Geochemical Facets of Global Tectonics

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THERE can be little doubt that geochemical evidence is potentially a major factor to be taken into account in deciding between the possible and impossible in the new global tectonics. That this potential has not yet been fully realized is, in part, due to the fact that data are still comparatively sparse. For obvious reasons, geochemical analysis, unlike some types of geophysical investigation, requires direct access to rock samples, and in so far as the active global tectonic processes largely take place on or beneath the ocean floor, the difficulty in acquiring large numbers of samples is only too clear. This situation is likely to improve as more and more samples become available from the JOIDES programme, but even the Glomar Challenger is incapable of drilling far into the sub-oceanic basement, and access to the critical upper mantle remains a dream.

Moreover, at present it is still not clear to what extent the number of unknowns within geochemistry itself will limit the ultimate ability of geochemical evidence to set boundary conditions to global tectonic processes. This problem is best illustrated by an example. Some years ago, Kushiro (*Yearbook Carnegie Inst. Wash.*, **64**, 103 ; 1965) showed experimentally that partial fusion of a pyrolitic mantle produces magmatic liquids whose composition depends on the lithostatic pressure at the point at which the fusion takes place. He then went on to suggest that the lower the pressure the greater will be the degree of oversaturation in the liquids. Three years later, however, O'Hara (*Earth-Sci. Rev.*, **4**, 69 ; 1968) suggested that with a hydrous mantle the opposite relationship could be more valid at higher pressures. In such a situation, it is not easy to decide which view is the more appropriate because critical information is lacking and is likely to remain lacking for a long time to come.

But in spite of such problems, Gass (*Phil. Trans. Roy. Soc.*, A, **271**, 131; 1972) is able to conclude that the geochemical pattern of volcanism on the ocean floor is broadly consistent with the tenets of ocean floor spreading, although there are certain anomalies. In terms of volume (estimates vary between 3.4 km^3 and 10 km^3 per year), the most important regions of oceanic volcanism are, of course, the oceanic ridges where in each case mantle material is upwelling into a comparatively narrow fracture coincident with the ridge crest. The rock injected here is dominantly olivine tholeiite, a form whose derivation is quite consistent with partial melting at low pressures. That these tholeiites are the products of high-level fusion is also supported by the fact that they are usually relatively poor in the incompatible elements such as K, Rb, Ti, Ba, Sr, U and Th, for lower-level fusion and the consequent fractionation would have produced enrichment in such elements. In short, the overall geochemical picture here seems to be entirely consistent with the model derived from geophysical considerations.

On the other hand, as Gass points out, there are "other facets to this grandiose pattern"—what appear to be reasonable predictions, but predictions not apparently supported by the data. One of the tenets of plate tectonics, for example, is that the rate of ocean floor spreading must increase with distance from the relative pole of rotation of the relevant plates. Where the spreading rate is faster, Gass argues, heat flow should be greater and thermal gradients steeper. In this case, the zones of partial melting should be shallower and, accepting Kushiro's view (which appears to be the most appropriate in the 5–60 kbar range), the injected rocks should be more oversaturated. But is this last prediction supported by the evidence? Here one comes up against the problem of shortage of data, but what little evidence there is fails to support the conclusion. Thus on Iceland, where the half-spreading rate is less than 1 cm per year, the degree of oversaturation is high; and on Bouvet Island, also astride the mid-Atlantic Ridge but where the half-spreading rate is about 2 cm per year, the degree of oversaturation is still high but lower than on Iceland.

The second type of ocean floor volcanism is that associated with linear fractures in general and transform faults in particular. In these regions, the dominant product of volcanism is the alkaline basalt with soda in excess of potassium. This, too, is consistent with physical models. For one thing, faults will presumably allow a relatively easy path from the asthenosphere to the crust, fractionation along the path will thus be minimal, and there should be little enrichment in the incompatible elements. Second, if Oxburgh (in *Understanding the Earth*, Artemis Press, Sussex ; 1971) is correct in concluding that the oceanic lithosphere thickens away from ridge axes, it follows that the magma source in the asthenosphere will become deeper for increasing distance from a ridge. Accepting Kushiro's interpretation again, this should mean an increasing degree of undersaturation with distance—a relationship which is confirmed by the compositions of oceanic islands such as Trindade and Martim Vaz, Fernando de Noronha, the Cape Verde Islands and the Azores in the Atlantic, the islands south of Tahiti, Rapa, Pitcairn and the Tuamoto ridge in the Pacific, and San Benedicto, Socorro and Clarion on the Clarion fracture zone.

The third major source of oceanic volcanism is the volcanic islands, such as the Tristan da Cunha group and Gough Island in the Atlantic and the Marquesas in the Pacific, which are not related to either ridge axes or linear fractures. The rocks here, although still alkaline, are highly enriched in the incompatible elements, suggesting that they are the products of extreme fractionation. Such a history seems quite reasonable in view of the lack of any obvious easy path from asthenosphere to crust and the consequent necessity for some form of gradual progress through the lithosphere.

The overall picture of the relationship between geochemistry and the new global tectonics is thus fairly clear and consistent, although there is at least one major anomaly which may or may not be simply a reflexion of shortage of data. This is truly a situation in which more detailed results are urgently required from all oceans, but Gass looks particularly to the Red Sea—a region of ocean floor spreading in its early stages—for a guide to the underlying geochemical processes involved. As it happens, Glomar Challenger is drilling there at present. —From our Geomagnetism Correspondent.