Magmatism

Oxygen and the differentiation of magmas (*January 2011*)

The bulk of igneous rocks found within and upon the crust formed by one of two fundamental processes of magma differentiation: calc-alkaline and tholeiitic, responsible for island arcs and ultimately continents forming and for generating oceanic crust and flood basalts. The parental material for both is basaltic magma, but the first leads to a decrease in iron in more fractionated magmas, whereas an increase in iron characterised the second. In the first case conditions favour iron entering igneous minerals, whereas in the second they urge crystallising minerals to exclude iron. The most likely explanation is that the calc-alkaline magmas of volcanic arcs devour electrons so that iron exists in the oxidised ferric or Fe^{3+} state and readily forms dense iron oxide minerals whose progressive removal makes the remaining magma less and less rich in iron. More reducing conditions that lack an abundant electron acceptor, primarily oxygen, make the formation of iron oxides less likely, and iron can build up in residual magmas. But how greater oxidation occurs in arc magmas than in those of the oceanic crust has several possible explanations.

The most-widely assumed is that it happens because volcanic arcs lie above subduction zones where hydrated and therefore oxidised ocean floor descends into the mantle conferring oxygen to the products of partial melting. Another candidate is the depth at which fractional crystallisation takes place and there are other possibilities. The oxidation state of fundamental magmatic processes can be proxied by determining in rocks produced by fractionation the relative proportions of elements that behave differently in conditions of increased or decreased oxygen. One such pair is insensitive zinc and sensitive iron (Lee, C.-T.A. *et al*. 2010. The redox state of arc mantle using Zn/Fe systematics. *Nature*, v. **468**, p. 681-685; DOI: 10.1038/nature09617). The surprise is that the parent magmas of both calc-alkaline and tholeiitic fractionation series have identical Zn/Fe ratios, suggesting that both partially melt from mantle with much the same availability of oxygen. The Zn/Fe ratios differ in more evolved igneous rocks from the two series, suggesting that it is in the fractionating magma chambers that the distinctively different oxygenation occurs, not in the zone of mantle melting.