The Timing of Atmosphere and Ocean Changes during an Abrupt Climate Change

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The abrupt warming at the end of the Younger Dryas cold period (about 11,500 years ago) contains a wealth of information about the nature and timing, and thus the mechanisms, of abrupt climate change. The warming on the ice sheet of about 15˚C was completed in a human lifetime, about 50 years (Dansgaard, et al 1989). Recently, we showed that this warming was not uniform, but rather had at least two steps, each lasting about one decade, with decade long plateaus in temperature in between. The excellent agreement between the stable isotope ratio records from four ice cores ranging from southern Greenland (DYE3) to northern Greenland (NorthGRIP) confirms that the steps are climate, and not local artefacts of individual ice core records. Past studies of the nature of this abrupt warming have focused on the inter-relationships between stable isotopes, ice chemistry and accumulation (Taylor et al, 1997). Here, we examine the interrelationships between stable isotope ratios and ice and the deuterium excess of the ice. The former records ice sheet conditions, primarily temperature changes, but also potentially changes in the seasonality of snow. The latter is sensitive to the physical conditions of evaporation at the ocean moisture sources, primarily sea surface temperature, but also potentially humidity and wind speed. We look first at the timing between the stable isotope ratios and the deuterium excess, which indicates if the ocean is leading the atmosphere, or vice versa. There are many sub-events during the warming, and in general, the ocean appears to be the first to record changes in the environment. However, this is not universally true, and the initial abrupt warming on the ice sheet, for example, appears to precede the abrupt retreat in sea ice at the beginning of the warming. Also, while the variations in the stable isotope ratios during the warming between four deep ice cores in Greenland (DYE3, GISP2, GRIP and NorthGRIP) are quite similar, the deuterium excess records show consistent differences, indicating that while climate over the Greenland ice sheet is relatively uniform at this time, the conditions over the ocean appear to be more heterogeneous, and those patterns may hold valuable clues to the mechanisms driving this abrupt warming.

References

Dansgaard, W., J. W. C. White, and S. J. Johnsen, (1989) *Nature*, **339**, 532-534.

Taylor, K.E and 12 others, (1997) *Science*, **278**, 825-827.

Constraints on ^{232}Th/^{238}U in the crust from Pb isotopes and heat flow

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Recent estimates of the ^{232}Th/^{238}U ratio (κ) in the continental crust vary from 3.87 to 6.01. This is a surprisingly large uncertainty, given the chemical similarity of these elements and their importance in heat production and Pb isotope evolution. Here we use heat flow, mass balance, and forward evolutionary modelling to better constrain this ratio. We use lower crustal xenoliths to estimate the ^{208}Pb/^{204}Pb of the lower continental crust to be 37.36 to 37.84 (corresponding to the range of ^{206}Pb/^{204}Pb and ^{207}Pb/^{204}Pb of RUDNICK and GOLDSTEIN (1990) of 16.49 to 17.20 and 15.20 to 15.55 respectively). This implies a time-integrated ^{232}Th/^{238}U (κ_{Pb}) of 4.30 to 4.46. The upper crustal Pb isotopic composition of ASMERON and JACOBSEN (1993) corresponds to a κ_{Pb} of 4.20. Combining these estimates, the entire continental crust has ^{206}Pb/^{204}Pb = 18.43, ^{207}Pb/^{204}Pb = 15.62, ^{208}Pb/^{204}Pb = 39.02 and κ_{Pb} of 4.25. Using a forward model of Pb isotope evolution in a 3-layer Earth (crust, depleted mantle, primitive mantle), a present-day value of κ in the continental crust of 5 is required to produce a time-integrated κ of 4.25. Assuming a K/U of 12,500, our model crust produces 7.7 TW of heat, well within the range geophysical-based estimates. Finally, since κ in the depleted upper mantle and bulk silicate Earth are well constrained at 2.5±0.1 and 4.0±0.2 respectively, and because Th contributes to mantle heat flow, κ in the continental crust can be estimated from mass balance. Assuming that the depleted upper mantle is 45% of the mass of the mantle (TURCOTTE et al., 2001), a minimum value for the mantle Urey ratio (ratio of radiogenic heat production to heat flow) of 0.4, and that the remaining mantle is primitive, the minimum value of κ in the crust is 4.68. Higher mass fractions of depleted mantle and Urey numbers imply higher κ in the crust. Oceanic island basalts have mean κ of 3.8. If these values characterize the lower mantle, even higher values of κ are required in the crust. WEDEPOHL'S (1995) estimate of Th/U in the crust best fits these constraints.

References

ASMEROM, Y. & Jacobsen, S. B. (1993) Earth Planet. Sci. Lett. **115**: 245.

RUDNICK, R. & GOLDSTEIN, S. L. (1990) Earth Planet. Sci. Lett. **98**: 192.

TURCOTTE, D.L., PAUL, D. & WHITE, W.M. (2001) J. Geophys. Res., **106**: 4265.

WEDEPOHL, K. (1995) Geochim. Cosmochim. Acta, **59**: 1217.