

A chip of the old (mantle) block

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A recent article in *Nature*¹ presents credible evidence for a nearly 4500 million years (m.y.) long chemical isolation of a mantle pocket from convective disruption and mixing.

Condensation of small, high-temperature mineral grains from the cooling solar nebula has been precisely dated at 4568 ± 1 Ma (Ma, one million years ago) as one of the earliest events known in the solar system. The accretion of such small grains of meteoritic material dispersed throughout the solar nebular cloud into a few large planets like the earth was quite rapid as inferred from the former presence of radionuclides with very short half-lives in early-formed solid objects. Specifically, the decay of ^{182}Hf with a half-life of just 9 m.y. to ^{182}W in the terrestrial silicate mantle shows that the earth not only accreted to almost its present size, but also was differentiated into a central iron core and a thick silicate slag floating over it within 30 m.y. after the above condensation event. This sets the age of the earth as not younger than 4500 Ma. After the loss of much iron, the chemical make-up of this silicate slag (called the primitive mantle) would match that of the bulk earth only for silicate loving or preferring (lithophile) elements. So if, as currently believed, the bulk earth had the composition of the chondritic group of meteorites, the primitive mantle would retain exactly chondritic proportions, especially for the two neighbouring and chemically similar elements, samarium and neodymium belonging to the chemically coherent rare earth family. What makes this pair of elements a powerful geochemical and cosmochemical tracer is that two (^{146}Sm and ^{147}Sm) of the several Sm isotopes produced in galactic nucleosynthesis are radioactive and decay by alpha emission to two of the stable isotopes of Nd (^{142}Nd and ^{143}Nd respectively), but with highly contrasting half-lives (1.02×10^8 and 1.06×10^{11} yrs). This tracks the temporal evolution of the primitive mantle with the ^{147}Sm - ^{143}Nd radioactive clock still running, but the ^{146}Sm - ^{142}Nd clock having stopped (extinct chronometer) in the first few hundred million years of solar system formation.

The primitive mantle with chondritic or nearly chondritic Sm/Nd ratio con-

tinuously melted partially in its upper parts to produce large volumes of basaltic lavas called mid-ocean ridge basalts (MORB) along constructive plate margins, and sporadically generated thermal plumes from depth to produce ocean island basalts (OIBs) like in Hawaii, Galapagos and Iceland. The profuse partial melting in the upper mantle leads to a superchondritic Sm/Nd ratio in the residue and a complementary subchondritic ratio in the extruded MORB, a part of which contributes eventually to generate the continental crust. With such a large-scale chemical processing (termed depletion by geochemists) of the upper mantle and contamination of the lower mantle by deeply subducted oceanic crust over geologic time, it is unlikely that any sizeable part of the primitive mantle remained chemically unscathed or unperturbed. However, Jackson *et al.*¹ have proposed that basaltic lavas from Baffin Island, Canada were derived ~60 m.y. ago from a deep earth reservoir that was

chemically isolated from almost the time of earth formation until 60 m.y. ago. They rely on combined analysis of the relative abundances of the radiogenic and nonradiogenic isotopes of helium, lead, neodymium and hafnium.

It must be noted that Jackson and others did not sample the actual source of the basalts, but only the basalts as erupted to the surface at the time of opening of the Atlantic Ocean. These basalts would exactly copy the isotopic composition, but not the chemical make-up of their source. The authors used standard checks to avoid lava samples inadvertently contaminated by chemically and isotopically distinct extraneous material during their ascent to the surface.

Helium isotope ratio, $^3\text{He}/^4\text{He}$ is often used as an indicator of primitiveness of deep reservoirs. This ratio inherited by the earth at its formation is expected to be close to that of the present-day solar wind, $\sim 310 R_a$ (R_a is the present-day atmospheric ratio, 1.38×10^{-6}). ^3He is

