By applying current concepts in metabolic regulation to the study of scaling, Darveau *et al*. are left to conclude that most previous attempts at understanding the mouse-to-elephant curve were simply red herrings. If their approach holds up to the intense scrutiny that it will no doubt receive, their contribution will fan studies of Kleiber's "fire of life," as would a breath of fresh air.

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PERSPECTIVES: GEOCHEMISTRY

Tiny Tracers Tell Tall Tales

Chris J. Ballentine

Recent advances in seismic tomography and dynamic modeling of Earth's interior have reopened the question of how Earth's mantle has evolved. Did the mantle evolve as a chemically layered system, or has it always convected as a whole? And what are the consequences for the preservation and location of its geochemical components?

Noble gases trapped in the silicate mantle may hold the key to resolving this question. These volatile, unreactive, and silicate-incompatible elements give us information about the origin of terrestrial volatiles and the processes and conditions in early Earth history that have incorporated these elements into the silicate mantle (rather than partitioning them into the atmosphere). They further constrain how much of the mantle's volatiles have escaped to the atmosphere over Earth's history, and they preserve a record of volatile-rich regions still existing in the mantle today.

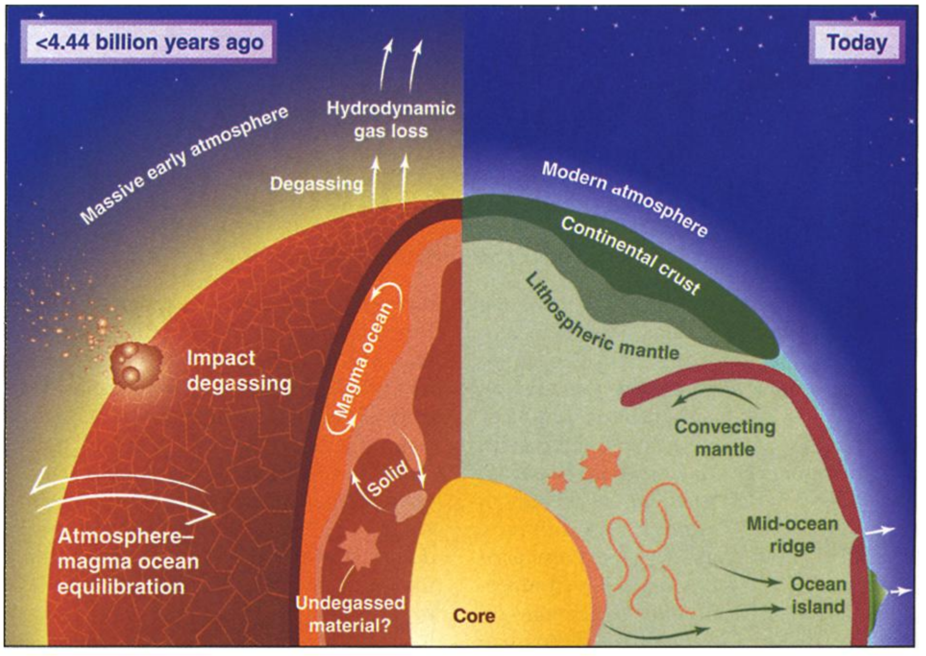
The noble gases He, Ne, Ar, Kr, and Xe produced by radioactive decay (mostly from U, Th, and K) differ in their isotopic composition from the original or "primordial" noble gases. Primordial noble gases in today's Earth originate either directly from the solar nebula or from volatiles trapped in accreting material (such as meteorites hitting the early Earth). Compared with these sources, the primordial noble gases in today's terrestrial atmosphere are enriched in their heavy isotopes.

The enrichment may be a result of the loss of an early, dense atmosphere in the first 100 million years of Earth's history (*1*). During a high-energy phase of the early Sun, hydrogen streamed from this atmosphere into space, carrying with it lighter volatile elements and isotopes (*2*). However, different noble gases have varying degrees of enrichment that cannot be caused by a single event. Differential release of noble gases from the mantle into the atmosphere because of their different solubilities in magma, combined with various stages of atmosphere loss, may provide the answer (*3*).

