Geochemistry

Mantle heterogeneity and convection

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THE nature of mantle heterogeneity and its geodynamic significance was the subject of a recent symposium* catalysed by the presentation of the first on-shore results of IPOD Leg 82 of the *Glomar Challenger* drilling. The Leg had been designed to study in time and space mantle heterogeneity beneath the North Atlantic around the Azores.

The symposium was intended to determine what constraints could be placed on convective processes in the mantle from the growing amount of data on incompatible trace elements and isotopic ratios of Pb, Sr, Nd, Hf and rare gases (He, Ar, Xe) in mantle-derived rocks. Geochemical tracers can provide information on mantle heterogeneity that cannot be had from geophysical observations such as gravity field, mean heat flow, deviation in the square root of time law for seafloor elevation, or seismic wave velocities. Their distribution, as observed in mid-ocean ridge basalts (MORB) and in ocean island volcanics (hotspots), gives an integrated picture of the mixing and differentiation going on within the Earth's mantle, and provides clues to the number, geochemical nature and mean age of reservoirs present in the mantle.

The potential for resolving dynamic processes in the mantle has attracted much attention to this infant subject. The important questions at this stage are: what do mantle heterogeneities look like, how do they vary in time, how do they interact with each other and how were they formed?

Isotopic ratios are important indicators of the sources of crustal rocks. Perhaps the most striking fact to emerge from the meeting was that anomalies in isotopic ratios from mid-ocean ridges and island basalts can span an enormous range of spatial scales, and their temporal variability can be short as well as long term. Indeed, the first requirement for any unified model of mantle sources of basalts is that it be able to account for this broad spectrum of spatial and temporal scales.

Results from IPOD Leg 82 illustrated such variability of scales particularly well. The purpose of the Leg was to document when and how the large-scale isotopic gradient (> 800 km long) extending along the present axis of the Mid-Atlantic Ridge (MAR) from the Azores Platform to the Hayes fracture zone developed; whether the Hayes fracture zone was always a boundary between the incompatible element-enriched Azores mantle domain and the depleted source of MORB; and whether the narrow (100–200 km) spike-like geochemical anomaly now present at 35°N (Oceanographer fracture zone) and superimposed over the large-scale gradient is a permanent feature, or simply spurious.

Samples were taken from a coarse grid (the best there is so far, however) of nine holes covering three isochrons (~ 35 Myr, 18 Myr and zero age) and four spreading flow lines at the latitude of the Azores, FAMOUS, 35°N and south of the Hayes fracture zone. Results presented by the French, British and US laboratories show that south of the Hayes fracture zone the mantle source of MORB has retained its depleted character over the last 35 Myr, thus further confirming the first-order uniformity, or well mixed, nature of this world-wide reservoir. In contrast, lavas derived from both the light rare-earth-enriched and radiogenic Sr- and Pb-rich (Nd-poor) source and the depleted MORB source were observed within a single hole (558) which sampled a time span of only 100–100,000 yr.

The group from the University of Rhode Island emphasized that such local variability is characteristic of hotspots that are no longer centred on the ridge axis, and may reflect the poor mixing conditions resulting from flow along sublithospheric channels extending between the near-ridge hotspots and migrating ridges, which act as sources and sinks of mantle materials, as proposed by Morgan in 1978. The 35°N anomaly, which appears to have persisted over the last 35 Myr sampled, could represent such a case and be associated with the long activity of the New England hotspot. This possibility can fit kinematic reconstructions of the migrating MAR axis relative to fixed North Atlantic hotspots presented by R. Duncan (Oregon State University) and S. Cande and co-workers (Columbia University). There is also general agreement that the Azores mantle plume must have reached the Earth's surface within the last 20 Myr, judging from kinematic reconstructions, the lack of a geochemical anomaly at the latitude of the Azores until 16 Myr and the absence of a down-ridge large-scale isotopic gradient in the oceanic crust of 35–10 Myr age sampled.

In general the on-shore analysis of trace elements (rare earths, for example) and isotopic ratios reported on Leg 82 confirm the conclusions regarding mantle sources and degree of mixing that were reached on-board ship from trace element patterns measured by XRF analyses (for example Nb, Zr, Ti, Y, V). There are, however, two notable exceptions. First, in hole 558 one light rare-earth-depleted lava horizon had a relatively low $^{143}Nd/^{144}Nd$ ratio comparable to the light rare-earth-enriched source that otherwise characterizes this hole. The discrepancy was interpreted by Jenner and co-workers (Max Planck Institute) as suggesting a recent depletion event, perhaps by fractional or dynamical melting. Second, hole 558 is enriched in radiogenic Pb to a similar degree as the present Azores mantle source, whereas the rare-earth pattern and Nd and Sr isotopes show the source of basalts from this entire hole to be MORB-like. No explanation was provided for this discrepancy.

The two exceptions emphasize both the need for analysis of various isotopes and trace elements in the same samples, and the power of the geochemical approach in providing constraints on the timing of enrichment events in the mantle. This was also well illustrated by the correlation of $^{129}Xe/^{130}Xe$ with $^{134}Xe/^{130}Xe$, $^{40}Ar/^{30}Ar$ and $^{3}He/^{4}He$ presented by Staudeger and Allègre (University of Paris) which suggest that the Earth's mantle must be more than 99 per cent degassed; the depletion of the MORB source must have taken place within some 80 Myr from the time the Earth accreted; and mixing between blob sources and the MORB source must have taken place recently.

Fine-scale local mantle source variability was best illustrated from data on intraplate island chains in the Pacific. For example, from Pb, Sr, Nd and Hf isotopic variability among basalts from the Hawaiian–Emperor Chain, the USGS team at Denver recognized six distinct groups. Episodic variability of sources over the 30,000-yr time span of the single Mauna Loa volcano, Hawaii, was also documented by J. Rhodes (University of Massachusetts), and the entire spectrum of world oceanic variability in Pb, Sr and Nd isotope ratios was observed among the French Polyne-

*The spring meeting of the American Geophysical Union was held in Baltimore on 31 May–3 June.

100 years ago

A PLEA FOR PURE SCIENCE

I am required to address the so-called Physical Section of this Association. Fain would I speak pleasant words to you on this subject; fain would I recount to you the progress made in this subject by my countrymen, and their noble efforts to understand the order of the universe. But I go out to gather the grain ripe to the harvest, and I find only tares. Here and there a noble head of grain rises above the weeds; but so few are they that I find the majority of my countrymen know them not. We must consider what must be done to create a science of physics in this country, rather than to call telegraphs, electric lights, and such conveniences by the name of science. I do not wish to underrate the value of all these things: the progress of the world depends on them, and he is to be honoured who cultivates them successfully. And yet it is not uncommon to have the *applications* of science confounded with pure science; and some obscure American who steals the ideas of some great mind of the past and enriches himself by the application of the same to domestic uses, is often lauded above the originator of the idea.

Condensed abstract of the address of Prof. H.A. Rowland of Baltimore before the American Association at Minneapolis.

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