Hf isotopes in Mn-nodules and the oceanic Hf-Nd isotopic correlation as a tracer of lithogenic input

T. Simonetti
W. Abouchami
S. Goldstein
Max-Planck Institut für Chemie, D-6500 Mainz, Germany

J. Vervoort
University of Arizona, Tucson, AZ 85721, USA

J. Blichert-Toft
F. Albarède
Ecole Normale Supérieure de Lyon, 69364 Lyon Cedex 7, France

The Hf isotope composition of Mn nodules from the Atlantic (29) and the Pacific (4) has been determined in Lyon by plasma-source mass spectrometry, as a complement of an ongoing program of Nd and Pb isotopes (Simonetti, Abouchami and Goldstein, ms). The overall pattern of inter-ocean basin Hf isotope variability described by previous authors (White *et al.*, 1986; Godfrey *et al.*, 1997) still holds with a substantially enlarged set of data. As expected from the Nd-Hf isotopic correlation amongst hard rocks, the least radiogenic Hf ($\varepsilon_{Hf} \sim -1$) is introduced into the Atlantic, and the most radiogenic in the Pacific Hf ($\varepsilon_{Hf} \sim +5$). The argument made elsewhere (Albarède *et al.*, 1997)} that regional extrema corresponds to input locations suggests that the western tropical Atlantic acts as the source of unradiogenic Hf, while the most radiogenic Hf is incorporated into the Pacific at the other end of the conveyor belt. As for Nd, the intermediate values of the Indian Ocean (0.7–3.2) do not indicate any particular source associated with the sedimentary and riverine input from the Himalayas.

Out of the 33 samples for which both the Nd and Hf isotopic compositions are known, 27 define a reasonably good correlation (Fig. 1). Some of the points stand as anomalous because of diagenetic effects. This correlation, however, is distinct from the hard-rock main correlation trend. For a given ε_{Nd} value, a Mn nodule has more radiogenic Hf than crust or mantle rocks. The most likely explanation is that it corresponds to a mixing line between a mantle-derived radiogenic component and a crustal zircon-free component. It is unlikely that the slope of the nodule correlation is less than that of the hard-rock correlation because of a shorter oceanic residence time. If mixing was reducing the Hf isotopic spread

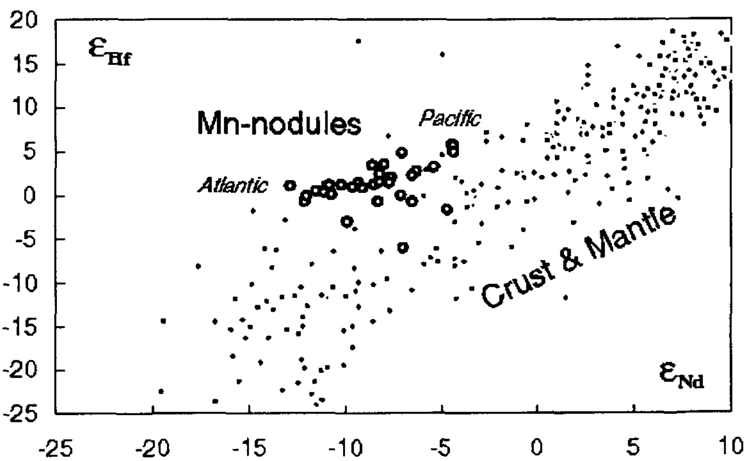

FIG. 1. ε_{Hf} *vs* ε_{Nd}

much more efficiently than the Nd spread, the correlation line would hinge around a mean point that should still lie on the hard-rock correlation, which is not what is observed. The Mn-nodule Hf-Nd isotope correlation is not very tight and the Hf/Nd ratio in the input components may be fairly different, so that the end-members cannot be be precisely identified. The 'mantle' radiogenic component may be incorporated upon low-temperature alteration of mid-ocean ridge, ocean island, island arc basalts, possibly of glass shards in the nepheloid layer. The strength of the high-temperature hydrothermal flux added by seawater circulating through the mid-ocean ridges is inadequate for Nd and, consequently, also for Hf.

The 'crustal' unradiogenic component is actually more radiogenic than expected from its Nd isotope composition and this holds true regardless of the quality of the correlation and of the Hf/Nd ratios. Is has been observed (White *et al.*, 1986) that Hf Mn nodules plot on the radiogenic side of deep-sea clays. White *et al.* interpreted the Hf and Nd isotopic data on deep-sea clays and nodules as signaling the strong resistance of the low Lu/Hf zircon to weathering. They argued that zircon is concentrated in shelf sediments and turbidites, while weathering forms clays and liberate ions in runoff at the expense of more fragile minerals.

We suggest that, although a mixing relationship between end-members may be achieved in a number of ways, the source of unradiogenic Hf and Nd in the ocean is essentially eolian. Rivers are not the major contributor to marine Nd, since the rare-earth elements are largely removed at estuaries (Goldstein and Jacobsen, 1988). The correlation observed between ε_{Hf} and ε_{Nd} in nodules seem to indicate that riverine Hf has the same fate. Also, the major rivers at their mouth do not stand up as sources of crustal Nd (Goldstein and Jacobsen, 1988). Exchange with suspended clay transported across ocean basins does not appear more plausible. The largest source of detrital material is in the Indian Ocean, in which nodules looks neither particularly unradiogenic nor heterogeneous, and in the Pacific, which is the most radiogenic reservoir of oceanic Hf and Nd. On the contrary, most of the least radiogenic Hf and Nd compositions are located in the western Atlantic, where the tropical gyre reduces lateral transport to a minimum. It was argued by Jeandel *et al.* (1995) and by Albarède *et al.* (1997) that the main gateway of unradiogenic Nd into the ocean is the eolian input which injects Saharan particles that rapidly settle down to the bottom where they react with ambient seawater. Heavy zircons are not transported by winds Sargasso Sea from the Sahara, as easily as are light and fluffy clay minerals.

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