they are subject to the whims of landowners. Most ranchers see prairie dogs as a threat to their livestock, although the evidence for this is equivocal (*3*). David Wilcove, senior ecologist with the Environmental Defense Fund, sees both the prairie dogs and ferrets as an important opportunity, rather than a threat to cash-strapped cattle ranchers, most of whom make only a modest one dollar per acre per annum. "In the long term, the biggest obstacle to recovering the black-footed ferret is the shortage of really large prairie dog colonies. There aren't many places left in the West that have enough prairie dogs to sustain a viable population of ferrets." Wilcove and his colleagues are examining the possibility of using economic incentives to encourage ranchers and farmers to maintain prairie dog colonies on their property. As he says "Wouldn't it be great if we could declare a cease-fire in our century-old war against prairie dogs? I'm confident there's enough room for both people and prairie dogs in the American west." Hopefully some of these prairie dog colonies may prove large enough to be sites for future introductions of captive black-footed ferrets, allowing their range to be extended even further.

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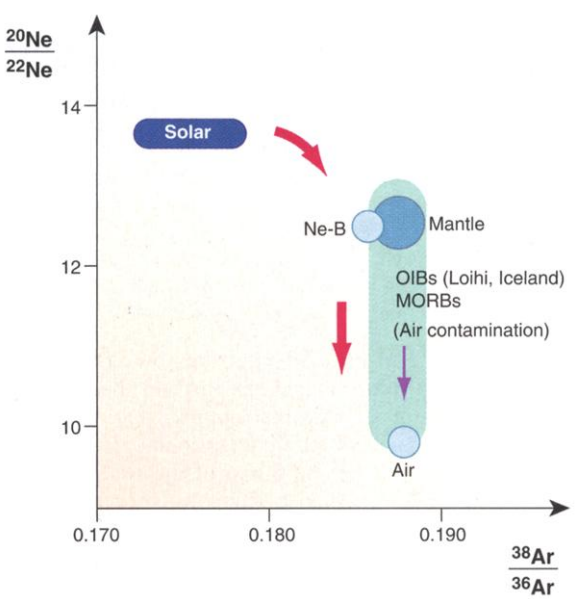
PERSPECTIVES: GEOCHEMISTRY

Earth's History Trapped in the Mantle

Ichiro Kaneoka

The isotopic compositions of noble gases in the mantle have been assumed to be the result of two processes: the incorporation of nuclides from various sources during the formation of the solar system, and the loss or addition, during the evolution of Earth, of radiogenic components that decay or accumulate at defined rates. If this assumption is correct, measurements of the isotopes of the noble gases should be able to constrain models of Earth's birth and evolution. Indeed, the ratios of isotopes in Earth's atmosphere are quite different from those in extraterrestrial materials. And so, if noble gases from Earth's atmosphere have been incorporated in the mantle—either early in Earth's history or over time—the assumed starting composition of the mantle would change. There has been considerable debate whether the nonradiogenic noble gases in the mantle reflect mostly solar-like or mostly atmosphere-like compositions. As reported on page 1036 of this issue, Trieloff *et al.* (*1*) have analyzed typical oceanic island basalts from Loihi, Hawaii, and Iceland with high-precision mass spectrometry in an effort to settle this problem, with strikingly clear results that point to a terrestrial atmospheric origin for these trapped gases.

The evidence so far has beeen mixed. Solar-like Ne isotopes have been reported in mid-ocean ridge basalts (*2*) and oceanic island basalts (*3*), supporting the idea of solar-type noble gases in the mantle (*4*). In addition, the $^{3}He/^{4}He$ ratio in mid-ocean ridge basalts (*2*) and oceanic island basalts is one order of magnitude higher than that of the atmosphere, which suggests the presence of pristine components in the mantle with a likely solar origin, to which radiogenic ^{4}He was added over time, causing a drop in the ratio. These solar components would have originated directly from the nebular gases from which the solar system was formed.



Isotopic ratios. The arrows indicate a conjectured sequence describing the evolution of noble gas isotopic ratios during the formation of Earth. OIBs, oceanic island basalts.

For the heavier noble gases Ar, Kr, and Xe, however, the situation is quite different. In the mid-ocean ridge basalts, atmosphere-like compositions have been reported for nonradiogenic isotopes on the basis of precise analyses of an anomalously gas-rich basalt called popping rock (*5*). Clear observation of excess ^{129}Xe and $^{131\text{-}136}Xe$ in the same sample precludes the possibility of air contamination at shallow depths because excess ^{129}Xe is the decay product of the extinct nuclide ^{129}I (half-life, 16 million years) and excess $^{131\text{-}136}Xe$ is the fissiogenic product of both ^{244}Pu (half-life, 83 million years) and ^{238}U (half-life, 4.47 billion years). Although the isotopic compositions of oceanic island basalts are also indistinguishable from those of the atmosphere for nonradiogenic components, no clear excess ^{129}Xe or $^{131\text{-}136}Xe$ has been identified. Hence, such observations have been suggested to be the result of air contamination (*6*). Recent statistical work on data for mid-ocean ridge and oceanic island basalts and diamonds also suggests atmosphere-like nonradiogenic isotopes of heavier noble gases (*7*), and these too have no associated excess ^{129}Xe or $^{131\text{-}136}Xe$.

