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Response to Comment on "Neodymium-142 Evidence for Hadean Mafic Crust"

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Andreasen and Sharma raise concerns about the neodymium-142 data and age that we reported for rocks from the Nuvvuagittuq greenstone belt in Quebec, Canada. We agree that the issue of accurate mass fractionation correction is important, but stand by our discussion of this issue in our original report and our conclusion that the variation in $^{142}Nd/^{144}Nd$ ratios reflects the decay of ^{146}Sm caused by Sm-Nd fractionation within 300 million years of Earth's formation.

We reported neodymium isotope data for rocks from the Nuvvuagittuq greenstone belt in northern Quebec, Canada, which suggest that these rocks formed 4.28 billion years ago and may represent the oldest preserved crustal section on Earth (*1*). We discussed a number of possible interpretations of the Nd isotope variation we measured, including those given by Andreasen and Sharma (*2*). Putting aside the issue of data accuracy for the moment, as shown in Fig. 3 in (*1*), the 103-million-year half life of ^{146}Sm means that measurable variations in $^{142}Nd/^{144}Nd$ values can result only if a range in Sm/Nd ratios was present in the Nuvvuagittuq rocks well prior to 4.0 billion years ago (Ga). As Andreasen and Sharma note, the average ^{147}Sm-^{143}Nd model age of the faux-amphibolite is 4.29 Ga (*1*), which supports the 4.28 Ga age given by the Sm-^{142}Nd data for the faux-amphibolite. We share Andreasen and Sharma's opinion that the gabbro and faux-amphibolite are not genetically related and should not be fit with a single isochron. Nevertheless, if the faux-amphibolite Sm-^{142}Nd data are fit with a line that is forced to go through the modern terrestrial mantle point [as shown in Fig. 3 in (*1*)], which is the equivalent of calculating an average Sm-^{142}Nd model age, the age decreases insignificantly to 4.26 Ga. If the faux amphibolites were not derived from a source that followed bulk-mantle Sm-Nd evolution, then a regression of the faux-amphibolite data alone gives a slope corresponding to an age of 4286^{+96}_{-370} million years. This age was pointed out in (*1*) and is essentially the same age as the isochron fit to both the faux-amphibolites and the gabbros, but with a larger uncertainty because of the small spread in Sm/Nd ratios. We also presented calculations showing the insensitivity of the ^{146}Sm-^{142}Nd system to later metamorphic perturbations of Sm/Nd ratio, which can reset ^{147}Sm-^{143}Nd isochrons to younger ages (*1*). We thus stand by the conclusion that, if the $^{142}Nd/^{144}Nd$ data reported in (*1*) are accurate, the low Sm/Nd ratios of the faux-amphibolite, their protoliths, or their sources in the mantle, had to have been established by 4.28 Ga or earlier.

Addressing the question of the accuracy of mass fractionation correction during mass spectrometry is crucial. This issue was addressed in considerable detail in the supporting online material (SOM) associated with our original report (*1*). Nonexponentially mass-dependent fractionation can be induced during chemical separation or through mixing between different reservoirs of Nd on the filament (*3*, *4*), potentially leading to the low $^{148}Nd/^{144}Nd$ and $^{150}Nd/^{144}Nd$ seen in many samples (those not affected by spike contamination). In contrast to Andreasen and Sharma's comment (*2*), however, we reached the conclusion that the problem lies with mass fractionation of the La Jolla Nd standard, the standard used to normalize the rock data, not with the rock data themselves. Mass fractionation of the La Jolla standard was documented by the stable isotope measurements reported in the SOM for (*1*). Unfortunately, this issue with the La Jolla standard was not recognized until all the analyses reported in (*1*) were complete and this was the only standard run in concert with the Nuvvuagittuq samples.

In support of this interpretation, we noted that the La Jolla data reported by Carlson *et al.* (*5*) shows statically measured $^{148}Nd/^{144}Nd$ and $^{150}Nd/^{144}Nd$ higher than the JNdi standard by 9.5 and 30 ppm, respectively. Andreasen and Sharma

