N94-16271

CONSTRAINTS ON THE DIFFERENTIATION OF THE EARTH FROM THE COUPLED ^{146,147}Sm-^{142,143}Nd SYSTEMATICS,

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The coupled Sm-Nd systematics are a powerful (albeit analytically challenging) tool for investigating the geodynamic history of the Earth. We have previously reported evidence for a 33 ppm difference of an Isua sample relative to our terrestrial standard [1]. Interpretation yields a formation age range for the depleted mantle (DM) source reservoir of 4.45-4.55 Ga. This is consistent with an epoch of LREE-enriched melt extraction from the mantle (proto-crust formation), soon after magma ocean freeze-up following the putative Moon forming giant impact.

The rate of crustal recycling inferred from ^{143}Nd/^{144}Nd evolution in DM over Earth history using a two-reservoir recycling model [2,3] can be evaluated from the following equation:

$$\frac{d\epsilon_{143Nd}}{dt} = -\left(\frac{\varphi}{Y_{Nd}}\right)\epsilon_{143Nd} + Q_{143Nd} f^{Sm/Nd}$$

Here φ is the fractional rate of recycling, Y_{Nd} is the mass fraction of Nd in the depleted mantle, $Q_{143Nd} = 25.13$ Ga^{-1} and $f^{Sm/Nd}$ is the Sm/Nd fractionation factor in the DM. The constraints from the ^{143}Nd evolution may be used to calculate the average ^{142}Nd/^{144}Nd evolution of DM. As shown in Fig. 1 such a continuous model (with both growth and recycling) would not allow the survival of ^{142}Nd/^{144}Nd >+10 ppm (w.r.t. bulk Earth) in bulk DM at any time. Use of the above equation, however, requires detailed knowledge of the $f^{Sm/Nd}$ evolution of the depleted mantle. The mantle source of Isua 715-28, however, can be interpreted with a two-stage model with an initial time of differentiation of 4.45-4.54 Ga, as shown by the two-stage evolution curves in Fig. 1. The survival of a +33 ppm ^{142}Nd enrichment in the mantle source region of the Isua 715-28 at 3.8 Ga indicates an isolation with respect to geodynamic remixing. The survival of the effect in the mantle as late as 3.8 Ga also suggests that crustal recycling (and therefore contemporary style plate tectonics) may not have been active in the Hadean. If the Isua 715-28 source reservoir represents bulk DM, then our results suggest that contemporary-style crustal recycling was not active prior to ~ 3.9 Ga and that the 'lost' ancient cratered terrains survived on the Earth's surface at least until the epoch of 'heavy bombardment' at this time.

The oldest (~4.0 Ga) known terrestrial crustal rocks are found in the Acasta region of the Northwest Territories [4]. Sam Bowring kindly provided powder aliquots of some of his oldest samples (SB91-37 and SB89-39), for which he obtained initial ϵ_{143Nd} of +2.9 and +3.5 respectively using ~4.0 Ga U-Pb zircon ages. We measured ^{142}Nd/^{144}Nd for these samples by both static and dynamic multicollection methods. The deviations (in ppm) relative to the Ndβ standard are shown in Fig. 2. It appears that these samples are within 5 ppm of the Ndβ value and within error of our inferred bulk Earth value (based on Ndβ and a young flood basalt sample BCR-1). If Ndβ is representative of the present bulk Earth value of ^{142}Nd/^{144}Nd, this implies an extreme LREE depletion at a relatively late time (<4.3 Ga) in the source region(s) of the Acasta gneisses, in contrast to that of the Isua 715-28 source where the depletion appears to have taken place very early in the Hadean (~4.5 Ga).

^{142}Nd heterogeneity is generated only as a result of early differentiation (plausibly protocrust formation). The primary step in exploring the utility of the ^{142}Nd tracer is to determine the magnitude of the 'initial' post-^{146}Sm-decay (*viz.*, ~4.3 Ga) ^{142}Nd/^{144}Nd of DM. Subsequent measurements of younger samples will allow a first order estimate of the progressive 'erasure' of the initial heterogeneity in the average DM by geodynamic remixing of the complementary reservoir (the protocrust). For the post-^{146}Sm-decay we have

$$\frac{d\epsilon_{142Nd}}{dt} = -\left(\frac{\varphi}{Y_{Nd}}\right)\epsilon_{142Nd}$$