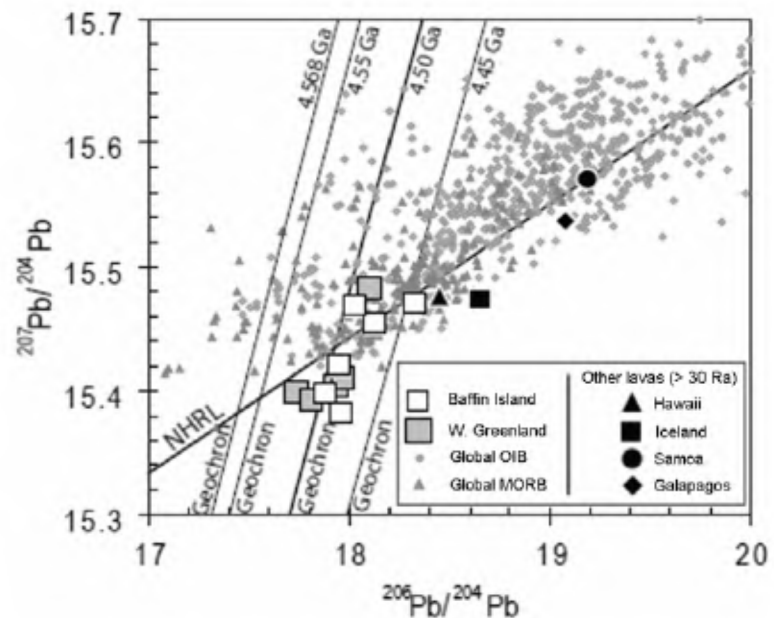


Figure 1. Baffin Island lead isotopic data are bracketed by the 4.55 and 4.45 Ga geochrons. Some lavas from the same sequence as well as most other previously analysed lavas from elsewhere plot off the geochron believed to be due extraneous contamination. Mid-ocean ridge basalts (MORB), ocean island basalts (OIB) and geochrons are explained in the text. Reproduced with permission from the publishers.

primordial and not produced in the earth, but ^4He is continually produced from the alpha decay of U and Th. Thus, helium ratio decreases with time in the deep earth. Mantle sources of some OIBs (Hawaii, Galapagos and Iceland) show relatively high ratio ($>30 R_a$), but Baffin Island basalts show the highest ratio yet known (up to $50 R_a$). Although helium ratios are not uniquely relatable to primitiveness, the authors selected Baffin Island basalts as most likely to have been derived from an ancient reservoir.

How ancient is their mantle source? The parallel decay of ^{238}U and ^{235}U to ^{206}Pb and ^{207}Pb respectively, provides the only method of dating a chemical reservoir from the radiogenic isotopic composition inherited by its chemical derivative, as in this case. All other methods require both parent/daughter and daughter isotope ratios in the parent reservoir itself. It is, of course, necessary that the isotopic composition inherited by the derivative has not changed significantly since its extraction. A plot of $^{207}\text{Pb}/^{204}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$ will define a straight line (called Pb–Pb isochron) with its slope corresponding to the duration of isolated evolution of the parent reservoir. Baffin Island lava samples do not show sufficient spread in their lead

ratios to define a straight line on their own. But they fall strikingly between 4.55 and 4.45 Ga (Ga, one billion years ago) hypothetical isochrons called geochrons defined by all possible U/Pb systems of the earth's age (Figure 1). Most other oceanic lavas so far analysed plot in a large cluster to the right of these two geochrons, including even the few OIBs with comparably high helium ratios. This scatter of points is attributed to variable contamination by recycled surface materials.

The analysis of Nd and Hf isotopes was not to get an independent age estimate, but to show that the source of the Baffin Island basalts is a part of the mother-of-all present-day mantle reservoirs, which started out with a Sm/Nd and Lu/Hf ratio not exactly chondritic, but a few per cent higher². The helium, lead, neodymium isotopic data, considered individually, are not compelling, but collectively they provide coherent evidence that the source of Baffin Island lavas is nearly as old as the earth itself.

Mass balance calculations require that as much as 45–60% of the above mantle be depleted from top-down to feed the growing continental crust. Materials recycled from the surface to the depths must have contaminated the remaining

portions of the mantle, albeit unevenly. One can dismiss the source region of the Baffin Island basalts as a freak or blind spot which somehow retained its chemical integrity in a convecting sea of silicates. But the problem is that there could be many other lavas like in Baffin Island that have not yet been sampled or been lost forever due to convective overturn in the last few hundred million years. At least some of them could well have been spawned by long dormant mantle segments. No mechanism is yet known for long-term storage of such sizeable pristine blobs in a convecting mantle. The present geochemical and geophysical models of mantle structure, dynamics and evolution may need drastic rethinking.

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1. Jackson, M., Carlson, R. W., Kerz, M. D., Kempton, P. D., Francis, D. and Blusztajn, J., *Nature*, 2010, **466**, 853–856.
 2. Boyet, M. and Carlson, R. W., *Science*, 2005, **309**, 576–581.

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