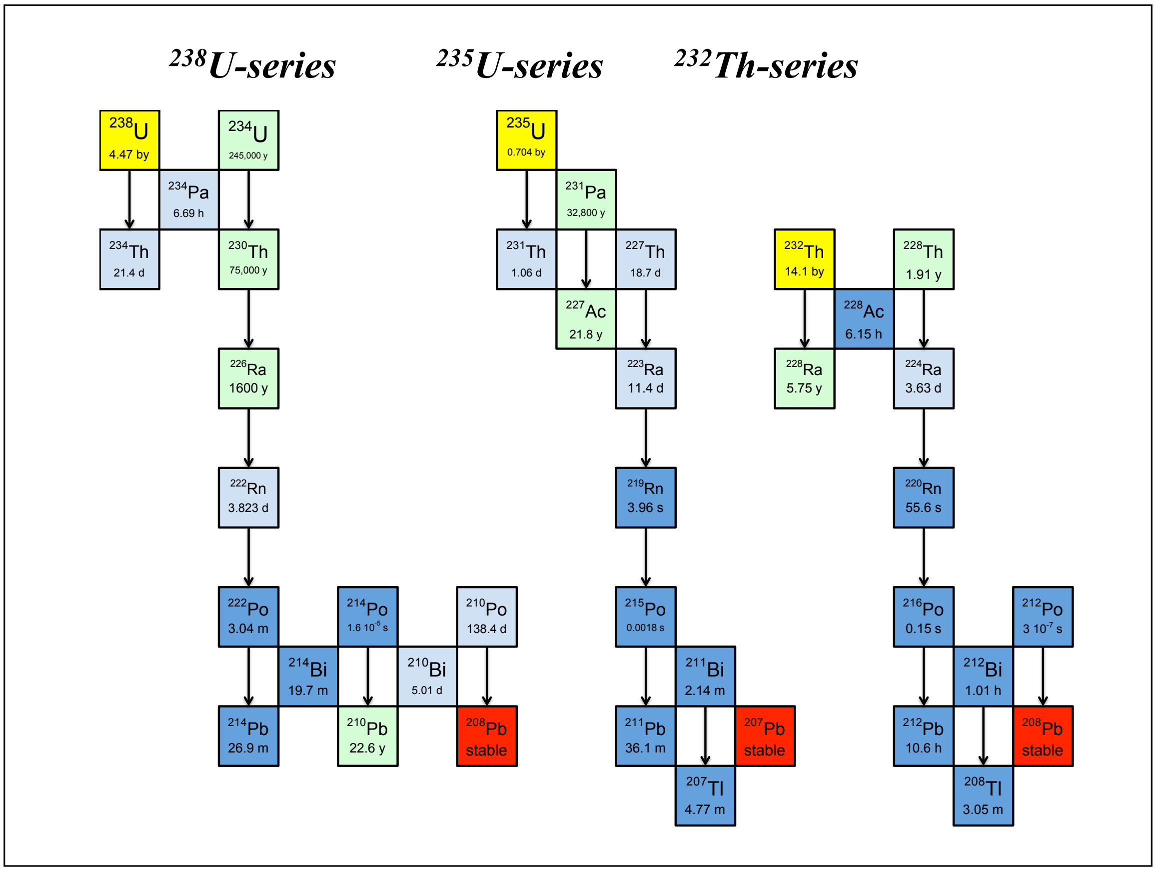
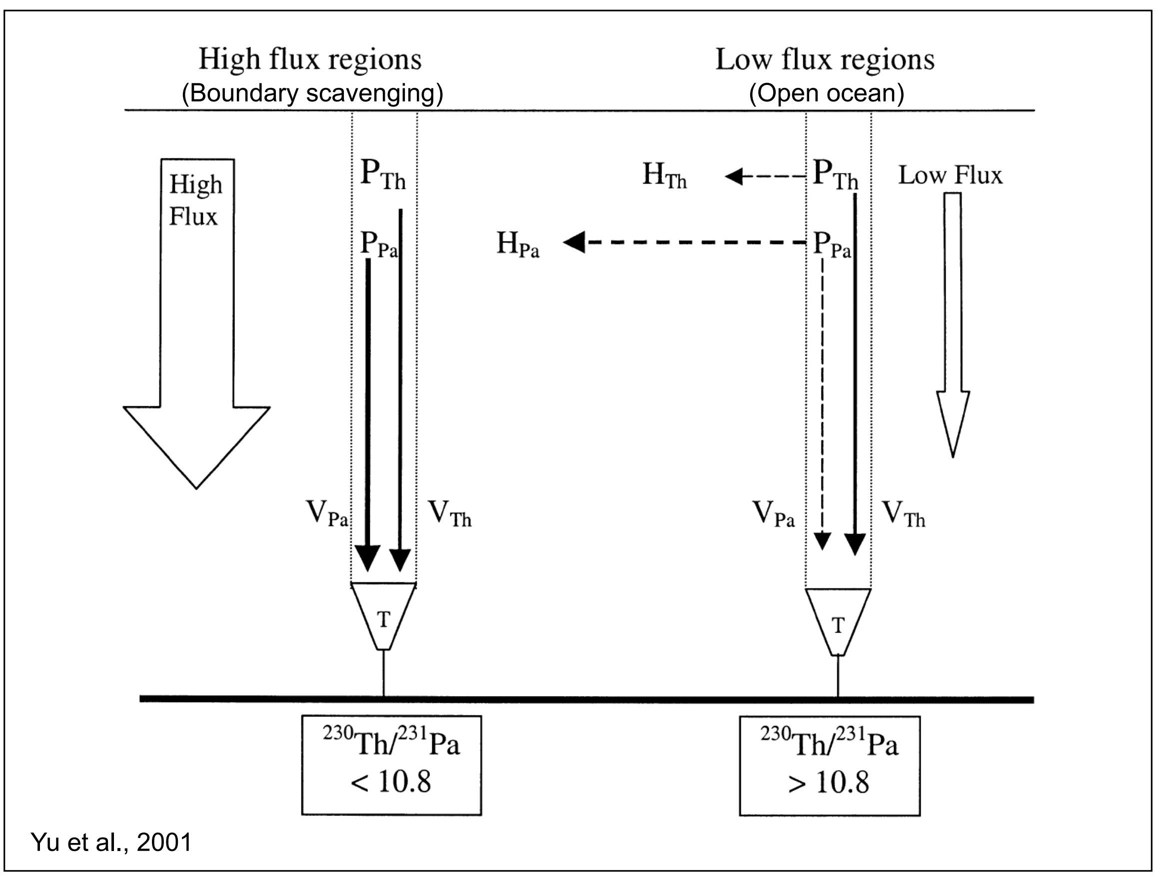
