Igneous petrology

Old magma chambers replenished by new ideas

from R. Stephen J. Sparks and Herbert E. Huppert

IGNEOUS processes are a dominant mechanism for chemical differentiation within the Earth. They set up complicated plumbing systems which connect the deep source of magma generation to the surface. Some magma ascends to the surface to initiate volcanic activity, while some can be trapped at depth to form intrusions. The plumbing can include magma chambers, which for some time have been envisaged to play an important role in controlling the chemical evolution of magmas and the behaviour of volcanoes. Only a decade ago, magma chambers and their associated conduits were generally assumed to be closed systems in which chemical equilibrium was commonly attained. A recent meeting* illustrated how ideas have changed; the main theme was that most magmatic systems are open, being replenished from below and tapped from above with non-equilibrium and dynamical processes playing an important and dominant role.

New ideas on the role of fluid dynamics in the evolution of magma chambers formed a major part of several presentations. These included simulations carried out in our laboratory of the convective movement of magma through a crystal pile, which has been proposed as a mechanism for adcumulus growth (*Lithos* **17**, 139; 1984). The fluid dynamical principles of magma chamber replenishment by both heavy and light inputs of primitive magma were described by a number of speakers who argued that thermal and compositional stratification can be created by such replenishments, as well as by mixing between magmas. Illustrating the practical application of such ideas, A. Naldrett (University of Toronto) explained how a light input of primitive magma can lead to the formation of PtS ore deposits in the Bushveld Complex (*J. Petrol.* **24**, 133; 1983). S. Blake (Australian National University) discussed the eruptive withdrawal of a two-layer chamber and suggested that only very large eruptions can tap magma from a lower layer which is more than a few tens of metres below the chamber vent.

One of the most fascinating and controversial topics in recent petrological discussions concerns the origin of compositional zoning in magma chambers. Some detailed petrological studies (G. Worner, Bochum University and J. Wolff, University of Texas) showed how extreme fractionation of trace elements can occur in alkaline phonolitic systems as well as in the better-known rhyolitic systems. Some elegant experimental studies on Soret diffusion (C. Lesher, Yale) showed that distribution coefficients of trace elements are very sensitive to slight changes in melt composition in highly evolved magmas. This implies that large changes in melt structure accompany fractional crystallization of highly evolved magmas and strongly influence the development of extreme enrichments or depletions of trace elements. A. McBirney (University of Oregon) described the results of fluid dynamical analyses of boundary-layer flows in a magma chamber which is cooling and crystallizing at a vertical wall in an otherwise uniform magma. He showed that many magma chambers should be in the regime of counter flow, in which a thin, inner compositional boundary layer of differentiated fluid can ascend to the top of the chamber to form a zoned region. The theory predicts a vertical flux of 1 $cm^2 s^{-1}$ per unit wall width, somewhat larger than previously postulated. The mechanism provides the most plausible way yet proposed to cause zonation in highly evolved magma chambers.

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Volcanic studies

New ideas in experimental petrology are contributing to our understanding of open magmatic systems. T. Grove (Massachusetts Institute of Technology) showed how small amounts of crystal contamination can have substantial effects on the chemical evolution of magmas, producing calcalkaline rather than tholeiitic trends from a basaltic parent. An application of experimental and observational petrology to the Mount St Helens magma from the 18 May, 1980 plinian eruption established that the magma had a temperature of about 920°C, ascended from a chamber at 6-7 km depth and contained 4.6 per cent H_2O (H. Sigurdsson, Rhode Island and M. Rutherford, Brown). The petrological model showed excellent agreement with volcanological and geophysical results.

A major reason for believing open-system behaviour is dominant in many magmatic systems has come from detailed investigations of the petrology and geochemistry of igneous centres that have well-documented geological histories. The fine details of individual volcanic and plutonic units have shown that closed-system processes generally provide inadequate explanations of the data. Several speakers discussed how an interaction of basaltic magma with crustal rocks is required to explain the isotopic systematics. For example, volcanic rocks of the Hebridean Province, Scotland (R. Thompson, Imperial College) and the Taos Plateau, New Mexico (M. Dungan, Southern Methodist) show isotopic and trace element signatures of complex interaction with the crust. Z. Palacz (Open University) documented how large variations of isotopic composition can occur within individual layers of the Rhum intrusion, which implies that open-system processes play a dominant role.

An interesting controversy emerged from petrological studies of the Fish Canyon Tuff (J. Stormer, Rice University). The conventional view of the evolution of large caldera complexes envisages establishment of a high-level magma reservoir prior to collapse. Compositional zonation is thought to develop in such chambers. Stormer, however, concludes that the Fish Canyon magma is not chemically zoned and that the minerals in the magma formed in a deep chamber, 20–30 km in the crust. If a shallow chamber existed before the eruption, then it must have been intruded rapidly, since there is no signature of its existence in the mineral chemistry. This is still very controversial but, if correct, the arguments for the conventional high-level magma chamber will have to be re-examined.

Isotope geochemistry, which has led the way in recent years on many questions of magma genesis, is now producing a deluge of data, combining a number of radiogenic and stable isotope systems. For example, several speakers showed how the sediment, mantle and crustal components can be distinguished in island arc volcanics. However, there are signs that the law of diminishing returns may be operating. The answers to some fundamental questions (for example, how much subducted oceanic crust and sediment is recycled in arc magmation) remain essentially qualitative. More and more isotopic data may not produce any clearer picture unless combined with other approaches.

Finally, everyone was greatly saddened by the death of the Japanese petrologist Masanori Sakuyama, who was to have presented a paper at the conference. Sakuyama was an outstanding young scientist who had already made several important contributions to understanding open-system magmatism, particularly the role played by magma mixing and andesite petrogenesis. □

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Erratum

In Fig. 2 of Nancy L. Craig's article 'Resolution of intermediates' (25 October, p. 707), the labels *att*L and *att*R were misplaced and should be transposed.