Geochemistry

Neon illuminates the mantle

David W. Graham

The outer Earth grew largely from material added by impacts from planetesimals, rather than by capture of dust grains from the solar nebula — or at least that's the inference from the latest geochemical analyses.

A record of Earth's formation and its evolutionary history during the past 4,500 million years is preserved within the chemical and isotopic composition of the mantle. Fluids and the magmas expelled at the Earth's surface as basalt rocks provide samples for deciphering this record. In particular, isotopes of the noble gases contain unique clues to the structure of the mantle, the formation of the hydrosphere and atmosphere, and the history of the building blocks used during our planet's accretion. On page 33 of this issue, Ballentine *et al.*[1] provide high-precision measurements of neon and helium isotopes in carbon-dioxide-rich well gases from New Mexico. Their results illuminate all of these issues, and have profound implications for our understanding of Earth's accretion history.

The initial (primordial) noble gases in the Earth were either trapped directly from a gas-rich solar nebula, or implanted as ions during intense irradiation by a young Sun[2]. Terrestrial noble gases differ in their isotopic make-up from primordial values because they have been modified by the radioactive decay of uranium (U), thorium (Th) and potassium (K), the major heat-producing elements. The ratio of primordial to radiogenic noble gases in Earth's mantle therefore reflects the time-integrated ratio of primordial noble gas to U, Th and K. For example, the relatively high ratios of helium isotopes (^{3}He/^{4}He) observed in ocean island basalts (OIBs) from localities such as Hawaii and Iceland indicate a mantle source that is characterized by high ^{3}He/(U+Th). This OIB source has a higher ^{3}He/^{4}He than that of mid-ocean-ridge basalts (MORBs), and is therefore less degassed and generally considered to lie somewhere below the upper mantle[3].

Support for this model is found by comparing the neon-isotope compositions of OIBs and MORBs[4–9]. Elevated ^{21}Ne/^{22}Ne is a result of ^{21}Ne production by nuclear processes involving the collision of energetic α-particles (^{4}He atoms produced by U and Th radioactive decay) with ^{18}O in mantle silicates — the silicon- and oxygen-rich rocks that make up most of the mantle. Hence, the trend in OIBs from Hawaii and Iceland[6–8], towards high ^{20}Ne/^{22}Ne and low ^{21}Ne/^{22}Ne when compared with MORBs[4,5,9] (Fig. 1), is consistent with a deep, relatively undegassed 'mantle plume' source beneath those ocean islands. Elevated ^{20}Ne/^{22}Ne cannot be explained by nucleogenic processes, and is attributed to the presence of a solar neon component in the Earth[4–10]. A major goal is therefore to identify the upper limit for ^{20}Ne/^{22}Ne in various parts of the mantle, because this potentially distinguishes between different accretion scenarios for the Earth[7].

Ballentine and colleagues' results[1] establish an upper limit of 12.2 to 12.5 for ^{20}Ne/^{22}Ne in Earth's upper mantle. In contrast, ^{20}Ne/^{22}Ne ratios for the deep mantle, estimated from analyses of basalts at Hawaii and Iceland[6–8], and rocks from the mantle-plume province of Russia's Kola Peninsula[10], extend to 13.0 or higher. These higher ^{20}Ne/^{22}Ne values approach the value for the solar wind (13.8), a present-day proxy for the early solar nebula. The shallow- and deep-mantle sources are systematically different in ^{21}Ne/^{22}Ne as well (upper mantle, 0.056; deep mantle, <0.04). The primordial neon-isotope composition for the upper mantle strongly resembles the neon component (Ne-B) observed in meteorites that underwent significant ion implantation by solar energetic particles (SEPs). Therefore, the primordial Ne-isotope composition of the deep mantle (OIB source) resembles that produced by direct trapping from a gas-rich solar nebula, whereas the primordial Ne-isotope composition of the upper mantle (MORB source) resembles that produced by a mixture of solar wind and SEPs (Fig. 1).

These measurements suggest that deep-mantle sources, such as those beneath Hawaii and Iceland, do not contribute much to the inventory of noble gases in the convecting upper mantle. Evidently, steady-state models for upper-mantle noble gases[11] that invoke a flux from these deep-mantle sources need to be re-evaluated.