and thus the recycling rate may be obtained directly from the ϵ_{142Nd} evolution in DM without any estimate of the Sm/Nd fractionation in the source region. After ~4.3 Ga, therefore, the evolution of ^{142}Nd/^{144}Nd in the Earth's depleted mantle reservoir becomes a tracer for geodynamic mixing and can be employed to quantify the 'global' geodynamic history of the crust-mantle system throughout geological time. Figure 3 shows the general properties of the coupled Sm-Nd systematics in relation to investigations of global-scale history of geodynamic mixing in the Earth. Here the lowermost panel diagram has been scaled to fit the boundaries of the Isua 715-28 result (+33±4 ppm) at 3.8 Ga. Initiation of (plate tectonic) recycling, shown here in the second panel as a step function in the recycling rate at 3.75 Ga, leads to progressive diminution of the initial anomaly in the average DM by remixing of the complementary reservoir (the protocrust). Companion plots of time evolution in ϵ_{143Nd} and in the total mass of the crust are also shown.

The above considerations demonstrate the potential utility of the coupled chronometer as a tracer of geodynamic mixing. However, our new results on the Acasta samples as well as other reports [5,6,7,8] do not support ^{142}Nd enrichments to be a widespread effect in early crustal rocks derived from inferred high ϵ_{143Nd} sources. The most critical aspect of continuing these studies is to firmly establish the bulk Earth value for ^{142}Nd/^{144}Nd [see our companion abstract]. It is possible that Ndβ could itself have been derived from an early-formed depleted mantle reservoir. At present we are only beginning to explore the potential of the coupled Sm-Nd systematics and our efforts are mostly focused on the challenges of very high precision Nd mass spectrometry. We emphasize, however, that all of the measurement problems are solvable by development of better techniques and mass spectrometers and consequently that there is very great promise for the eventual exploitation of ^{142}Nd/^{144}Nd measurements in addressing a range of fundamental issues in global geodynamics.

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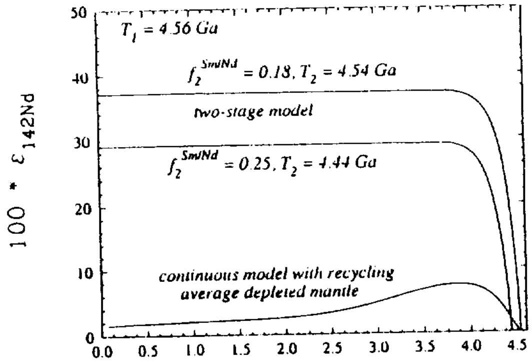

FIGURE 1.

ACASTA GNEISSES, N.W.T., CANADA

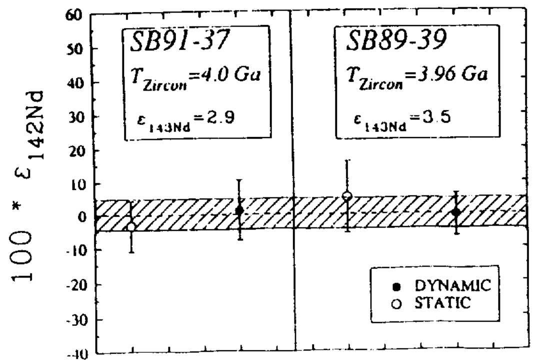

FIGURE 2

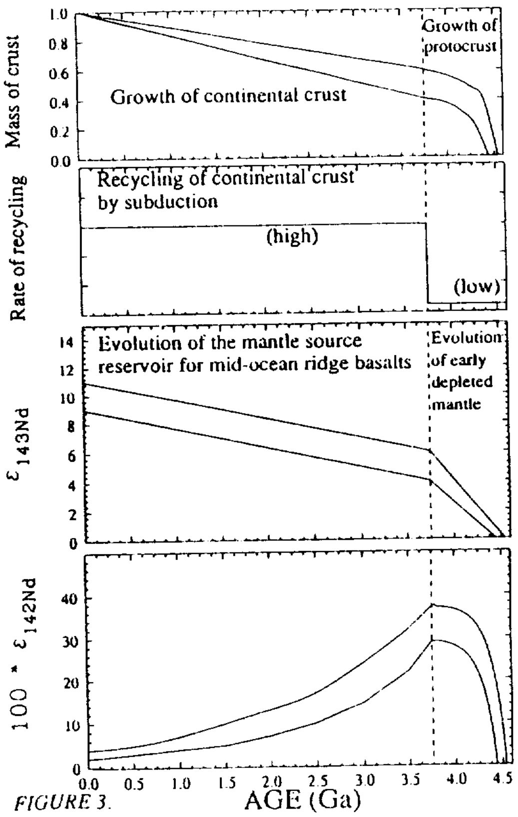

FIGURE 3.