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A case of alkali metasomatism: olivine, orthopyroxene and spinel xenocrysts in phonolite melt

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Rejuvenation of depleted mantle by pyroxene veining is considered an important aspect of mantle metasomatism. Even stronger alkali metasomatism leading to mica-amphibole-clinopyroxene rocks is documented by xenoliths transported in kimberlites and also other alkaline volcanics and is thought to represent parts of the mantle that reacted with highly alkaline melts. The insight into the reaction mechanisms leading to such metasomatites is hampered by their fragmentary occurrence at the Earth's surface.

We turn the tables by studying frequently occurring xenocrysts of olivine, orthopyroxene and spinel in exotic phonolites that have differentiated within the upper mantle, like the Heldburg phonolite in Thuringia, Germany. Around these xenocrysts reaction rims have evolved several 10s of micrometers in width, that provide evidence of the range of mineralogical and chemical zoning between metasomatising melt and mantle minerals and that can be analysed in detail with current methods. The xenocrysts of interest occuring within the Heldburg phonolite include olivine (near Fo90), orthopyroxene (two populations, near En90 and En75), and spinel (two populations, rare hercynitic Mg-Al spinel and Mg-Al chromite), where the refractory types can be traced back to disaggregated lherzolite and harzburgite xenoliths and the others to norite xenoliths.

The most frequent type of metasomatic rims around olivine consists of mica (phlogopite-rich biotite), mostly with some clinopyroxene (diopside to Mg-rich augite) within the inner parts of the reaction zone. Reaction zones around orthopyroxene contain amphibole (richterite to magnesiokatophorite) that occurs either in amphibole-mica or less frequently amphibole-clinopyroxene double rims. Rims around the spinels are dominated by mica of various compositions. Altogether, the metasomatic micas show a conspicious range in fluorine content from 0.01 to 1.0 F p.f.u.

In cases it is possible to reconstruct the position of the original xenocryst-melt interface within the reaction rims, f. ex. by pigeonite lamellae in orthopyroxene that are preserved as Ca-rich stripes within the amphibole zone and abruptly end at the amphibole-mica boundary. From the identification of the original interface a mass balance can be derived between the mobile metasomatising agents and the solid reactants. Such modelling indicates that practically all chemical components of the mantle minerals are retained within the reaction zones and that their intake from the melt is very selective. Reaction of phonolite melt with orthopyroxene especially depletes the latter in Ti, Mn, K.

All mineral zones show chemical zoning from the interior towards the margin, f.ex. marginal enrichment in Ca and depletion in Mg in amphibole layers or marginal enrichment in Ti in mica zones. The mobility of chemical species is closely related to porosity within the metasomatite layers. On the μm-scale transitions can be demonstrated from dense to porous amphibole metasomatite rims. In general, the chemical zoning within the reaction layers indicate kinetics somewhere between the classic dissolution-reprecipitation mechanism and transport-controlled growth.