Sm-Nd Isotopic Data and Earth's Evolution

Samuel A. Bowring and Todd Housh (*1*) report Sm/Nd isotopic data giving a wide range of initial ϵ_{Nd} values, from +3.5 to −4 at 4.0 billion years ago (Ga) and from +4 to −7 at 3.6 Ga. Their samples were from the Acasta gneisses of northern Canada, which represent the oldest known outcrops of continental crust (*2*). Their modeling of the Sm-Nd isotopic data is taken to suggest that the Acasta granitoid rocks were formed from mixtures between mantle-derived melts and crustal melts derived from extremely ancient (about 4.3 Ga), heterogeneous, depleted (high Sm/Nd) and enriched (low Sm/Nd) reservoirs. We consider it likely that the wide range of initial ϵ_{Nd} values has a much simpler explanation.

We plot the Acasta gneiss Sm-Nd data of Bowring and Housh (*1*) and Bowring *et al.* (*3*) on a Sm-Nd isochron diagram (Fig. 1). Ten out of 13 points define a well-correlated regression line ("errorchron"), yielding an age of 3239 ± 150 million years ago (Ma) (2 σ errors; MSWD = 36), with an initial ϵ_{Nd} value of −7.9 ± 1.8. These data points are based on samples for which SHRIMP ion-microprobe zircon U-Pb dates range between 4.0 and 3.6 Ga (*1*, *3*). If we consider only those samples with the oldest zircon U-Pb dates of about 4.0 Ga, the regression age for five out of six samples is 3156 ± 100 Ma (MSWD = 6.4) and the initial ϵ_{Nd} value is −9.0 ± 1.3 (Fig. 1).

We therefore propose that the Acasta gneisses suffered a tectonothermal event at about 3.2 Ga that caused open-system behavior of Sm-Nd and resulted in an approximation to Nd-isotope homogenization on the scale of sampling, regardless of whether the samples were originally cogenetic or not. Geological scatter (MSWD > 1) about the errorchron shows that either pre-3.2 Ga ϵ_{Nd}–heterogeneities were not totally eradicated, or that post-metamorphic disturbance [for example, at about 1.9 Ga (*4*)] caused limited additional open system behavior in the Sm-Nd system. Nevertheless, an Nd-isotope evolution diagram (Fig. 2) illustrates that calculated initial ϵ_{Nd} values in rocks about 4 Ga old that underwent approximate Nd-isotope homogenization at 3.2 Ga would yield a wide range of apparent initial ϵ_{Nd} values with no geological significance whatever. On the other hand, initial ϵ_{Nd} values of about −8 to −9, obtained from the regression lines in Fig. 1, point to the existence of an enriched (low Sm/Nd) crustal protolith with an age greatly exceeding 3.2 Ga. Assuming an age of 3.96 Ga for the oldest Acasta gneisses (*1*, *2*, *3*) and an initial $\epsilon_{Nd}(3.96)$ ratio of +1.0 in line with the conventional depleted-mantle model of De Paolo *et al.* (*5*), then an average Sm/Nd ratio of 0.17 is required for the rocks to evolve to an ϵ_{Nd} value of −9.0 at 3.2 Ga. This correlates with the average Sm/Nd ratio of 0.17 for upper continental crust (*6*). This consistency of plausible parameters provides independent, though circumstantial, evidence for the great age of the Acasta gneiss protolith.

In summary, our interpretations are that (i) the Sm-Nd system in the Acasta Gneisses was opened and largely reset by metamorphism some 0.7 to 0.8 Ga after the time of rock formation and, therefore, (ii) precise U-Pb dates on zircon cannot necessarily be used as a basis for inferring the existence of extremely heterogeneous, rare earth element–fractionated mantle and crust reservoirs during earliest earth history (that is, pre-4 Ga in the present case) because the calculated ϵ_{Nd} values may be spurious.

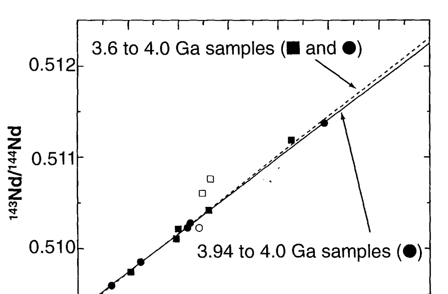

Fig. 1. Sm-Nd isochron diagram for Acasta gneiss samples analyzed by Bowring and Housh (*1*) and Bowring *et al.* (*3*). The dashed line includes samples whose zircon U-Pb age ranges from 3.6 to 4.0 Ga [3239 ± 150 Ma; $\epsilon_{Nd}(t)$ = −7.9 ± 1.8; (n = 10; MSWD = 36)], while the continuous line includes those from 3.94 to 4.0 Ga only [3156 ± 100 Ma; $\epsilon_{Nd}(t)$ = −9.0 ± 1.3 (n = 5; MSWD = 6.4)]. Open symbols were omitted from the regression.

