

Comment on “Mixed-Layer Deepening During Heinrich Events: A Multi-Planktonic Foraminiferal $\delta^{18}\text{O}$ Approach”

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Rashid and Boyle (Reports, 19 October 2007, p. 439) analyzed oxygen isotopes in planktonic foraminifera from marine sediments and concluded that Heinrich events (massive iceberg discharges into the North Atlantic Ocean) caused upper water masses to deepen. We question the robustness of this interpretation and argue that a strongly stratified mixed layer characterized by dense sea-ice cover and production of oxygen-18–depleted brines likely prevailed during such events.

Rashid and Boyle (1) argued that substantial mixed-layer deepening occurred during Heinrich events (HEs) in the North Atlantic Ocean, citing similar oxygen isotope variations in mixed-layer- and thermocline-dwelling planktonic foraminifera during HEs 0, 1, and 4 as evidence. This hypothesis was already put forth by Hillaire-Marcel and Bilodeau (2) based on comparative $\delta^{18}\text{O}$ analysis of two of the planktonic foraminifera studied in (1)—*Globigerina bulloides*, an epipelagic species, and *Neoglobobulimina pachyderma* sinistral (s), a left-coiling deeper dwelling species—in a deep Labrador Sea sequence. However, further investigations lead the authors of (2) to reject this hypothesis. Rather, multiproxy approaches indicate dense sea-ice cover and strong stratification of surface waters during most Heinrich events, including HE0 (3, 4). More important, the data used by Rashid and Boyle do not unequivocally support their conclusion, and their interpretation bypasses basic ecological requirements of the foraminifera they studied.

Turning first to the analysis of sediments from Chain 82 Station 50 Core 20 (CHN82-20) [figure 3A in (1)], the overall data resolution is low and does not permit one to infer a similar water mass structure for all HEs. In the layers corresponding to HE4, HE1, and HE0, where a better resolution is achieved, $\delta^{18}\text{O}$ records differ between layers and species and occasionally depict opposite trends (compare *G. bulloides* versus *N. pachyderma* (s) in HE0). In core CH69-K09 [supporting online material in (1)], some oscillations of *G. bulloides* seem in phase with those of *N. pachyderma* (s), but this is not the case in HE0 and HE5.

Next, although the claim of similar (lighter) $\delta^{18}\text{O}$ values of the different foraminiferal species

in core CHN82-20 seems plausible for HE1, closer examination raises questions about the robustness of this claim. A sharp, light isotopic shift at the base of HE1 seen in core CH69-K09 suggests that *G. bulloides* and *N. pachyderma* (s) are simply recording the ^{18}O shift of meltwater pulse 1A [e.g., (5)]. An out-of-phase return to heavier $\delta^{18}\text{O}$ values follows, first in *G. bulloides* and later in *N. pachyderma* (s) (when, on the contrary, *G. bulloides* returns to lighter $\delta^{18}\text{O}$ values). Furthermore, the isotopic record attributed to the right-coiling *N. pachyderma* dextral (d) in core CHN82-20 is curious: Almost flat throughout most HE events, it shows a short, heavy excursion [~ 3 per mil (‰)] just before HE1 and switches to lighter $\delta^{18}\text{O}$ values (< 2 ‰) from HE1 to the present. This unusual behavior leads us to question the possible mixing, in *N. pachyderma* (d) assemblages, of *N. incompta* (6), a more thermophilous right-coiling species whose isotopic records resemble those of *G. bulloides*, whereas right-coiled specimens of *N. pachyderma* closely follow the isotopic behavior of their left-coiled parent (7). In many studies, and possibly in the study of Rashid and Boyle, the distinction between these two right-coiled forms of *Neoglobobulimina* has been ignored. Heavy excursions in the isotopic records referred to as *N. pachyderma* (d) may therefore correspond to enhanced relative contributions of dextral forms of *N. pachyderma* (s.s.), when *N. incompta* shells are less abundant, due to colder conditions in surface waters. Thus, the abundance and isotopic composition of *N. pachyderma* (d) reported in (1) could potentially be misleading.

The abovementioned data ambiguities and discrepancies in $\delta^{18}\text{O}$ values between sites and different HEs open the door to other possible interpretations. Moreover, caution is needed when comparing isotopic properties of *N. pachyderma* (s) with those of more temperate species, such as *G. bulloides*, at sites and during situations when the development of warmer species was certainly

sporadic. *N. pachyderma* (s) may have found suitable temperature conditions during HEs, but it seems unlikely that *G. bulloides* did. Although this species has been observed across a broad range of surface water temperatures, it fully develops in the modern northwest Atlantic, at sites where summer surface temperatures range between 8 and 12°C (8). When simultaneously present, *N. pachyderma* (s) calcifies relatively deeper along the pycnocline, in colder waters (9). Adapted to very high salinity (10), *N. pachyderma* (s) seems to require salinities above 34.5 (11) and develops well from about 4°C to near freezing temperatures, in Arctic and sub-Arctic environments. In the modern northwest Atlantic, the upper temperature threshold probably matches that of its habitat, on top of the upper Labrador Sea Water mass (12). Thus, it seems difficult to imagine that *G. bulloides* and *N. pachyderma* (s) shared the same “homogenized upper water column” during the relatively cold spell of the HEs, when iceberg dispersal and sea-ice spreading would probably have induced overall cold conditions, unsuitable for *G. bulloides*, and low-salinity conditions, unsuitable for *N. pachyderma* (s). It seems more likely that *G. bulloides* developed only sporadically when exceptionally warm summers occurred, and even possibly that sparse *G. bulloides* shells (alive but not calcifying) could have been transported by currents from distal warmer productive areas to the area under HE influence [e.g., (13)]. Thus, $\delta^{18}\text{O}$ values of *G. bulloides* cannot be linked unequivocally to *N. pachyderma* (s) records. Caution is also required when peaks in foraminiferal abundances are found above Heinrich layers [as in (1)], when more temperate conditions favorable for *G. bulloides* resumed. In such cases, the possible “injection” through bioturbation of isotopically lighter *G. bulloides* shells in the underlying Heinrich layer cannot be discarded. This is particularly critical in light of the low sedimentation rates ranging from 2.5 to 4.5 cm/thousand years (ky). Evidence for such injection of *G. bulloides* into *N. pachyderma* (s)-dominated layers has been provided by Duplessy *et al.* (14) based on comparative ^{14}C chronologies in a North Atlantic core.

A final argument to consider relates to the nearly stopped or sluggish Atlantic Meridional Overturning Circulation proposed during HE1 and HE4 [and, to a lesser extent, during HE0 (15)]. This must have resulted in relatively large salinity gradients along the halocline between the surface and intermediate water masses, a situation unlikely to lead to identical isotopic forcings for species developing at both extremities of the halocline. Rashid and Boyle (1) hint at the possible impact of brine production but then dismiss the idea without full explanation. Enhanced sea-ice cover during HEs, resulting in the addition of isotopically light brines along the halocline, as in the modern Arctic Ocean (16), could indeed explain some light isotopic excursions along the whole pycnocline.

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