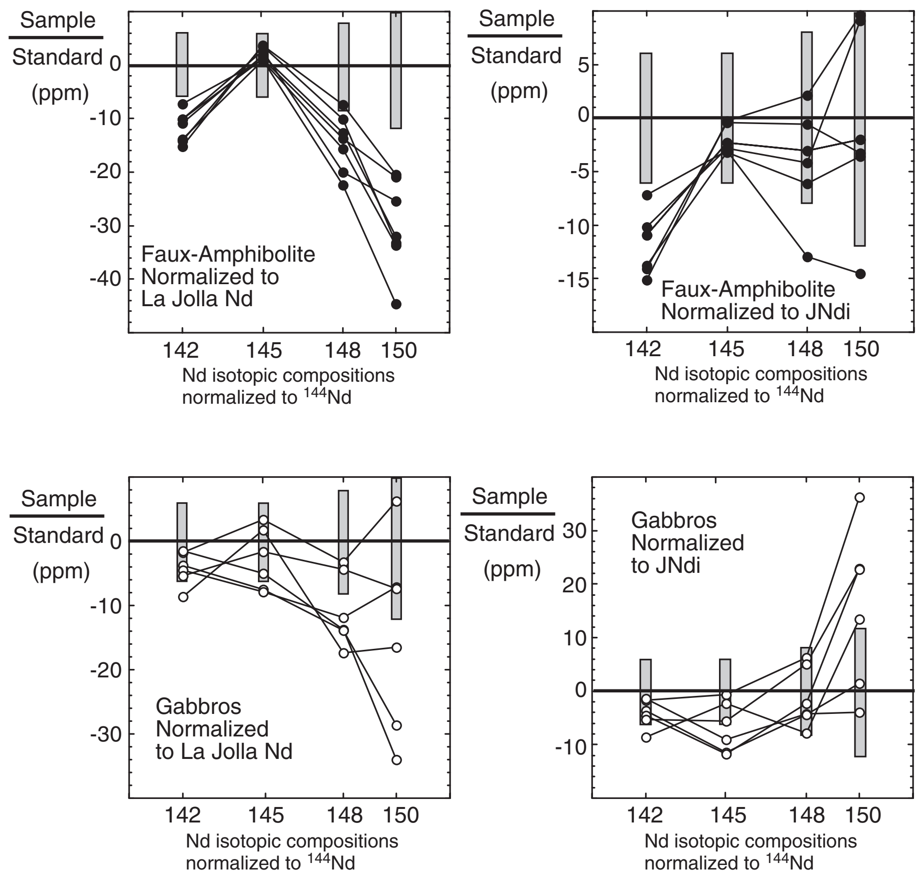

Fig. 1. Plot showing the isotopic compositions of Nd, normalized to ^{144}Nd, measured for the Nuvvuagittuq faux-amphibolites and gabbros (*1*). The data on the left-hand set of figures are the deviations in each ratio, in ppm, compared with the La Jolla Nd data reported in (*1*). The data on the right-hand set of figures are again the differences in each ratio (in ppm) compared with the La Jolla Nd data reported in (*1*), but corrected for the difference in isotopic composition between La Jolla Nd and JNdi Nd reported by (*5*). The large gray bars in the figures show the external reproducibility of the standard.

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note that Nd standard data reported in Boyet and Carlson (*6*) show no difference in the $^{150}Nd/^{144}Nd$ measured in the La Jolla and JNdi Nd standards. What they do not note is that the Boyet and Carlson (*6*) $^{150}Nd/^{144}Nd$ data carry uncertainties ranging from 21 to 30 ppm and, thus, are insufficiently precise to address the pertinent issue here.

When the difference between La Jolla and JNdi standards reported in (*5*) is used, Fig. 1 shows that the $^{148}Nd/^{144}Nd$ and $^{150}Nd/^{144}Nd$ ratios of the Nuvvuagittuq rocks (for those samples not contaminated by spike), including both gabbros and faux-amphibolite, overlap within uncertainty with the average measured for the JNdi standard. The data reported in (*5*) for JNdi and La Jolla were measured shortly before the Nuvvuagittuq analyses, on the same mass spectrometer, using the same data reduction procedure. Given that $^{148}Nd/^{144}Nd$ and $^{150}Nd/^{144}Nd$ ratios are determined by static measurement and, hence, subject to variable collector efficiencies, we consider it critical to compare standard values measured over a similar time interval on the same instrument in order to properly account for the collector inefficiencies.

In Fig. 1, we interpret the trend of gabbro data to high $^{150}Nd/^{144}Nd$ ratios as a sign of spike contamination. The gabbros and several of the faux-amphibolites dissolved and processed through the chemical separation at GEOTOP are the only samples showing elevated $^{150}Nd/^{144}Nd$ ratios. No gabbro samples were dissolved at DTM (Department of Terrestrial Magnetism, Carnegie Institution of Washington), but none of the faux-amphibolites dissolved and processed at DTM showed high $^{150}Nd/144Nd$ ratios. Whether normalized to JNdi or to La Jolla, the $^{142}Nd/^{144}Nd$ ratio of the faux-amphibolites remains below that measured for the standard. When normalized to the JNdi data reported in (*5*), only the $^{142}Nd/^{144}Nd$ ratio of the faux-amphibolites differs from that of the standard outside of measurement uncertainty. Furthermore, as noted by Andreasen and Sharma (*2*), the type of mass fractionation problem that occurs during mass spectrometry (*3*, *4*) does not occur for every sample, which is why we analyzed six out of the seven faux-amphibolites in duplicate or triplicate (*1*) and, in every case, were able to reproduce the deficiency of $^{142}Nd/^{144}Nd$ within the external measurement precision of ±6 ppm, in spite of wide variations in measured $^{146}Nd/^{144}Nd$ ratios. We take these observations as confirmation that the low $^{142}Nd/^{144}Nd$ ratio is related to the initial presence of ^{146}Sm in these rocks and is not an artifact of an inaccurate correction for mass fractionation.

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