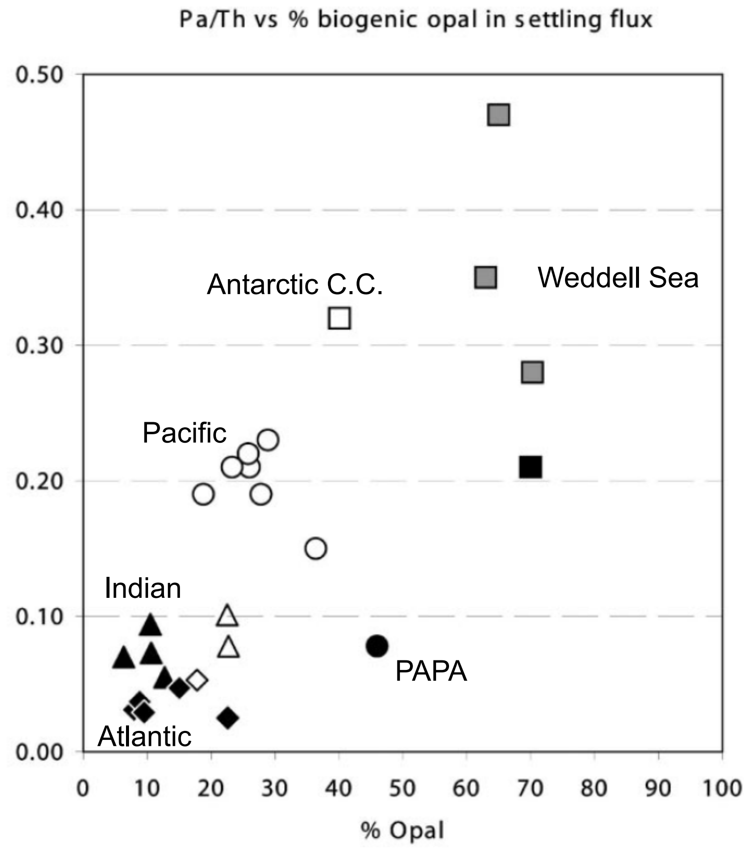


