Calibrations of modal space for metamorphism of mafic schist

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ABSTRACT

Three independent net-transfer reactions determine compositional and modal changes for greenschist-, blueschist-, and amphibolite-facies metamorphism of mafic rocks, as different paths are followed through pressure, temperature, and $a_{H_2O}$ space. For natural terrains, only one $a_{H_2O}$-dependent reaction is chosen, whereas to interpret experimental studies, where $H_2O$ is in excess, there is an advantage to choosing two dehydration reactions. Published experimental studies on the greenschist to amphibolite transition and thermodynamic calculation in simple systems and with pseudosections, show that reactions involving Al,Mg, Si in amphibole and chlorite predominate, that FeMg exchange and Al,Mg,Si are strongly coupled, and that all reactions and, in particular, the stability of chlorite are affected by Fe$^{3+}$/Fe$^{2+}$ ratios. Modal spaces for mafic schist are constructed for different sets of independent reactions, and permit correlation of mineral mode with directions of change of pressure and temperature. These can be used to deduce field gradients in these variables in natural terrains, when only modal change data are available and when compositional and thermodynamic data are limited.

INTRODUCTION

Much effort has been devoted to deducing depth-temperature-time histories of lithospheric segments from the mineralogical record in individual samples of metamorphic and magmatic rock, and from exposed whole geologic terrains. Very useful petrological procedures have been developed to attempt the deduction of the external variables, pressure ($P$), temperature ($T$), and sometimes ($a_{H_2O}$), from the preserved compositions of coexisting minerals ($X_{\text{mineral}}$) at equilibrium. The calibration for $P$-$T$-$X$ studies derives from the increasing amount of experimental and thermodynamic data for common minerals and natural fluids, and whole-rock experiments.

Relationships between $P$-$T$-$X$ space and modal space

Most $P$-$T$-$X$ studies use mineral composition with calibrated compositional isopleths in $P$-$T$ space to deduce points on the rock’s $P$-$T$ path. $P$-$T$-$X$ studies rarely utilize the information stored in compositionally zoned minerals (but see Karabinos 1985; Okamoto and Toriumi 2001), or in changing mineral modes. A study by Carson et al. (1999, Fig 7, p. 16) calculated pseudosections for eclogite assemblages in $P$-$T$ space and presented contoured modal percentages of the minerals present in the $P$-$T$ phase fields.

Metamorphic mineral reactions produce changes in mineral mode simultaneously with changes in mineral composition. Modal information can be obtained visually and without recourse to thermodynamic information. Aspects of simultaneous changes in mineral mode and composition were considered in terms of “net-transfer reaction space” or simply: “reaction space” by Thompson (1982a, 1982b; Thompson et al. 1982). Subsequently, he preferred to use the term “modal space,” Thompson 1988, 1991, 2002). Modal space is represented as an $n$-dimensional polyhedron condensed in its complexity by separating out compositional variation into exchange reactions (which influence mineral composition but not noticeably mineral mode), and net-transfer reactions (which influence both mineral composition and mode; Thompson 1982a, 1982b; Schneiderman 1990; Poli 1991). Independent net-transfer, or continuous, reactions, are chosen as the axes of modal space (see Nicholls et al. 1991). Modal space can be calibrated either by mineral mode or mineral composition because the reaction relationships are written in terms of both additive end-member components and exchange components. Modal space can distinguish prograde from retrograde effects, and helps define the microdomains of equilibration in the prograde parts of metamorphic assemblages, not needing to account for local diffusional resetting of mineral compositional geothermobarometers. The location of individual samples in modal space can be done using either compositional or modal change. Taken together, these data can be used to decide whether rocks contain equilibrium assemblages and how samples systematically collected in terranes may be related to each other by changes in $P$, $T$, or $a_{H_2O}$.

We illustrate here some procedures and strategies using both mineral composition and mode, together with experimental calibration of whole-rock reactions, with some examples from low-, medium-, and high-pressure facies series for mafic schists (Laird 1980; Laird et al. 1993) to show how modal space provides useful complementary information to $P$-$T$-$X$ studies in deducing metamorphic histories.

REACTIONS INVOLVED IN THE GREENSCHIST, AMPHIBOLITE, BLUESCHIST TRANSITIONS IN MAFIC SCHIST

The five-mineral phase assemblage amphibole (Amp), chlorite (Chl), plagioclase (Plg), epidote (Epi), and quartz (Qtz) is common to greenschist-, amphibolite- and blueschist-facies