

sian Islands reported by P. Vidal and co-workers (University of Chermond-Ferraud). The apparent multiplicity of isotopic sources for intraplate hotspots is not entirely surprising since additional complexity is expected to arise in the interaction and mixing of magmas from various mantle sources with old lithosphere which has been altered by seawater-derived hydrothermal activity, and sedimentary products of various provenances. Furthermore, longer magma residence times in the lithosphere expected for intraplate volcanism are likely to enhance dispersion in elemental abundances by fractional crystallization. Subsequent mixing of such differentiated melts derived from distinct sources will also enhance scatter in mixing correlations between two isotope ratios. This effect was demonstrated by Verma and co-workers (University of Mexico) by comparing scatter in mixing trends in Sr and Nd space for lavas from the Galapagos Islands and the nearby spreading centre.

The identification of various end-member reservoirs, of which other reservoirs may be a mixture, was also discussed at length. Zindler (Columbia University) further stressed the need to recognize three end-member reservoirs in terms of Pb–Sr–Nd isotopic space (*Nature* **298**, 519; 1982). The three reservoirs comprise two of hotspot type: the St Helena, also reported to be present beneath Tubuai Island in the Pacific by Vidal, and the Tristan d'Acunha; and, of course, the depleted MORB source. Allègre showed on the basis of relative dispersion of $^{87}\text{Sr}/^{86}\text{Sr}$ that the depleted MORB source is more contaminated by injection of hotspot-type material beneath the MAR than the more rapidly spreading East Pacific Rise. Independently, Craig (University of Southern California) pointed out two extreme hotspot mantle source types relative to the MORB source: a low $^3\text{He}/^4\text{He}$ which may correspond to the Tristan type in Nd–Sr–Pb space (for example, Azores, Erebus, Easter, Grand Comore and Galapagos) and which is also found along island arcs and a high $^3\text{He}/^4\text{He}$ type (for example, Iceland, Hawaii, Reunion, McDonald Seamount, Samoa Island) which does not correspond to any end-member identified in term of Nd–Sr–Pb isotopic space. This raised the question that rare gases may be decoupled from the mantle reservoirs identified with Nd–Sr–Pb isotopes, and may be migrating independently within the mantle, perhaps in association with metasomatic fluids — a mechanism which received direct mineralogical and isotopic support from the study of various peridotites by S. Haggerty (University of Massachusetts), Hawkesworth and co-workers (Open University, UK) and S. Hart and co-workers (Massachusetts Institute of Technology).

It was clear from the meeting that the distribution of the various reservoirs, how they interact and mix, and their origin are continuing problems. The following ques-

tions were raised in one form or another. Is the mantle layered and convection confined to such layers, or are the enriched mantle domains passively and randomly distributed within the depleted MORB source as emphasized by Davies (Washington University)? Do interactions between layers take place only at the interface between the layers, such as by entrainment by convective eddies from one reservoir to another as suggested by the fluid dynamic experiments of P. Olson (Johns Hopkins University) or is the interaction taking place by buoyant heat-producing element-enriched blobs which penetrate the depleted asthenosphere source of MORBs as emphasized by J-G. Schilling (University of Rhode Island), G. Thompson (Woods Hole Oceanographic Institute) and Allègre and co-workers? Do some of the enriched-mantle-type domains reflect either deeply buried, previously untapped mantle reservoirs as implied by the rare-gas

isotopic data; or reinjection into the mantle of (recycled) continental crust material (De Paolo, University of California, Los Angeles); or subduction of aged lithosphere which would penetrate the 650-km discontinuity (D. Yuen and U. Christensen, Arizona State University and Max Planck Institute); or combinations of these? Are small incompatible element- and volatile-enriched mantle domains embedded in the more depleted MORB source preferentially melted as they rise towards the Earth's surface (N. Sleep, Stanford University)? No unified model emerged from the meeting, but what was achieved was a better sense of where the ambiguities lie and what the important questions will be in the future. □

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Mineralogy

The epidote jigsaw

from Colin Graham

MINERALS of the epidote group $[\text{CaAl}_2(\text{Al,Fe})\text{Si}_3\text{O}_{12}(\text{OH})]$ are stable throughout the Earth's crust, from the shallow levels of geothermal systems to the depths of the lowermost crust or upper mantle. They are widely distributed in metamorphosed basaltic and calcareous rocks, and their occurrence and stability are sensitive to both temperature and pressure, as well as to the activities of water and oxygen. They should therefore preserve important information about the conditions of crystallization or metamorphism of rocks throughout much of the Earth's crust. The stability relations of epidote-group minerals, however, are so far insufficiently well known to use to the full the information they contain. Even the relative stabilities of the iron-free end-member polymorphs clinozoisite and ortho-epidote (or zoisite) are quite uncertain, despite their common coexistence as iron-poor polymorphs in metamorphic rocks.

In a recent issue of *Nature* however, Jenkins, Newton and Goldsmith (*Nature* **304**, 622; 1983) have shown unambiguously that Fe-free zoisite is significantly more stable than Fe-free clinozoisite, by experimentally studying their relative stabilities in equilibrium with kyanite, anorthite and quartz at high pressure and temperature. Zoisite has been found to grow in mixtures of zoisite and clinozoisite at temperatures as low as 350°C. Furthermore, Jenkins *et al.* have been able to suggest from a survey of occurrences of coexisting zoisite plus clinozoisite in metamorphic rocks that clinozoisite is only likely to be stable relative to zoisite below about 200°C. This elucidation of the relative stabilities of orthorhombic and monoclinic Fe-free epidote polymorphs constitutes an

important piece in the epidote jigsaw.

The surprisingly limited stability of monoclinic iron-free epidote (clinozoisite) indicated by Jenkins *et al.*'s work prompts speculation as to why monoclinic epidotes should be so widespread and common in crustal rocks. A quantitative solution to this problem is an important experimental and mineralogical task, which must focus on the substitution of iron for aluminium in the epidote structure. It is clear that the easy replacement of Al by Fe in the monoclinic epidotes relative to the ortho-epidotes enormously enhances their stability. But the inferred existence of a region of immiscibility in the clinozoisite-epidote solid solution underscores the likely mineralogical complexity of this solid solution. Jenkins *et al.*'s successful high-pressure study of a metastable mineral reaction involving clinozoisite, albeit over a narrow temperature interval between that of spontaneous nucleation and growth of zoisite at high temperature and that of prohibitively slow reaction at low temperature, paves the way for further systematic experimental study of the stabilities of the Fe-bearing monoclinic epidotes. Such a study, although experimentally complex, holds the prospect of locating more key pieces in the epidote jigsaw, and of allowing petrologists and mineralogists to make fuller use of epidote-group minerals than has been possible to date in deciphering the conditions of formation of a wide range of crustal rocks. □

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