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Amphibole equilibria as monitors of P–T path and process in the exhumation of HP/UHP terranes

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Recent advances in modelling and the development of refined activity-composition relations allow the calculation of phase diagrams involving complex mineral solid solutions, such as calcic, sodic-calcic and sodic amphiboles (e.g. Diener et al., 2007, J metamorphic Geol.). Amphiboles are commonly found in eclogite facies metabasites, and formed at different metamorphic stages. Such rocks commonly show complex reaction microstructures that reveal their history. The focus in this contribution is on two distinct amphibole types: coarse, post-peak matrix amphibole, and amphibole involved in symplectitic microstructures replacing omphacite. These studies serve as a test of the current activity models and calculation approaches, but more importantly as a framework for understanding the processes and P–T path during exhumation of subducted terranes. Examples are taken from the Western Gneiss Complex of Norway and from the Kaghan Valley (Pakistan), but are more generally applicable to crustal blocks that have exhumed through the P–T 'window' in which comparable petrological features develop.

The microstructural types of interest here are: broad irregular interstitial amphibole grains, which commonly merge with a coarse spongy intergrowth of amphibole with quartz and/or albite (most likely replacing omphacite); and a fine-grained symplectite of low-Na clinopyroxene with sodic plagioclase and minor hornblende invading omphacite. Many specimens show these varieties as a sequence, inferred to reflect decreasing pressure (and ultimately, temperature). Amphibole compositions cover a wide range: the most sodic occur in large interstitial grains and fall near the junction of the winchite, barroisite and taramite fields of the IMA classification; they trend towards a pargasitic hornblende, still with significant glaucophane component; spongy amphiboles typically lie on a trend towards lower glaucophane component; symplectite amphibole is generally a common hornblende on a typical trend between actinolite and pargasite, with low glaucophane component.

Pressures and temperatures for matrix and spongy amphiboles are constrained by mapping phase compositions and proportions on P–T phase diagrams calculated for a range of water contents in bulk rock and local systems. In HP eclogites they define near-isothermal decompression trajectories from $\sim$20 to $\sim$12 kbar at $\sim$630–670°C. Matrix and spongy amphiboles from UHP eclogites lacking significant hydrous minerals require influx of external fluid in the interval 16–12 kbar. In symplectites conditions are derived from an internal equilibrium among amphibole, pyroxene and plagioclase. In a number of cases the variation along lamellae in a symplectite colony defines a P–T array covering $\sim$60°C of cooling over $\sim$3 kbar decompression down to 12–10 kbar.

In many cases amphibole development can be linked to both external and local sources of aqueous fluid. Microstructural and chemical evidence links symplectite formation to the breakdown of phengite. The near-isothermal earlier stages of P–T paths in these slices dominated by continental units suggest that exhumation did not take place in a cold subduction channel, but may reflect a post-collisional mechanism. The lower P–T slope of paths associated with later symplectite arrays may reflect the loss of buoyancy contrast as exhuming slices reach crustal levels.