More remarkably, however, the results indicate that accretion of the outer portions of the Earth was dominated by aggregated solids (planetesimals) that had been heavily irradiated by solar ions. This is remarkable because such intense irradiation is likely to have occurred during an active phase of the

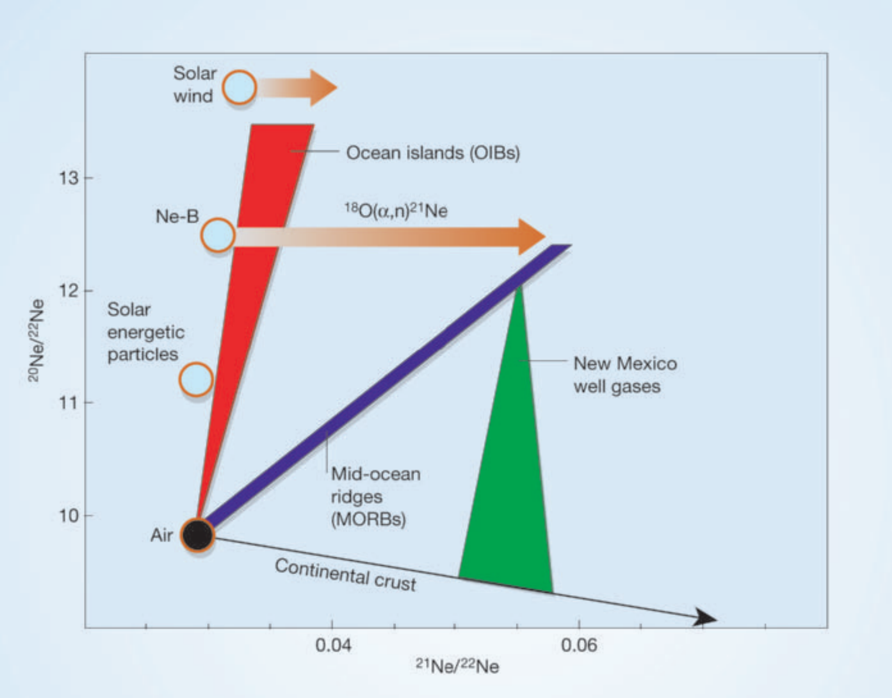

Figure 1 **A three-component isotope mix. The diagram illustrates the neon-isotope compositions for air, solar energetic particles, Ne-B (the neon component in meteorites that underwent ion implantation by solar energetic particles) and the solar wind. Basalt rocks from mid-ocean ridges (MORBs) and ocean islands (OIBs) have air as one end-member because they contain atmospheric contamination released during mass spectrometric analysis. The OIBs from Hawaii and Iceland define a mixing line between air and a deep-mantle component similar to that of the solar wind, and MORBs define a mixing line between air and a primordial neon-isotope component that has been modified by addition of nucleogenic ^{21}Ne from α-particle collisions with ^{18}O in mantle silicates (arrows). Ballentine and colleagues' data[1] for well gases from New Mexico define a wedge-shaped field, because air- and crustal-derived neon are pre-mixed before the addition of gases from the upper mantle. This provides an estimated upper limit for ^{20}Ne/^{22}Ne in the upper mantle, which implicates Ne-B as the primordial composition for most of the mantle.**

early Sun, and only after the rotating disk of nebular gas had been swept clear. The effects of this process have recently been imaged around the main-sequence star β Pictoris, where sub-micrometre dust has been swept out of this extrasolar planetary system by radiation pressure[12]. With respect to Earth, only the deep-mantle regions feeding ocean islands such as Hawaii and Iceland seem to retain a considerable remnant of gases from the early solar nebula, captured from a dense atmosphere during the earliest parts of planetary formation.

One outstanding problem in this research is achieving a self-consistent model that incorporates the noble-gas constraints together with trace-element and isotope ratios of lithophile elements (those elements that tend to be concentrated in silicates, such as the alkaline earths and rare earths). The new neon-isotope results suggest that there is little or no exchange between the deep-mantle regions feeding ocean islands and the upper mantle. Yet there is currently no evidence in the lithophile tracers for any vestiges of primitive, undifferentiated mantle[13]. Evidence emerging from tungsten isotopes in oceanic basalts also seems to exclude significant interaction between the core and deep mantle[14], making it unlikely that the core is the ultimate source of the solar neon-isotope signature observed in mantle plumes.

Consequently, the ultimate source seems to be remnants of the very earliest silicates involved in terrestrial accretion, and these remnants have remained effectively isolated from overlying mantle convection throughout Earth's history. If this source is associated with the seismically anomalous (D″) layer at the base of the mantle, the neon-isotope results indicate that this layer may have formed during Earth's accretion[15]. ■

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Human immunodeficiency virus

Nuclear RNA export unwound

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The ways in which HIV can subvert cellular processes for its own ends seem boundless. The latest discovery — a cellular enzyme that helps to export HIV RNA from the nucleus — reveals a possible drug target.

