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Multi-stage arc magma evolution recorded by apatite in volcanic rocks

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The chemical diversity observed in the rock record of volcanic arcs is determined by a multitude of processes operating between the magma source region and the surface. A fundamental step in producing this variability is fractional crystallisation, assimilation and melting in the lower crust which drives magmas to more evolved and hydrous compositions. During extensive fractionation of hydrous magmas in the lower crust, amphibole (\pm garnet) is stabilized in the fractionating assemblage and plagioclase is suppressed resulting in melts with elevated Sr, an absence of strong negative Eu anomalies (both elements being compatible in plagioclase), and depleted Y (compatible in amphibole and garnet). The high Sr/Y values that result can be used to provide insights into arc magma evolution, evaluate whether a magmatic system has the potential to form a porphyry-related ore deposit and track crustal thickness. However, this deep fractionation history may be obscured due to differentiation and mixing upon ascent to the shallow crust. Since arc rocks are a product of this multi-stage, polybaric process, unravelling the complete history of magmatic evolution using bulk-rock chemistry alone can be challenging. However, accessory minerals such as apatite, are capable of capturing discrete periods of melt evolution during differentiation [1]. For example, apatite has been shown to record the Sr content of the melt at the time of its crystallization which has been used to reconstruct host rock compositions in provenance studies [2, 3].

Here, we use a novel approach to track the petrogenesis of arc magmas using apatite trace element chemistry in volcanic formations from the Cenozoic arc of Central Chile. These rocks formed during magmatism that culminated in high Sr/Y magmas and porphyry ore deposit formation in the Miocene. We use Sr/Y, Eu/Eu* and Mg in apatite to demonstrate that apatite tracks the multi-stage differentiation of arc magmas. We apply fractional crystallization modelling to show that early crystallizing apatite inherits a high Sr/Y and Eu/Eu* melt chemistry signature that is predetermined by amphibole-dominated fractional crystallization in the lower crust. Our modelling shows that crystallisation of the in-situ host rock mineral assemblage in the shallow crust causes competition for trace elements in the melt that leads to apatite compositions

diverging from bulk magma chemistry. Understanding this decoupling behaviour is important for the use of apatite as an indicator of metallogenic fertility in arcs and for interpretation of provenance in detrital studies. We suggest our approach is widely applicable for unravelling the composite evolution of arc magmas and studying magmatic processes conducive to porphyry ore deposit formation.

References

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