Noble gases trapped since accretion are still degassing from the mantle into the atmosphere today. The ratio of primordial to radiogenic noble gas isotopes in mantle material, for example, $^3He/^4He$, reflects the ratio of noble gas to U and Th. Basalts from mid-ocean ridges, which sample the upper mantle, have a remarkably uniform $^3He/^4He$ ratio. In contrast, $^3He/^4He$ ratios of ocean island basalts may be lower or higher than at the ridges. Major ocean island "hot spots," such as Hawaii and Iceland, have a higher $^3He/^4He$ ratio than mid-ocean ridges, an observation that has been a cornerstone of the "layered mantle" model that has dominated mantle geochemistry for the last 20 years. In this model, ocean island volcanoes sample a lower, more volatile-rich layer that has been preserved over Earth's lifetime below the seismic discontinuity at 670 km depth.

This model has recently come under scrutiny. Tomographic images have provided evidence for subducted material passing through the 670-km discontinuity (*4*). And numerical models of mantle convection show that neither the high viscosity of the lower mantle nor the phase change at 670 km can preserve layering or large-scale geochemical heterogeneity in the deep mantle (*5*). The models also show that the observed mass balance of radiogenic noble gas between atmosphere and mantle is not unique to a layered mantle (*5*). This presents us with a fundamental problem: How and where are primordial noble gases preserved in the mantle?

The problem is compounded by the fact that a large portion of ocean island basalt stems from material that has been subducted and recycled into the mantle (*6*). Recy-



Then and now. During accretion, large bodies are efficiently degassed on impact (**left**), yet noble gas measurements suggest that reservoirs within Earth's mantle remain volatile-rich today (**right**). Possible causes include equilibration between a magma ocean and an early massive atmosphere, or incorporation of undegassed material into the mantle, perhaps from an early stage of accretion. Any model describing the evolution of the mantle must account for why different regions in the mantle preserve distinct geochemical signatures in a dynamic convecting regime.

The author is in the Department of Earth Sciences, University of Manchester, Manchester M13 9PL, UK. E-mail: cballentine@fs1.ge.man.ac.uk

cled material has been degassed and cannot contain primordial noble gases but will generate a substantial amount of radiogenic noble gases. To produce the observed high $^3He/^4He$ ratios at ocean islands, it is necessary to add material with a high ^3He concentration. Some models place the high ^3He in an even lower layer separated from the convecting mantle by a seismically invisible density contrast, or in the D'' layer at the bottom of the lower mantle, or in the core. Other models advocate islands of heterogeneity in the lower mantle, or small-scale heterogeneity distributed throughout the mantle and sampled preferentially by the relatively small volume of partial melts at ocean islands.

Understanding how the mantle may have assimilated primordial noble gases provides an important perspective on these models. For example, equilibration of a dense early atmosphere with a magma ocean (see the figure) can readily generate the ^3He concentrations required for a high ^3He silicate mantle (*7*). With such a high early mantle ^3He concentration and our poor understanding of noble gas partitioning between silicate and metal, we cannot rule out a high ^3He core that may provide a ^3He source for the present-day mantle (*8*). Alternatively, material that survived degassing during accretion may have been buried in the deep mantle, providing the ^3He source.

Ne isotopes in the mantle provide a test for these different concepts (*9*). Noble gases introduced into the silicate mantle or core by way of a magma ocean will reflect the solar nebula gases that formed the early atmosphere and should therefore have a solar Ne isotopic composition ($^{20}Ne/^{22}Ne = 13.8$). In contrast, Ne trapped in extraterrestrial material has an isotopic value of $^{20}Ne/^{22}Ne = 12.5$. Upper limits for mantle Ne are similar to implanted solar values (*9*) but cannot yet be distinguished unambiguously from air contamination during the eruptive process (*10*).