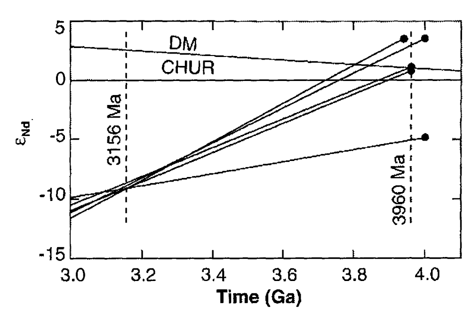

Fig. 2. Nd isotope evolution for the five oldest Acasta gneiss samples which plot on the continuous line in Fig. 1. Extrapolation from the Nd-isotope homogenization age of 3156 Ma (Fig. 1) back to the average age of 3960 Ma for the samples yields a wide range of apparent initial ϵ_{Nd} values.

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24 October 1995; revised 26 April 1996; accepted 29 May 1996

Response: The effect of metamorphism on whole rock Nd isotopic data is an important issue, and we welcome the opportunity to address it in more detail. Moorbath and Whitehouse challenge our interpretation of highly variable initial ϵ_{Nd} values in different rock types of the Acasta gneisses largely on the basis of the distribution of our data on a $^{143}Nd/^{144}Nd$ -$^{147}Sm/^{144}Nd$ isotope correlation diagram. If 3 of the 13 data points are disregarded, the remainder "define" a linear array that Moorbath and Whitehouse interpret as an isochron. The age it suggests is considerably less than the crystallization ages of the rocks (about 3.2 Ga) and is referred to by Moorbath and Whitehouse as a time of "Nd-isotope homogenization." This interpretation is in error for several reasons: (i) Moorbath and Whitehouse use "errorchrons" with MSWDs significantly greater than 1 and conclude that the age and initial ratio calculated for the slope of this linear array has statistical significance. This is a statistically invalid approach, as outlined by Wendt and Carl (*2*); (ii) they hand-pick a subset of rocks to lower the MSWD of the linear array by arbitrarily removing points (the three that are the most displaced); and (iii) they refer to the scatter about the linear array as "geologic scatter," which they interpret as being caused by either incomplete homogenization of pre-3.2 Ga heterogeneities or another younger disturbance. This seems essentially an ad hoc explanation that relies on the assumption that the calculated age is significant. An equally plausible interpretation is that the scatter is a result of the fact that the samples were never isochronous.

It is possible to produce linear arrays on isotope correlation diagrams (even statistically significant ones) that do not have any age significance and are best interpreted as mixing lines. The half-life of ^{147}Sm is so long that even for geologically significant periods of time (hundreds of millions of years) little change occurs in the Nd isotopic composition of rocks; thus, a number of rocks that start with slightly different initial ratios and Sm/Nd may produce linear arrays on an isotope correlation diagram with no age significance.

As described in the notes of our article (*1*), we selected our samples with an understanding of their geological history. Our test for metamorphic disturbance is to analyze multiple samples from the same rock unit to see if this results in variable calculated initial ratios or an isochron that is considerably younger than its crystallization age as determined by U-Pb geochronology. The data presented in Bowring and Housh (*1*) passed the screening tests. The geology of the Acasta gneisses is complex, and we are working on a better understanding of it. However, we have yet to document evidence for a metamorphic event at 3.2 Ga, as suggested by Moorbath and Whitehouse, despite the application of a wide variety of thermochronometers to the Acasta gneisses (U-Pb zircon, U-Pb titanite, $^{40}Ar/^{39}Ar$ hornblende, and others).

There is a significant difference between interpreting all linear arrays on isotope correlation diagrams as having geological significance and actually documenting it. We are in agreement that the role of metamorphism must be understood; the key to doing so lies in the integration of both geochemical and geological constraints, something that Moorbath and Whitehouse do not address in their comment.

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10 January 1996; accepted 29 May 1996