Evaluating the significance of mineral parageneses in very low grade metabasites

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The metamorphic recrystallization of basaltic rocks at P-T conditions below those of the greenschist facies results in the development of many petrographic features that can be interpreted as indicative of non-equilibrium conditions. Examples include partial recrystallization of the protolith with an abundance of relict phases and new minerals of a very fine grain size which are often difficult to identify; domainal recrystallization with new minerals being found in restricted areas of recrystallization, such as an original feldspar phenocryst or groundmass areas; lack of mineral compositional homogeneity. However, recognition of mineralogical regularity in rocks of S. Island, New Zealand metamorphosed at sub-greenschist facies led Coombs (1959, 1961) to designate the zeolite facies, with the later recognition of the prehnite-pumpellyite, and pumpellyite-actinolite (Hasimoto, 1966) facies. Although, since then, petrographic and petrochemical mineralogical regularity has been increasingly recognized in metabasites, the application of modern phase equilibria approaches was not thought suitable due to the inhomogeneity of the recrystallization at this grade.

Initial attempts to analyse such rocks applying compatibility diagrams and phase equilibria modelling has provided useful constraints to aid understanding of the sub-greenschist metamorphism of these rocks. The application of the "epidote projection" to sequences from several areas demonstrated regularised mineral chemical relationships that have been interpreted as representing an approach to equlbrium, and thus the recognition of metamorphic assemblages. One example of such a feature was the regular actinolite-chlorite distribution coefficients (Act/Chl $K_D^{Mg\text{-}Fe}$) of 1.17 (1σ 0.16) for sub-greenschist metabasite samples and 1.39 (1σ 0.13) for greenschist facies from the Caledonian Welsh Basin (Bevins & Robinson, 1993). In addition, phase equilibria studies employing basic model systems such as CASH and CMASH provided useful constraints against which to interpret sub-greenschist facies metamorphism. Analysis of the NCMASH system was used by Frey et al. (1991) to define the P-T ranges of the zeolite, prehnite-actinolite, prehnite-pumpellyite, and pumpellyite-actinolite facies, but with the proviso that use of use of simple end-member phases meant that substantial overlap in P-T conditions of these designated facies would be expected in natural systems. The estimated temperature overlap between the sub-greenschist and greenschist facies was in region of 80-100°C. At the transition from the sub-greenschist to greenschist facies, Powell et al. (1993) identified in the NCMASH system an invariant point (CHEPPAQ) with the assemblage chlorite + water + epidote + prehnite + pumpellyite + actinolite + quartz, separating a higher pressure (act+pump+ep+chl+qz) from a lower pressure (pre+chl) bathozone.

In this work, the aims have been to further investigate the transition from sub-greenschist to greenschist facies metamorphism modelled with the seven-component NCFMASH system using THEROMCALC, including the effects of mineral solid solution, and establishing the extent of facies overlap. THERMOCALC analysis undertaken in NCMASH with quartz and H_2O in excess, gives five reactions radiating about an invariant point (CHEPPAQ), which is at 3.2kbar/296°C. This NCMASH point lies some 0.7kbar/10°C lower than that given by Frey et al. (1991) and Powell et al. (1993).

The CHEPPAQ invariant assemblage in NCMASH becomes univariant in NCFMASH, but occupies a very restricted P-T range of ~2.6-2.9kbar and 315-313°C. The calculated restricted P-T conditions for this assemblage are supported by its rarity in natural systems. For example in the Welsh Basin, which shows a zeolite to greenschist metamorphic transition, of some two hundred metabasite samples examined, only one (PGC21) has this assemblage. In this sample, in which the chlorite has an XMgO value of 0.5, calculated P-T conditions are 2.84kbar/315°C. The Act-Chl $KD^{Mg\text{-}Fe}$ and Pump-Chl $KD^{Mg\text{-}Fe}$ values for PGC21 are 1.56 and 0.44 respectively, compared with calculated values of 1.12 and 0.41 respectively.

In the higher pressure bathozone of Powell et al. (1993), the assemblage pump+chl+q → act+ep+H_2O is divariant in NCFMASH, and represents the transition from sub-greenschist to greenschist facies conditions (Fig. 2). The first appearance of actinolite occurs in more Mg-rich rocks at 329°C and proceeds to a more Fe-rich composition over a very narrow temperature range of ~4°C at 4 kbar (Fig. 2). This modelled transition pattern closely follows that seen in many natural systems, with the common association at sub-greenschist facies of pump+chl and act+chl (+q + ab +cz +H_2O) assemblages in more Fe- and Mg- rich whole rocks respectively. With increasing grade into the greenschist facies, the act-chl assemblage becomes ubiquitous and occupies most of the complete rock Fe/Mg range. However, the major difference in the present work with that of Frey et al. (1991) is the very narrow temperature range of facies overlap predicted here of ~4°C, compared with ~ 80°C. The Act-Chl $KD^{Mg\text{-}Fe}$ values for samples from the Welsh Basin at the sub- greenschist-facies transition have an average of 1.2, while the Pump-Chl $KD^{Mg\text{-}Fe}$ values show a broad range from 0.3-0.8. The calculated values range between 2.0-1.1, and 0.41-0.45 respectively.

The implication arising from the previous work of Frey et al. (1991) is that the broad overlap of the P-T conditions of the sub-greenschist and lowest greenschist facies should result in the mineral assemblages of these facies being widely found in low grade metabasites. Indeed the widespread recognition of such regularised assemblages coupled with consistent KD associations appeared to support such an interpretation, and could be taken as representing a good approach to equilibrium in such rocks. The present results documenting very narrow overlap of the very low grade facies, contrasts with that interpretation, suggesting that many documented overlapping assemblages are instead due to relict phases occurring metastably in association with other low grade minerals.

References

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