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GEOCHEMISTRY

Relict mantle from Earth's birth

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Geochemical evidence for the existence of the mother of all mantle-source reservoirs for volcanism has come to light. The new results have provocative implications for our understanding of Earth's interior.

Earth is a differentiated planet. Its primordial building blocks of iron-rich metal, oxides, silicate minerals, and volatile elements and compounds have been transformed over geological time into the modern-day structure of core, mantle, crust, ocean and atmosphere. Chemical and physical processes such as mantle convection, tectonic-plate recycling and magma generation through partial melting should have scrambled, if not obliterated, any coherent geochemical signature of the primordial material. Even if a vestige of such material remained, it seems unlikely that it would be found in any samples from Earth's surface or the shallow subsurface that are available to geologists.

Yet that is what new evidence suggests. On the basis of a trace-element and isotopic study, Jackson *et al.*[1] (page 853 of this issue) propose that lavas from Baffin Island, Canada (Fig. 1), were derived from a deep-Earth reservoir that has remained isolated since the earliest days of planetary accretion some 4.5 billion years ago. Their work relies on combined analyses of the isotopes of helium, lead, neodymium and hafnium. Collectively, the results are the first of their kind for terrestrial volcanic rocks.

The essence of the argument for the survival of primordial material is threefold. First, there is the occurrence of the highest ever measured $^3He/^4He$ ratios, in 60-million- to 62-million-year-old volcanic rocks from Baffin Island and West Greenland[2]. The ratios are more than five times higher than values commonly observed along mid-ocean ridges that tap the shallow upper mantle. The very high $^3He/^4He$ signifies an elevated ratio of primordial to radiogenic noble gas — a trait that geochemists often regard as supporting the existence of a reservoir deep within Earth that is the ultimate source for volcanic hotspots such as Hawaii and Iceland[3].

Second, some of the Baffin and West Greenland lavas have lead-isotope compositions that lie on, or very close to, a 4.5-billion-year-old geochron. The geochron is a line in the $^{207}Pb/^{204}Pb$–$^{206}Pb/^{204}Pb$ diagram describing all possible parent/daughter (uranium/lead) ratios corresponding to Earth's age.

Third, the lavas have neodymium isotope compositions ($^{143}Nd/^{144}Nd$) consistent with derivation from a mantle source comprised of primordial silicates. On the basis of the landmark discovery of positive terrestrial ^{142}Nd anomalies[4], this mantle source has a samarium/neodymium ratio that is about 5% larger than the ratio in chondrites. (Chondrites are stony meteorites that formed during the earliest stages of Solar System development and were never melted after their formation. They are thought to closely resemble the building blocks involved in Earth's formation.) Because ^{142}Nd was produced by the extinct radioactive decay of ^{146}Sm (half-life of 103 million years), the excess of ^{142}Nd relative to chondrites in all terrestrial samples seems to require the formation, early in Earth's history, of an 'early depleted reservoir' with a high Sm/Nd ratio as a residue of partial melting. Negative ^{142}Nd anomalies have not been found in terrestrial rocks, so this early depleted reservoir represents the ultimate ancestor of all other mantle-source reservoirs for volcanism.

These three fundamentally coherent isotopic characteristics of helium, lead and neodymium have now been found together for the first time. Notably, they occur in contemporaneous primitive lavas from Baffin Island and West Greenland that erupted during the opening of the North Atlantic. The results are evidence that a

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Figure 1 | **Baffin Island — source of the lava samples isotopically analysed by Jackson and colleagues[1].**

deep source, and one that has been effectively isolated for all geological time, fuelled the mantle plume that gave rise to volcanic activity on Baffin Island and Greenland, and that is now responsible for volcanism in Iceland.

The results support the well-established idea that Earth's mantle is heterogeneous, although the origin and survival of this heterogeneity have long been debated. It is also well established that the depth structure of mantle viscosity, the strain rate associated with mantle convection, and the thermal history of Earth all act in preserving and destroying such heterogeneity[5]. Until now, geochemists have had to devise geodynamic arguments, not all of them mutually exclusive, to reconcile $^3He/^4He$ variations in mantle-derived rocks with isotopic variations in other elements such as lead and neodymium.

Those arguments include enhanced migration of helium into previously melted and degassed rock as material is stretched and folded during mantle convection[6]; freezing of some magma within the upper mantle beneath mid-ocean ridges that is later recirculated to the deep mantle, where it contributes to ocean-island (hotspot) volcanism[7]; and isolation of the mantle sources for ocean-island volcanism away from sites of melting near Earth's surface during the relatively recent geological past[8]. However, evolutionary models for helium isotopes based on mass balance, and the range of possible geological histories for the formation of Earth's crust, make it clear that high $^3He/^4He$ ratios are best explained by isolation of ancient mantle regions, rather than by continuous generation of high $^3He/^4He$ domains during Earth's history[9].

The new results[1] are not without complexity. High $^3He/^4He$ is found in Baffin lavas with both enriched and depleted trace-element signatures, emphasizing the need for a better understanding of the potential decoupling of noble gases from other elements during mantle convection, partial melting and magma transport. Additional tests may come from measuring $^3He/^4He$ in mantle-derived rocks of different ages, but it remains to be seen how successful those attempts will be in deciphering the helium-isotope evolution of the mantle. Such measurements rely on extracting noble gases contained within tiny fluid and melt inclusions trapped in crystals of the erupting lava. In older rocks, the measurements can be fraught with overprinting, primarily from the ^4He produced by radioactive decay of uranium and thorium within the rock since it was emplaced[10].

The large $^3He/^4He$ variability in the Baffin and West Greenland lavas[1,2] attests to the difficulty in relating $^3He/^4He$ to the isotopes of lead, neodymium and hafnium in rocks that are more than a few tens of million years old. Nonetheless, the frontier is open in that endeavour, in light of which the study of Jackson *et al.*[1] takes on increased importance — the possible survival of primitive mantle relicts needs full consideration in future models of mantle structure and evolution. ■

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