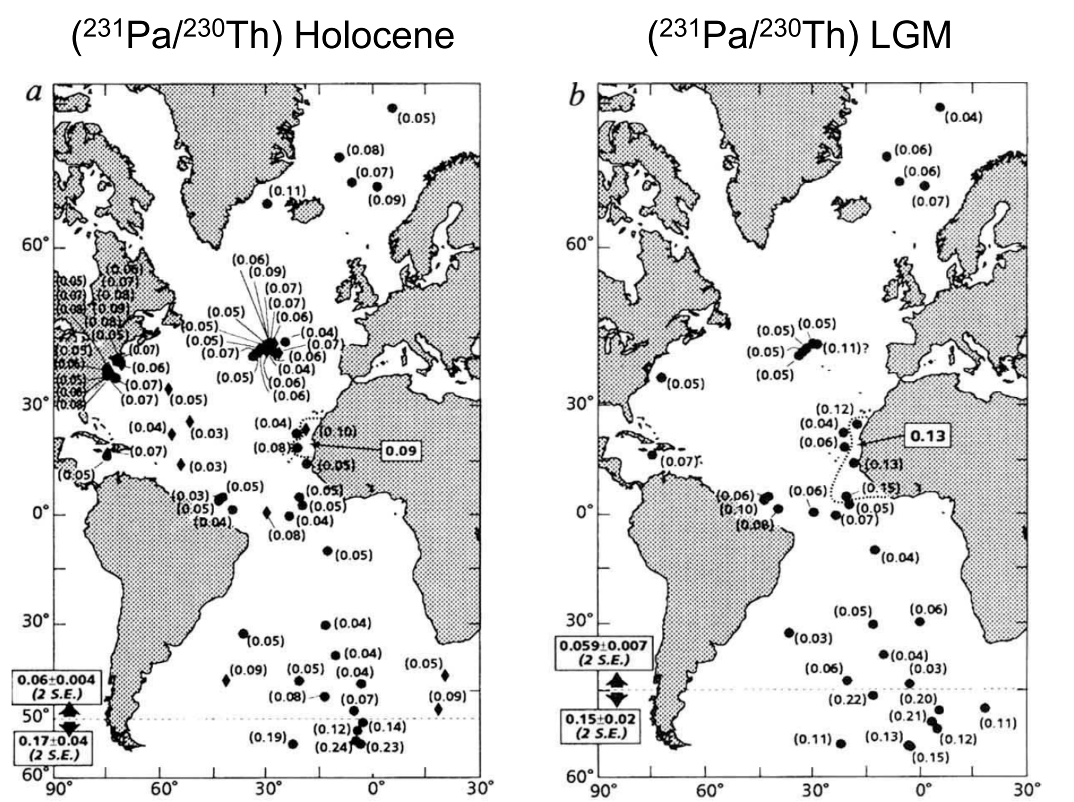
238U-series
235U-series
232Th-series
238U 4.47 by
234U 245,000 y
234Pa 6.69 h
234Th 21.4 d
230Th 75,000 y
226Ra 1600 y
222Rn 3.823 d
222Po 3.04 m
214Po 1.6 10-5 s
210Po 138.4 d
214Bi 19.7 m
210Bi 5.01 d
214Pb 26.9 m
210Pb 22.6 y
208Pb stable
235U 0.704 by
231Pa 32,800 y
231Th 1.06 d
227Th 18.7 d
227Ac 21.8 y
223Ra 11.4 d
219Rn 3.96 s
215Po 0.0018 s
211Bi 2.14 m
211Pb 36.1 m
207Pb stable
207Tl 4.77 m
232Th 14.1 by
228Th 1.91 y
228Ac 6.15 h
228Ra 5.75 y
224Ra 3.63 d
220Rn 55.6 s
216Po 0.15 s
212Po 3 10-7 s
212Bi 1.01 h
212Pb 10.6 h
208Pb stable
208Tl 3.05 m



