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CRUSTAL GROWTH-SOME MAJOR PROBLEMS

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The genesis and evolution of the continental crust are first-order geologic problems which remain unresolved. We still face several difficulties with respect to obtaining fundamental data necessary for solving the problems in the form of the composition and structure of the deep crust, and the nature of the crust-upper mantle boundary. While it is clear from a number of different approaches that the upper continental crust is generally of granitoid composition, the processes of upper crust production from middle and lower crust are unfortunately still obscure given the difficulty of inverting the geochemical data obtained on minimum and near-minimum melt magmas to the bulk composition of the sources. Thus it seems that the hope of using the granite cycle as a geochemical probe of the middle and lower crustal source regions is not going to be fulfilled, and other methods need to be employed. This is not to deny the use of granite geochemistry as a constraint on the isotopic spectrum of the source components and time-integrated parent/daughter isotopic ratios of these components.

The other major lines of evidence both direct and indirect that we have for the nature of the lower continental crust are: 1) exposed "deep crustal" segments; 2)xenoliths brought up in explosive, fast-moving alkalic igneous rocks; and 3) geophysical evidence (seismic wave travel times, electrical conductivity, gravity and the density-composition relations inferred from these data)

There has been considerable debate in the literature concerning the true nature and relevance to normal lower crust of uplifted slices of the continental crust that have been metamorphosed at high grades. For example, recent estimates of the P-T maxima reached by para- and orthogneisses of the Ontario (Canada) Grenville province are 10 - 12 kbar and approximately 800^{o}C, which would allow these materials to have been subjected to the conditions prevailing at the base of the normal thickness of continental crust. Nevertheless, there is still a thickness of some 30 - 40 km of crust beneath the present-day exposed Grenville and the exposed gneisses would appear to have been "middle" crust in some overthickened sequence about 1.2 Ga ago. A plausible mechanism for a) subjecting supracrustals to lower crustal conditions; b) allowing these to be exhumed to the surface is a Himalayan-style continent-continent collision, erosion and rebound. The conclusion therefore is that the Grenville terrain itself is not a direct sample of normal lower continental crust.

Studies of lower crustal xenolithic material have been increasing in number in recent years because of the difficulties encountered in other, large scale approaches. Although these studies are plagued by the minute size of sample, possible misrepresentative sampling of the lower crust and non-survival of some facies in hostile host magmas, and the lack of dimensional relations with surrounding lithologies, some interesting conclusions have emerged. For example, it is fair to say that one of the major conclusions of xenolith studies based on materials from southern Africa, the Colorado Plateau, northern Mexico, the Massif Central and eastern Australia is that the lower crust is predominantly mafic in character with polygenetic origins but predominantly of assimilation-modified under- and intraplated basaltic magmas and cumulates derived therefrom. As an example of the different conclusions that might be drawn from studies of Grenville-age outcrops and deep-seated xenoliths (entrained in Tertiary basalts) in Mexico, Ruiz et al. (1987)(1) have shown that the exposed granulites are on average of andesitic compostion (63 wt% SiO_2), whereas the xenoliths are significantly more mafic (average 53 wt% SiO_2).

There are however, difficulties in the way of accepting the hypothesis that the lower continental crust is everywhere mafic in character. Although petrologic and geophysical evidence for a mafic lower crust are satisfyingly in accord in the case of eastern Australia (2) (thermobarometry, crustal velocity structure, lack of Moho), the same is not everywhere true. While increasingly there is recognition that the Moho is not necessarily a simple ultramafic/intermediate rock contact, the persistence of rapid changes in seismic wave velocity at the base of the crust is incompatible with the presence of thick sequences of mafic materials in granulite-eclogite facies.

In more general terms, our models of crustal formation which depend heavily on the modern plate tectonic cycle are also in trouble. Despite occasional opinions expressed to the contrary, there is a consensus amongst petrologists actively engaged in the study of island arc magma genesis that the primary flux of material to the arc crust is basaltic in character. This flux may be expressed as intermediate to silicic eruptives in some arcs, expecially those constructed on pre-existing continental crust, but the point remains that modern-day crustal growth in arcs appears to involve basalt as the prime building block.

The granite extraction cycle can of course operate on this building block without the same volumetric lever that would exist in the case of an intermediate composition protolith. The major difficulties with this type of model are 1) the creation of an embarassingly large mafic-ultramafic restite that has not been recognized petrologically, but may not be distinguishable seismically from peridotite in the upper mantle; 2) the necessity of general disposal of this restite at least from the crust given the lack of evidence for its residence at the base of the crust.

It might be argued that present-day arc petrogenesis is not directly relevant to the problem of the major periods of Archean and Proterozoic crustal growth. For example, higher temperatures gnerally prevailing in subduction zones might have permitted the direct anatexis of hydrated ocean floor (solidus at about 800°C in the pressure range 5 - 25 kbar) rather than the devolatilization inferred at present. Two points should be made with respect to this model of direct silicic magma production in the Archean: a) the products of wet melting of basalt are not like "calcalkalic" series; b) the pervasive invasion of peridotite overlying the subducted lithosphere by melts of elevated Si/Mg ratios should surely have raised this ratio in upper mantle peridotite above chondritic, whereas the observed ratio is less than chondritic and thereby a major constraint on models of mantle formation.

It is clear that major problems persist with our detailed understanding of continental crustal growth, and that uniformitarianism may not be a helpful concept in the resolution of the difficulties.

References

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