

DNA can be used by many bacteria as a source of carbon, energy, nitrogen, and phosphorus. The ability to use DNA as a food source confers a dramatic survival advantage to *E. coli* cells in stationary phase over mutant bacteria that lack this ability. As once expressed, “DNA is good eating” (18). To what extent *V. cholerae* uses transformation to satisfy this appetite remains to be seen.

Note added in proof: *V. cholerae* secretes a chitin-binding protein that is also important in colonizing human intestinal epithelial cells (19).

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GEOPHYSICS

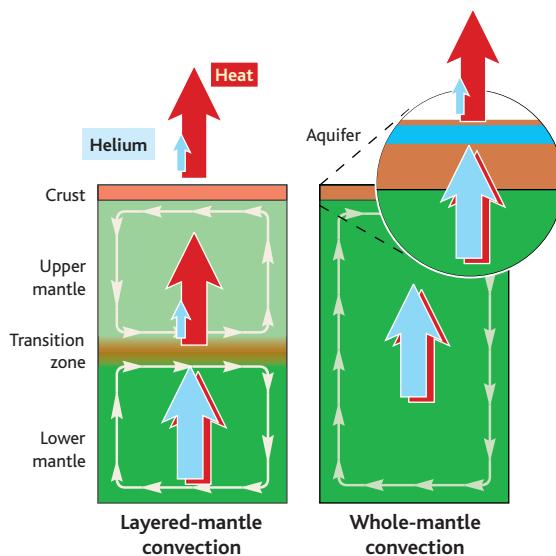
Helium Feels the Heat in Earth's Mantle

Francis Albarède

For nearly two decades, geoscientists held that the terrestrial mantle behaves as two superposed layers separated by a discontinuity at a depth of 660 km. In this picture, convection of mantle material occurs separately in each layer. This view was challenged in the 1990s by evidence from seismic tomography that some subducting plates penetrate almost all the way down to the core-mantle boundary (1, 2). Many of the arguments supporting layered-mantle convection still survive, however, and their impact—notably on chemical geodynamics and on the understanding of terrestrial evolution through geological ages—is still considerable. Most notably, researchers point to the noble gas helium. Reconciling whole-mantle convection with what we know about the abundances of helium isotopes in hotspot and mid-ocean ridge basalts (3–5) demands a solubility level of this gas in minerals that is rarely considered as acceptable. Second, the terrestrial inventory of the isotope ^{40}Ar created by radioactive decay of ^{40}K leaves too much of this gas unaccounted for. This is commonly interpreted to mean that deep mantle material never came close to the surface to lose its gas content (6).

A third very strong argument supporting the model of convection as occurring in separate layers is the apparent imbalance between heat flow and helium loss through the surface of Earth. Most of the energy that sustains convection movements in the mantle and that powers plate tectonics is heat

produced by the radioactive nuclides ^{238}U , ^{235}U , and ^{232}Th . These isotopes decay by emitting eight, seven, and six α particles, respectively. These particles are simply the nuclei of ^4He (with a small fraction of the energy produced by the decay of ^{40}K). O’Nions and Oxburgh (7, 8) pointed out that the production of heat and helium should be strongly connected but observed that the terrestrial flux of ^4He (at the proximity of mid-ocean ridges) only accounted for about 5% of the heat flow. They concluded that somewhere below the surface a



Mantle models. (Left) In layered-mantle convection, heat and helium are separated at the transition zone, which acts as a conductive boundary layer. (Right) As shown by Castro *et al.* (10), a similar effect is achieved by aquifers in continental crust and by seawater circulating through the oceanic crust. This picture of the crust reconciles the heat-helium flux imbalance with whole-mantle convection.

conductive boundary layer exists that allows heat to be transferred upward while retaining ^4He in the lower reservoir. After examining all the possible boundary layers, notably those located in the crust, they concluded that the helium-heat terrestrial imbalance was best explained by two convecting mantle shells separated by a conductive boundary layer at 660 km. This interpretation was recently reinforced by van Keken *et al.* (9), who demonstrated that such an imbalance is not a transient effect of the convective regime. Although the case of the heat/helium imbalance seemed to be clear, further work from an apparently unrelated field would prove it wrong.

A recent article by Castro *et al.* (10) is now placing the terrestrial helium-heat imbalance in a very different perspective. These authors constructed a two-dimensional (2D) numerical model of the Carrizo aquifer in Texas and surrounding formations in which the calculated hydraulic pressures, temperatures, and helium concentrations were carefully calibrated against measured field data.

They computed local heat and helium fluxes and discovered that for much of this multilayered aquifer system, heat is lost by conduction, whereas helium is transported by advection but only inefficiently because of the low hydraulic conductivities (and thus permeabilities) of the rocks. Under such conditions, the $^4\text{He}/\text{heat}$ ratio characteristic of radioactive sources is smaller than the “production ratio” in the crust by one to two orders of magnitude. In other words, this is the $^4\text{He}/\text{heat}$ ratio of radioactive sources. Recharge of the system with cold meteoric water (that is, from rain or atmospheric condensation), very poor in rare gas contents because it equilibrated with the atmosphere, enhances this effect. Castro *et*

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al. extend their interpretation to ocean basins in which water injected into the oceanic crust plays the same role as meteoric water in continental aquifers. Their article therefore does justice to the careful warning given by Oxburgh and O'Nions (8), who advised that "the systematics of the relation between the fluxes of helium and heat depend on transport processes." This warning was unfortunately lost in the turmoil of the debate between the advocates of whole-mantle versus layered-mantle convection.