High flux regions
(Boundary scavenging)
Low flux regions
(Open ocean)
High Flux
P_Th
P_Pa
V_Pa
V_Th
T
H_Th
H_Pa
Low Flux
230Th/231Pa < 10.8
230Th/231Pa > 10.8
Yu et al., 2001



Yu et al., 2001



Yu et al., 1996

Nd isotope composition of continental margins

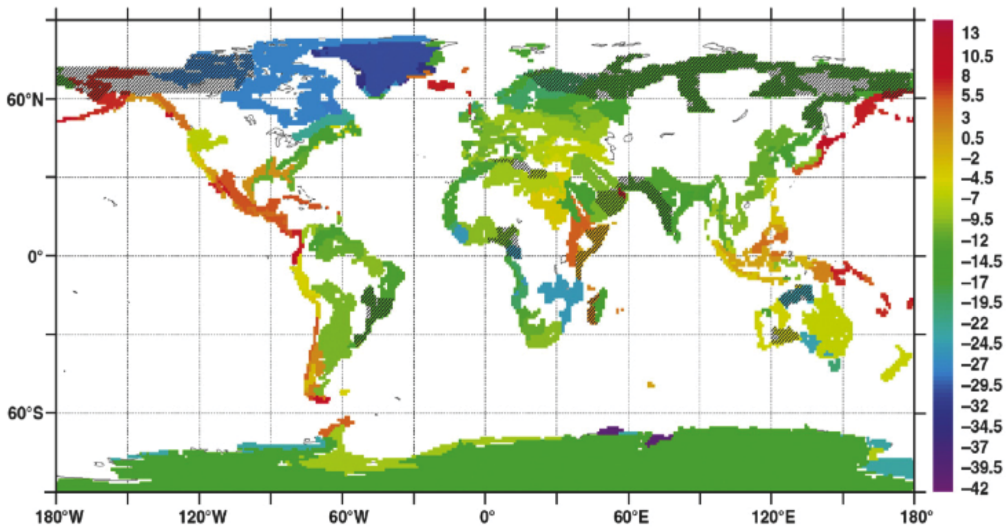
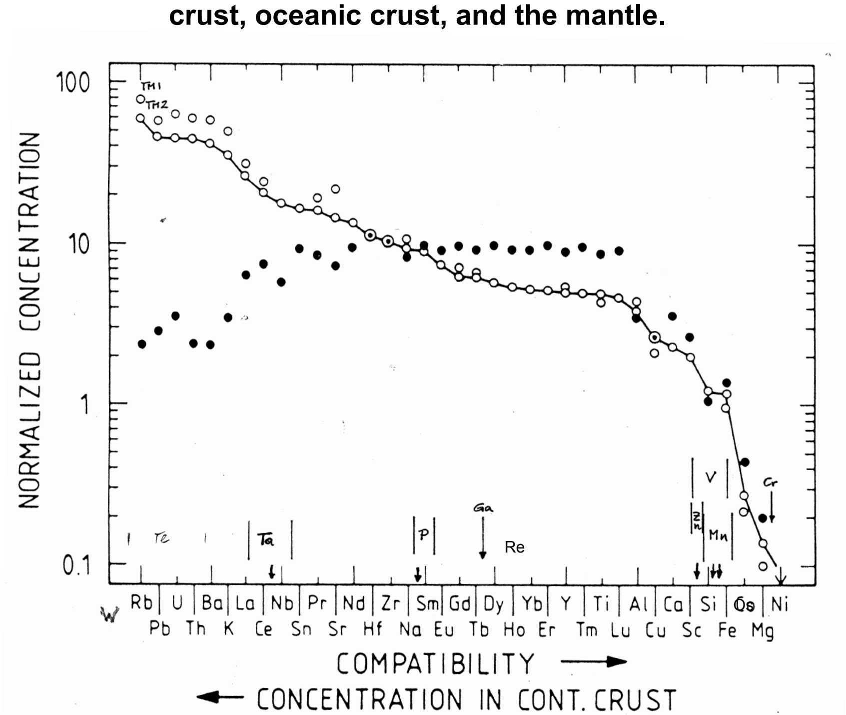


