footwall vein calcite compared to hanging wall vein calcite. (Footwall calcite in Devils Hole is coloured and finely banded, whereas hanging wall calcite — such as samples DH-11 and DH-2 — is white-to-yellowish white and rarely banded.); (3) the necessity of allowing for groundwater travel time means that the age of the onset of the last interglacial recorded in DH-11 (140 ± 3 kyr) must itself be too young by several thousand years; and (4) most conclusively, since receipt of an earlier draft of Shackleton's correspondence, we have measured the ²³⁰Th-²³⁴U-²³⁸U of the outermost surface (to a depth of 40–50 μm) of vein samples DH-2 and DH-11 and found only a negligible fraction (<1%) of the excess ²³⁰Th predicted by Shackleton. These analyses⁸ show that the effect of water-generated excess ²³⁰Th, accumulated on the surface of these veins during the past 60 kyr, corresponds to an age-bias of less than 20 years over the entire history of vein calcite accumulation for DH-11 and DH-2.

Shackleton reasonably asks whether ²³⁰Th in the Devils Hole water column could have significantly affected the accuracy of the ages we reported^{2,4}. However, neither the character of the aqueous environment, the petrology of the calcite, nor direct measurements of excess ²³⁰Th on the surface of the veins supports the 5 kyr age-bias suggested by Shackleton.

The Devils Hole dates^{2,4} therefore remain a challenge to the Milankovitch hypothesis.

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Scientific Correspondence

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