Bimodal amphibole populations in arc magmas

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Magmatic processes strongly modulate crustal growth and evolution in convergent margins, although the relative importance of processes such as fractionation, mixing and assimilation, and the locations within the crust where these occur remain a source of debate. Detailed studies of individual magmatic systems are valuable, however data compilations also provide important insights.

A global compilation of igneous amphibole compositions (n > 2300) from convergent margins shows these are highly bimodal in composition (Al, Si Mn, Na, Ti and K contents, and molar Al/Si ratios). Bootstrap based corrections for sampling bias show that bimodality is highly robust and not an artefact of variable sample density. A high proportion (> 70%) of individual volcanic centers reveal bimodal amphibole populations, and overall bimodality is most pronounced in intermediate magmas (andesites and dacites).

The compilation demonstrates that on a global scale crystallization of amphiboles in arc volcanics is dominated by two distinct environments: (i) crystallization from felsic magmas (Al/Si_{liquid} ~0.21) at relatively shallow crustal depths (~4-6 km); and (ii) from hotter and more mafic melts (Al/Si_{liquid} ~0.32) within the middle crust (~8-14 km). These depths also agree well with geophysical estimates of magma storage in active arc volcanoes.

Comparison with experimental studies of phase equilibria suggest that deeper crystallization of amphibole occurs within ascending hydrous mafic magma, which saturate with amphibole after moderate degrees of crystallization. Shallow amphiboles crystallize from crustal melts emplaced at relatively shallow crustal levels. In many instances these two types of amphibole occur in the same erupted magma, indicating extensive mixing between these two magmatic sources.

The highly bimodal nature of the amphibole distribution, and the presence of bimodal amphibole populations in many intermediate magmas is difficult to reproduce by models that argue for progressive fractionation of mantle-derived melts to produce the bulk of intermediate magmas in subduction zones. The observed distribution can be generated by mixing between mafic magmas, ultimately derived from the mantle, and more silicic magmas generated by melting within the arc crust, suggesting this is a dominant process in the formation of arc magmas.