

Multistage crystallisation recorded in zoned phenocrysts – an example from lamprophyres from the Central Menderes Massif, Turkey

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The petrogenesis of lamprophyres is perhaps the least well understood of any igneous rock group, mainly due to the confusion concerning their relationships with other rock types. There are many studies proposing lamprophyres to be primary melts for more common magma types like andesites or granites. Generally, lamprophyres are melanocratic hypabyssal igneous rocks with microporphyritic textures containing hydrous mafic phenocrysts. Felsic minerals are restricted to the groundmass. Calcalkaline lamprophyre sills in the Menderes massif core complex in Western Anatolia, Turkey are characterised by phenocrysts of biotite, amphibole, clinopyroxene and orthopyroxene in a groundmass dominated by feldspars. The sills also host a range of crustal xenoliths as well as significant amounts of quartz and calcium carbonate xenocrysts. The crystallisation path and evolution of a mantle derived lamprophyric magma within overthickened crust are constrained using zoned amphibole and clinopyroxene phenocrysts from a geochemically well-characterised sample set.

Amphibole phenocrysts show a clear and sharp zonation between a primitive core (Mg# 72–76, Al₂O₃ 11.9–12.8 wt%) and a wide, more evolved rim (Mg# 69–71, Al₂O₃ 10.0–10.7 wt%). Key trace element ratios vary significantly between the cores of different grains (e.g. Dy/Yb 2–5), whereas in the corresponding rims the variability is less. The rims also show a general enrichment in most trace elements. Geobarometric calculations imply that cores and rims crystallised at different pressures (6.8–7.6 kbar and 5.2–6 kbar, respectively).

At least four different groups of clinopyroxene are recognised. Group one, comprising the most primitive clinopyroxenes (Mg# 77–85, Cr₂O₃ up to 0.95 wt%), are sharply zoned and show more evolved rims (Mg# 68–74, Cr₂O₃ 0.07–0.25 wt%). Trace elements exhibit similar patterns to those of the amphiboles, with a significant spread in ratios between different cores and less variation, but overall enrichment, in the rims. Group two clinopyroxenes show a patchy zonation and a compositional range that is wider, but partially overlaps with both group one cores and rims. Group three and group four are late stage clinopyroxenes that formed around carbonate and quartz xenocrysts, respectively. These are also zoned, but generally of a more evolved composition (Mg# 58–78, Cr₂O₃ <0.15 wt%). Geobarometric calculations for the most primitive clinopyroxene cores yielded pressures of around 10 kbar.

After ascending from its mantle source, during which very primitive clinopyroxene cores crystallised, the magma was stored at a depth of around 20 km. Here, amphibole, clinopyroxene and orthopyroxene formed, recording substantial changes in magma compositions that is reflected in the spread of trace element ratios. During subsequent magma ascent to emplacement depths of around 15 km, the incorporation of xenoliths and xenocrysts along with significant enrichment in trace elements occurred, although trace element ratios were little affected. The trace element enrichment can be produced purely by fractionation of existing mineral phases. The geochemically-enriched rims of clinopyroxene and amphibole and the xenocryst reaction rims represent the final stages of crystallisation.