Gene expression is a multi-step process, the first stage of which is the production of a messenger RNA transcript of a gene. That mRNA is then used as a template to produce a protein. Here, cells whose genetic material is encased in a nucleus (eukaryotic cells) face a problem: their genes are transcribed in the nucleus but proteins are made outside it, in the cytoplasm, so the mRNA must be exported.

The same stricture applies to HIV, whose genes, once incorporated into the host genetic material, are likewise transcribed in the nucleus. It is known that the viral protein Rev recruits the cellular export factor Crm1 to export several essential HIV-1 mRNAs[1]. Host mRNAs, by contrast, generally rely on another export factor, the Tap–Nxt1 dimer. But this is not the only requirement — a 'remodelling' enzyme is also needed[2]. For cellular mRNAs, that enzyme is thought[3–5] to be Dbp5, but this has no role in mRNA export mediated by Rev–Crm1. Writing in *Cell*, however, Yedavalli *et al.*[6] suggest that the necessary enzyme is a member of the same family.

During transcription and processing, eukaryotic mRNAs are loaded with a wide variety of nuclear proteins that regulate the export, cytoplasmic localization, translation and stability of the mRNAs[2]. Although some of these RNA-binding proteins work by remaining associated, at least transiently, with newly exported mRNAs, many others dissociate during or immediately after export. For most cellular mRNAs, this remodelling step is thought to be mediated, at least in part, by Dbp5, an RNA helicase belonging to the ubiquitous DEAD-box protein family[3–5].

DEAD-box helicases use the energy released from the hydrolysis of adenosine triphosphate (ATP) to unwind RNA structures and, perhaps more importantly in this context, to dissociate RNA–protein complexes[7,8]. These enzymes each bear nine conserved amino-acid motifs, including the eponymous DEAD box itself — named after the abbreviations for the amino acids aspartic acid, glutamic acid and alanine — and computer analysis has used these motifs to identify numerous family members in all

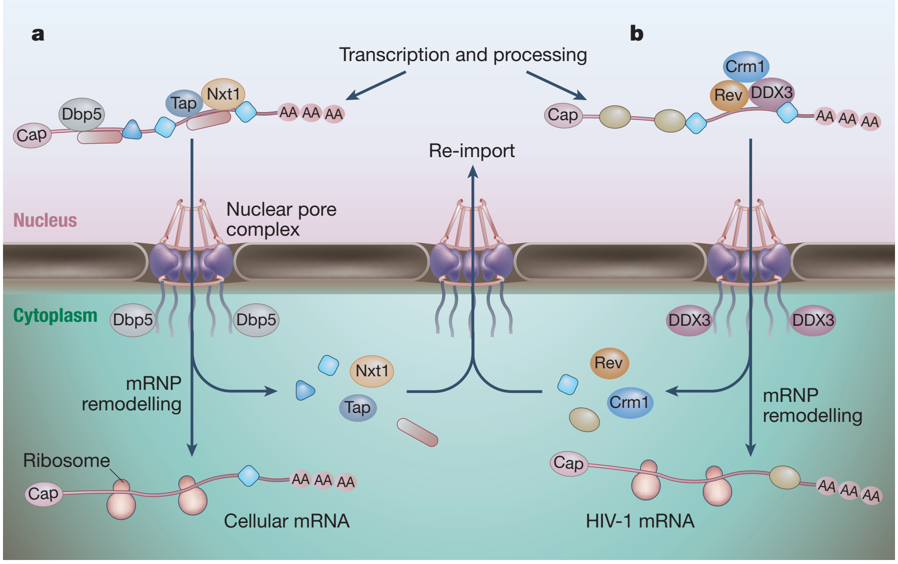

Figure 1 **Escape from the nucleus: how cellular and HIV-1 messenger RNAs are exported.** a, **Transcription and processing of cellular mRNAs give rise to export-competent mRNA–protein (mRNP) complexes that include a range of proteins, including the export factors Tap and Nxt1 and an RNA helicase, Dbp5. During transport through nuclear pore complexes (NPCs), the mRNP is remodelled by pre-bound and/or NPC-associated Dbp5, releasing a range of factors that then return to the nucleus. The string of A's represents the polyadenosine tail characteristic of mRNAs.** b, **HIV-1 mRNAs are bound by a distinct but overlapping set of nuclear proteins that includes the export factors Rev and Crm1 and, as the findings of Yedavalli *et al.* now suggest[6], the helicase DDX3. This mRNP is also remodelled during export, in this case by pre-bound and/or NPC-associated DDX3. Ribosomes then translate the cellular and HIV-1 mRNAs into protein.**