Trieloff *et al.* (*1*) analyzed noble gas isotopes in a dunite (a mantle rock rich in olivine) from Loihi, Hawaii, and in volcanic glasses from Iceland by crushing the rock slowly in steps to release trapped gas and then performing high-precision mass spectrometry of the gas. They have observed a correlated excess of ^{20}Ne and ^{40}Ar and found evidence for excess ^{129}Xe and $^{131\text{-}136}Xe$. Although many samples from Hawaii and Iceland have been analyzed to date, this is the first evidence that island basalts from these areas show clear excess ^{129}Xe and $^{131\text{-}136}Xe$. Furthermore, the nonradiogenic isotopic compositions of Ar, Kr, and Xe are indistinguishable from those of the atmosphere, which suggests that the source of these oceanic island basalts had atmosphere-like components of heavier noble gases. Trieloff *et*

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al. argue that Ne isotopes in the mantle are not genuinely solar-type as commonly assumed, but likely to be Ne-B, which may be a component of the early solar system having the $^{20}Ne/^{22}Ne$ value of about 12.5, as inferred from the results from most gas-rich meteorites (*8*). The clear, consistent findings of Trieloff *et al.* indicating an atmospheric origin of mantle noble gases can be attributed to several factors: their selection of the most gas-rich samples from these locations, analyses with high-precision mass spectrometry, and the stepwise crushing method for degassing.

Their results support the idea that the whole mantle contains pristine heavier noble gases with isotopic compositions that are indistinguishable from those of the atmosphere, except for the radiogenic components. Furthermore, they suggest that Ne-B is a possible candidate for the mantle Ne. Consistent with this suggestion is the fact that the reported values for Ne isotopic compositions in mid-ocean ridge basalts and oceanic island basalts rarely exceed the value of Ne-B; any examples exceeding this value are associated with large analytical uncertainties. If the pristine noble gases of Earth do in fact contain Ne-B, it suggests that the accretion process to form Earth might have occurred in an environment similar to that of some other meteorite parent bodies. Earth's atmospheric noble gas isotopic compositions could have been established afterwards in an environment different from that of meteoritic parent bodies. Such a scenario is quite different from the model that assumes trapping of the primary atmosphere from the dense solar nebula (*9*). After incorporation of such a component, partial atmospheric loss with the isotopic fractionation might have established the pattern of the atmosphere (*10*).

Trieloff *et al.*'s proposal would require that atmospheric noble gas components had been incorporated into the mantle by processes like subduction before the last homogenization of the two mantle reservoirs (within a few hundred million years after the formation of Earth) represented by mid-ocean ridge basalts and oceanic island basalts. It is not certain, however, whether such complete homogenization might have been possible, even in early Earth. If terrestrial noble gas isotopic compositions had almost been established during accretion of planetesimals to form Earth, the difference of the atmospheric Ne ($^{20}Ne/^{22}Ne = 9.80$) from the mantle Ne needs to be explained by some later process that did not affect the isotopic compositions of heavier noble gases. Although Ne-B is suggested as a likely candidate for the pristine component in the mantle (*1*), additional confirmation is needed to settle this problem. In addition, Trieloff *et al.*'s data have added to the evidence indicating decoupling between the He and Ne isotopes. Hence, a detailed examination is required to reevaluate its importance. Our knowledge about the pristine noble gas isotopes in the mantle has been greatly increased by these new data, but many problems remain to be solved.

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PERSPECTIVES: ATMOSPHERIC SCIENCE

Absorbing Phenomena

Stephen E. Schwartz and Peter R. Buseck

Most considerations of global climate change caused by human activities, including the Kyoto convention (*1*), have focused on the warming influence of greenhouse gases (*2*). However, aerosols are another important atmospheric constituent that influences climate and has been affected by human activities (*3*, *4*). Aerosol particles increase scattering and absorption of shortwave (solar) radiation (*5*, *6*), increase cloud reflectance (*5*, *7*), enhance cloud lifetimes (*8*), and suppress precipitation (*9*, *10*). These phenomena are all thought to exert a cooling influence on climate. Recently, Rosenfeld (*9*) presented results demonstrating that anthropogenic aerosols reduce cloud droplet size and suppress precipitation downwind of major urban areas and industrial facilities, consistent with earlier hypotheses (*7*, *8*). Now, a major study, the Indian Ocean Experiment (INDOEX) (*11*), has extensively documented several of these phenomena and a report from this group (*12*) has identified yet another important effect of anthropogenic aerosols on clouds.

The influences of aerosols on climate are much more complex than those of greenhouse gases. Bulk aerosol composition is highly variable spatially and temporally, because of different sources and production mechanisms and short atmospheric residence times, from less than a day to more than a month. Particle sizes range from nanometers to micrometers; within the same size class, particles can exhibit widely different compositions and morphologies (*13*), with different constituents commonly present even within the same particle. For example, 10-nm soot carbon spherules can be found embedded within much larger sulfate particles (*14*). The inhomogeneous in properties and geographical distributions of aerosols make it difficult to characterize their influences on climate and to represent these influences in models. INDOEX examined the chemical and physical properties and geographical distribution of natural and anthropogenic aerosols and their precursors, the effects of these aerosols on clouds and radiation, and the resultant influences on regional and global climate. The study focused on a geographical region that has not received much prior attention, the northern and equatorial Indian Ocean. The 1998 and 1999 field studies were conducted during the winter monsoonal months January through March, when air flow over the region is dominated by transport from the Indian and south Asian subcontinents. Aerosols and other atmospheric and radiative quantities were documented by a wide range of measurements from aircraft, ships, satellites, and island stations.

In an initial study coming out of the 1999 campaign, Satheesh and Ramanathan reported recently (*15*) that anthropogenic aerosols exhibit substantial loading over much of the North Indian Ocean, the Arabian Sea and the Bay of Bengal, and even somewhat south of the equator. Model calculations showed that this aerosol had been transported thousands of kilometers from source regions in the heavily populated areas of the Indian subcontinent. The aerosol (see figure) was surprisingly absorbing. The absorption resulted mainly from carbon from fossil fuel and biomass combustion, with a smaller con-

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