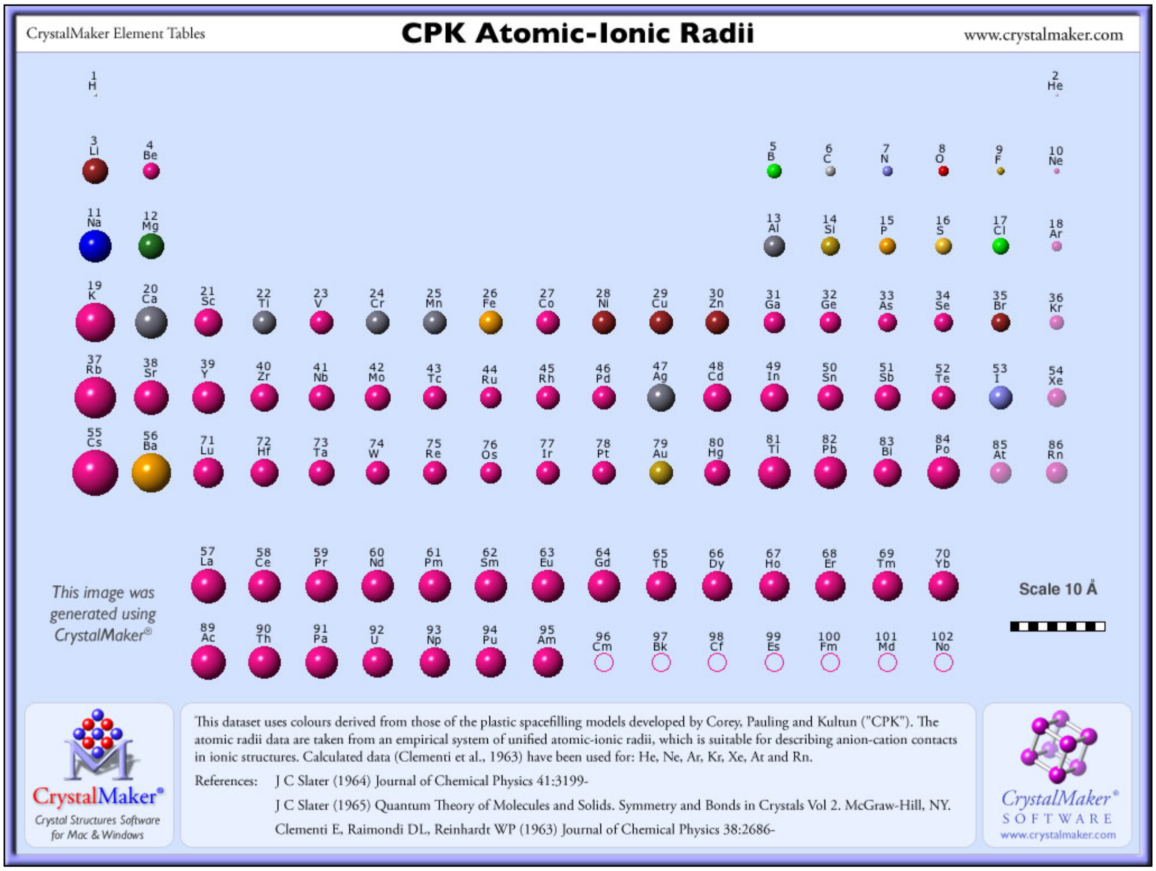
Fig. 2. Extrapolated map providing a picture of the Nd signature of all the margins surrounding the ocean. Same colour coding as in Fig. 1. Hatched areas correspond to those for which Nd signature was estimated because they were uncharacterized in the published literature, to our knowledge.

Jeandel et al., Chem. Geol., 2007

Chemical differentiation of Earth: The relationship between continental crust, oceanic crust, and the mantle.



