THE ^{146,147}Sm-^{142,143}Nd CHRONOMETER AND THE TIMESCALES OF EARLY PLANETARY DIFFERENTIATION. S. B. Jacobsen[1] , M. C. Ranen[1], [1]Dept. of Earth and Planet. Sci., Harvard Univ., 20 Oxford St., Cambridge, MA 02138 (jacobsen@neodymium.harvard.edu).

Introduction: Because the extinct radionuclides were live only during early Solar System history, they are particularly powerful tracers of early differentiation processes [1,2]. Thus, knowledge of very early planetary differentiation processes, in principle, can be inferred from isotopic variations of the decay products of the longer-lived extinct radionuclides ^{146}Sm, ^{244}Pu, ^{129}I, and ^{182}Hf, as well as the nearly extinct isotope ^{235}U. Each of these systems has contributed much to the knowledge of the timing and processes of early planetary differentiation and their potential for advancing understanding of different aspects of the early histories of terrestrial planets is still in development. Two of these chronometers (^{146}Sm and ^{235}U) are particularly useful when coupled with the long-lived chronometers ^{147}Sm and ^{238}U.

The Coupled ^{146,147}Sm-^{142,143}Nd System: This system is particularly attractive because accretion and core formation are not likely to fractionate Sm/Nd. Sm/Nd is fractionated by silicate differentiation and this coupled systematics should provide a highly selective 'window' on planetary silicate mantle and crust differentiation. A useful property relating to accretion is possible isotopic rehomogenization following giant impacts. Consequently this chronometer may be able to provide a lower time limit on completion of the major mass coagulation epoch. The very small volume of early (>3.5 Ga) Archaean crust preserved today (less than 1% of the present continental volume) has been interpreted as indicating that crustal growth did not begin until about 4.0 Gyr ago, before which the silicate Earth remained well mixed and essentially undifferentiated. However, the inferred initial ^{143}Nd/^{144}Nd ratios of many early Archean rocks are higher than that of the bulk Earth implying that by 3.8 Ga ago the volume of the crust must have been as large as about 40% of the present value [3]. When combined with measurements of ^{142}Nd/^{144}Nd ratios in Isua samples from west Greenland, it points to a significant early silicate differentiation within the first 100 Myr of Earth's formation [1].

Modeling of Planetary Mantle and Crust Evolution Based on Nd isotope Variations: The principles for both long-lived and extinct system have been discussed in detail before [2,4]. For long-lived systems (such as ^{147}Sm-^{143}Nd) the radiogenic isotope effect, ε_{143Nd}, yields ~ the mean age of the mass of a reservoir. This result is independent of the functional form of reservoir growth curve and is close to a two-stage model age. For short-lived systems (such as ^{146}Sm-^{142}Nd) the radiogenic isotope effect, ε_{142Nd}, also depends on the mean age of the mass of a reservoir, but in a more complex way than for long-lived systems. It is highly dependent on the functional form of reservoir growth curve and the mean age is usually not equal to a two-stage model age.

Creating Isotopic Heterogeneity: Subsequent to the magma ocean phase of a planet, the low chemical diffusion rates imply that subreservoirs that are created by mass transport into and out of the mantle effectively exist as distinct geochemical entities for all time. By tracking these subreservoirs, the full range of isotopic values represented in the mantle can be utilized. Applying simple statistics, the distribution of isotope measurements will be a function of the stirring time (τ_{stir}), effective melt fraction, sampling volume, and mass transport history [5]. The net effect of mechanical stirring is to change the length scales of the heterogeneity. Because in general the long axis of the heterogeneity is much greater than any reasonable length scale of concern, the relevant length scale of the heterogeneity is the one which has been progressively shortened. In the case of exponential stretching, this short axis as $l_h(t) = l_h(t_o)\exp[(t-t_o)/\tau_{stir}]$ where t_o is the time at which the heterogeneity was created, $l_h(t_o)$ is the initial characteristic length scale of the heterogeneity. The length of the short axis, l_h, decreases exponentially with the strirring time constant, τ_{stir} (~0.5 Ga for the Earth).

Sampling Planetary Mantle Reservoirs: The sampling length scale l_s, will typically be much larger than l_h. Therefore, mantle-derived igneous rocks always represent mixtures of multiple layers of diverse origin in any planet with solid state convection [5].

Radiogenic Isotope Effects in Igneous Rocks that Sample Convectively Stirred Mantle Reservoirs: Complexities are seen in recent results for the coupled ^{146,147}Sm-^{142,143}Nd system in Earth [1,6], Mars [7] and the Moon [8]. In particular the apparent discrepant chronologies obtained when comparing long-lived and extinct chronometers is exactly what would be expected from igneous rocks that sample a mantle with mixing due to solid state convection. This may mean that the simple static models of magma ocean layers in the lunar and martian mantles should be abandoned in favor of physically more realistic mantle models.

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