One of the cornerstones of layered-mantle convection is therefore weakening. The remaining evidence essentially revolves around our understanding of the properties and inventories of rare gases. We are still awaiting incontrovertible data on rare-gas solubility in mantle minerals and melts, which would consolidate the dominant interpretation of the ${}^3\text{He}/{}^4\text{He}$ evidence in oceanic basalts. Helium-3 is a stable nuclide essentially unaffected by deep-seated radioactive processes. Even if helium turns out to be particularly incompatible, enough undegassed mantle material with high ${}^3\text{He}/{}^4\text{He}$ ratios may be concealed in the lower mantle as streaks interlayered with recycled material (11). In addition, the argument based on the inventory of ${}^{40}\text{Ar}$ in Earth is crucially dependent

on our knowledge of the terrestrial concentration of potassium, an element that is known to be extremely volatile during planetary accretion.

By coincidence, the consensus on the heat/helium imbalance at the surface of Earth is being challenged at almost the same moment as new experiments overturn the well-entrenched idea that high ${}^3\text{He}/{}^4\text{He}$ ratios in basalts are the hallmark of primitive mantle. ${}^3\text{He}$ is a stable isotope of helium, whereas ${}^4\text{He}$ (α particles) is continuously produced by the decay of uranium and thorium. High ${}^3\text{He}/{}^4\text{He}$ ratios in hotspot basalts (e.g., Hawaii) with respect to mid-ocean ridge basalts have been held as prime evidence that the deep mantle never lost its primordial gases. Measurement of the helium solubility in mantle minerals (12) suggests instead that a high ${}^3\text{He}/{}^4\text{He}$ mantle ratio may not be primordial (3, 4) but rather corresponds to residues of earlier stages of melting (5, 13, 14).

We should not let the heritage of layered-mantle convection models fall into oblivion, however. Numerical models of mantle convection repeatedly suggest that radial transport is particularly slow across the 660-km discontinuity and display episodic surges of layered-mantle convection regime (14). The article by Castro *et al.* nevertheless provides the first rigorous framework against one of

the strongest arguments used to support the role of the 660-km discontinuity as a convection boundary, and the authors should be commended for their work. Further full 2D and 3D models of large well-characterized aquifer systems around the world will soon let us reevaluate the terrestrial heat and helium fluxes and provide a new perspective on the thermal regime of our planet.

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ECOLOGY

Population Evolution and Island Biogeography

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In most areas of empirical science, including biology, we take an experimental approach for granted. However, in evolutionary and related studies, large-scale natural or field experiments are rare because the large spatial and temporal scales of evolutionary and biogeographical processes render experimentation problematic. Classically, biogeography is about large-scale pattern: How many species are there on an island? Is the number related to extent of isolation, island size, or complexity of vegetation? For example, why are there so many tree lizard (anole) species on each of the Greater Antilles but only one or two on each of the Lesser Antilles? Is it simply island size that is accountable, even though the small islands are environmen-

tally heterogeneous and complex (1)? This is not readily subject to direct experimentation. However, these large-scale biogeographic patterns are mediated by small-scale population-level processes. These include ecological processes such as competition between species and habitat usage, and evolutionary processes such as adaptation by natural selection, ancestor-descendant relationships, and speciation (splitting into distinct species, which do not interbreed). Exceptionally, it may be possible to manipulate these fundamental population processes experimentally to gain insight into biogeographic patterns, although even population-level experimentation is difficult. For example, experimental introduction of small Caribbean anoles onto islands, and experimental translocation between large enclosures within islands, have revealed much about the evolutionary and ecological population processes underlying

their biogeography. Large-scale translocation of the small tree lizard *Anolis oculatus* (Dominica, Lesser Antilles) has demonstrated the rapid effect of natural selection on a wide range of genetically controlled traits in response to wet or dry habitats (2, 3), thus explaining the nature and cause of the geographic variation. In addition, experimental introduction of *Anolis sagrei* onto Bahamanian islands has shown how predators can alter the behavior, niche usage, and their selection for prey (4). These studies also suggested how introduced predators may render their prey more vulnerable to extinction by catastrophes such as hurricanes (5).

On page 1807 in this issue, Schoener *et al.* (6) show how the survival of resident anoles on islands with introduced predator lizards depends on vegetation height. On islands without the introduced predator, anoles survive better in habitats with shorter vegetation, but on islands with the introduced predator, anoles survive better in habitats with taller vegetation. Island size on its own did not appear to have a significant effect. Hence, the authors take the important step of linking a population process (survival) to a key feature of island biogeography (vegetation type), and this direct demonstration, using a field experi-

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