after Hofmann, EPSL 90, 297-314, 1988



…two step model of Earth differentiation…

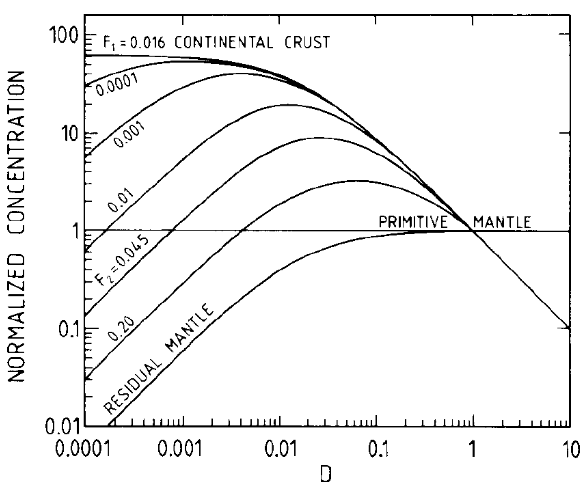


Fig. 3. Normalized concentrations of arbitrary chemical elements as a function of bulk partition coefficient. The curve labeled $F_1 = 0.016$ represents a partial melt of the primitive mantle. The curve labeled "residual mantle" represents the residue from the F_1 partial melt, and the remaining curves labeled $F_2 = 0.2$ to $F_2 = 0.0001$ represent partial melts of this residue. These have been calculated from equations (1), (2), and (3), assuming that the bulk partition coefficients $D_1 = D_2$ for all elements. Stage 1 simulates a partial melt with the composition of the continental crust, and its melt fraction is chosen to match approximately the maximum normalized concentration found in average continental crust. The second-stage melt that matches the concentration maximum of MORB (= 9 to 10 times primitive mantle) is obtained for a melt fraction of $F_2 = 0.045$.

Bulk partition coefficient: $D = c_{solid}/c_{melt}$
Concentration in melt: c
Concentration in primitive mantle: c_0
Normalized concentration in melt: C^*
Melt fraction: F
Subscripts $_1$ and $_2$: stage 1, stage 2

1) $C_1^* = c_1 / c_0 = 1 / \{D_1 + F_1 (1 - D_1)\}$

2) $C_{res}^* = D_1 C_1^*$

3) $C_2^* = c_2 / c_0 = D_1 / \{[D_1 + F_1 (1 - D_1)] [D_2 + F_2 (1 - D_2)]\}$

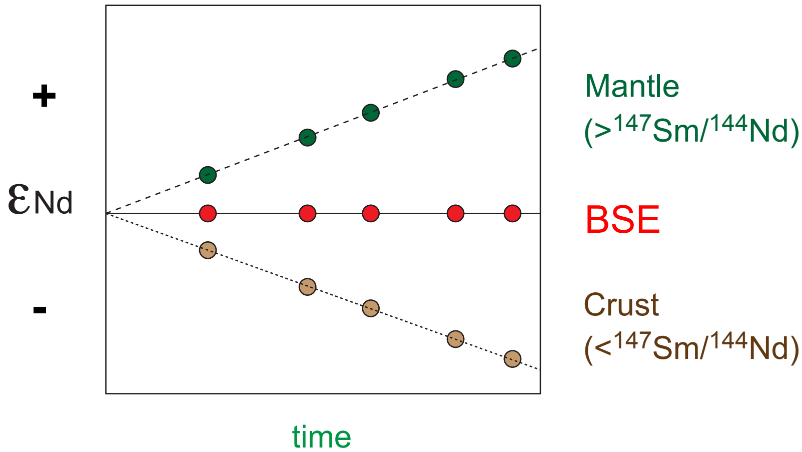
after Hofmann, EPSL 90, 297-314, 1988

^{147}Sm α–decays to $^{143}Nd + ^{4}He$ ($t_{1/2}$ = 146 Gyr)

$$^{143}Nd_m = {}^{143}Nd_i + {}^{147}Sm\,(e^{\lambda t} - 1)$$

$$^{143}Nd/^{144}Nd_m = {}^{143}Nd/^{144}Nd_i + {}^{147}Sm/^{144}Nd\,(e^{\lambda t} - 1)$$