For heavier noble gases, distinguishing air contamination from the real mantle signature is also critical. No solar component in the isotopes of Ar, Kr, or Xe has yet been resolved from an air-like composition in any basaltic sample (*9*). If the noble gases in the mantle-atmosphere system evolved from an early atmosphere, buffered by magma ocean degassing, we might expect some trace of this early system in the heavier noble gases. Either this trace never existed and we must reconsider the atmosphere-magma ocean equilibration model, or recycling of atmosphere-derived heavy noble gases back into the mantle has masked it.

Could remixing of fractionated heavy noble gases have occurred in the early Earth, or did it happen over time as a consequence of ocean crust recycling? The observation that these gases may be ubiquitous in both ocean island and mid-ocean ridge volcanism illustrates that resolving this question will be a key factor for future mantle models addressing the mixing of volatiles from different sources.

A first clue comes from an unexpected source. Isolated from the convecting mantle for long periods of time, the mantle beneath the continents has sampled snapshots of the mantle volatile composition over the last 2 to 3 billion years. Magmatic CO_2 occurs in many natural gas reservoirs (*11*) but is often subject to atmospheric contamination; however, in a few gas fields this contamination is minimal. The recent resolution of a solar Xe component in CO_2 well gas from New Mexico (*12*) is the first indication that the convecting mantle may have evolved from a solar-like composition.

The subcontinental mantle remains one of the least explored parts of the mantle with respect to the heavy noble gas tracers. Yet it may contain a unique, time-integrated signal from other mantle domains. Some exciting work is ahead.

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PERSPECTIVES: IMMUNOLOGY

A Pathogen Receptor on Natural Killer Cells

Eric Vivier and Christine A. Biron

Vertebrates have both an innate and an adaptive immune system to protect themselves against pathogen infection. Adaptive immunity depends on specialized lymphocytes, the T and B cells, that recognize pathogens and support the development of immune memory. These lymphocytes express antigen-specific receptors called T cell receptors (TCRs) or B cell (immunoglobulin) receptors (BCRs). The enormous diversity of this antigen-recognition repertoire is effected by rearrangements of multiple gene segments clustered in the TCR and BCR loci of the genome. Yet, it is unclear how cells of the innate immune system, such as Natural Killer (NK) cells, that lack the recombination machinery necessary for gene rearrangement, recognize pathogens. On page 1323 of this issue, Arase *et al.* (*1*) demonstrate that NK cells recognize a mouse cytomegalovirus (MCMV) protein, m157, through an activating Ly49H receptor. This receptor is related to inhibitory Ly49 receptors that are responsible for inducing tolerance to self antigens.

Enhanced online at www.sciencemag.org/cgi/content/full/296/5571/1248

The multigenic and multiallelic Ly49 family is encoded by genes clustered in a locus termed the NK complex on mouse chromosome 6. Ly49 genes encode two distinct types of receptor: one activating, the other inhibitory. These two types functionally correspond to the activating and inhibitory killer cell immunoglobulin-like receptors (KIR) of the human immune system. Inhibitory Ly49 receptors interact with class I major histocompatibility complex (MHC) molecules and are thus important for inducing self tolerance of NK cells. Their inhibitory function depends on an intracytoplasmic region of the receptor called the immunoreceptor tyrosine-based inhibition motif (ITIM), which is absent from activating Ly49 receptors (*2*). The extracytoplasmic domains of inhibitory and activating Ly49 receptors are highly homologous. As a consequence of a charged amino acid residue in the transmembrane domain, activating Ly49 receptors associate with the signaling polypeptide KARAP/DAP12 that harbors an immunoreceptor tyrosine-based activation motif (ITAM) (*3*, *4*). Similarly, all ITIM-bearing molecules coexist with activating "counterparts" that associate with an ITAM-bearing molecule (CD3ζ, FcRγ, or KARAP/DAP12) (*5*).

E. Vivier is at the Centre d'Immunologie de Marseille-Luminy, INSERM–CNRS–Universite Méditerranée, Marseille, France. E-mail: vivier@ciml.univ-mrs.fr C. A. Biron is in the Division of Biology and Medicine, Brown University, Providence, RI 02912, USA. E-mail: christine_biron@brown.edu