Note ε notation
Small difference in D,
small fractionation



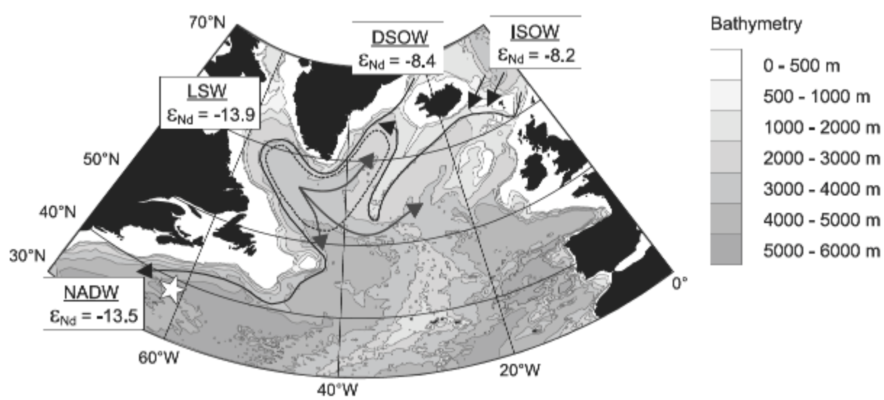


Figure 1. Bathymetric map with key features of the deep circulation of the North Atlantic. Solid arrows highlight the highly simplified deep ocean circulation pattern in the North Atlantic, with the stippled line indicating the major recirculation pathway in the subpolar North Atlantic [*Schmitz and McCartney*, 1993; *Dickson and Brown*, 1994]. Shaded arrows mark the flow of Labrador Seawater. Additionally, inflow of Southern Ocean water (Lower Deep Water) takes place in the western and eastern basins, and waters communicate between both basins through the Charlie Gibbs Fracture Zone at 52°N. Extensive recirculation also takes place in the eastern North Atlantic and along the Deep Western Boundary Current off North America (not shown) [*Schmitz and McCartney*, 1993]. Star marks the sampling location of deep-sea corals on the New England seamount chain. Boxes refer to water masses originating from the two main areas of convection in the North Atlantic, which are the Labrador Sea (Labrador Seawater (LSW)) and the Nordic Seas (Denmark Strait Overflow Water (DSOW) and Iceland-Scotland Overflow Water (ISOW)) Numbers denote the Nd isotopic compositions of waters formed in these areas, respectively [*Piepgras and Wasserburg*, 1987; *Lacan and Jeandel*, 2004a, 2004b, 2005a]. Mature North Atlantic Deep Water (NADW) carries a signature of −13.5 ± 0.5 [*Piepgras and Wasserburg*, 1987].

The Nd isotope vs Pa/Th Controversy

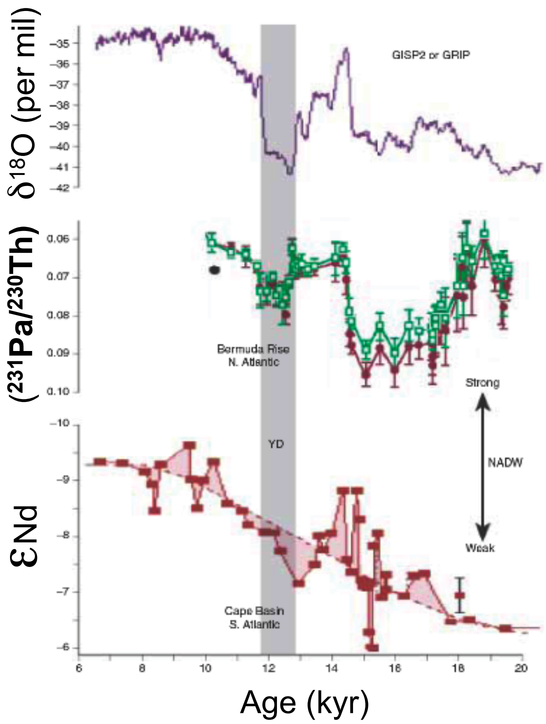


Figure 10. A comparison of two ocean tracers, both thought to provide information about the rate of past flow of North Atlantic Deep Water (McManus et al., 2004; Piotrowski et al., 2004). Although both tracers agree that flow was strong during the Holocene and weak during the Younger Dryas, $^{231}Pa/^{230}Th$ (middle) suggests a high rate of flow at around 19 kyr whereas ε_{Nd} (bottom) suggest a minimum flow rate. This illustrates the need to better understand proxies for past environmental change. The upper panel shows a proxy record for air temperature over Greenland based on the stable isotope composition of the ice (higher $\delta^{18}O$ values correspond to warmer temperatures) for reference. McManus et al. (2004) figure adapted by permission from MacMillan Publishers Ltd: Nature, Copyright (2004). Piotrowski et al. (2004) figure adapted by permission from Earth and Planetary Science Letters, Vol. 225, Piotrowski, A.M., Goldstein, S.L., Hemming, S.R. and Fairbanks, Intensification and variability of ocean thermohaline circulation through the last deglaciation, pages 205–220. Copyright (2004), with permission from Elsevier.

GEOTRACES Science Plan, 2006