Instability of Al$_2$SiO$_5$ “triple-point” assemblages in muscovite+biotite+quartz-bearing metapelites, with implications

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ABSTRACT

This paper uses constraints from experiments, thermodynamic modeling, and natural mineral assemblages to argue that Al$_2$SiO$_5$ “triple-point” assemblages, in which all three Al$_2$SiO$_5$ minerals are in stable equilibrium, are not possible in common muscovite(Ms)+biotite(Bt)+quartz(Qtz)-bearing metapelitic rocks because the reactions that first introduce an Al$_2$SiO$_5$ mineral to these bulk compositions occur at higher temperature than the triple point. Less-common, highly aluminous bulk compositions may develop Al$_2$SiO$_5$ minerals at temperatures below the triple point such that stable triple-point assemblages are theoretically possible. The “invisibility” of the triple-point to common Ms+Bt+Qtz-bearing metapelites calls into question most metapelitic triple-point localities reported in the literature, and carries implications for the topology of the metapelitic petrogenetic grid, the bathozone/bathograd scheme of Carmichael (1978), and the possibility of prograde kyanite → andalusite → sillimanite sequences. Re-examination of reported triple-point localities suggests that in most if not all cases, the Al$_2$SiO$_5$ minerals grew at different times in the metamorphic history of the rock.

INTRODUCTION

The triple point involving the Al$_2$SiO$_5$ polymorphs—kyanite, andalusite, and sillimanite—is arguably the most important invariant point in metamorphic petrology. Despite some remaining debate, most agree that it is located in $P$-T space somewhere in the interval between 3.8 kbar, 500 °C (Holdaway 1971; Holdaway and Mukhopadhyay 1993) and 4.5 kbar, 550 °C (Pattison 1992; Pattison et al. 2002) (see also Kerrick 1990 and Bohlen et al. 1991). These conditions are conveniently in a part of $P$-T space traversed by many crustal metamorphic sequences, so that immediate inferences about $P$-T conditions can be made based on the occurrence of one or more of the polymorphs.

One of the most common rock types that develops Al$_2$SiO$_5$ minerals is pelite (metamorphosed mudstone, siltstone, or wacke). There has been great interest in possible metapelitic “triple-point assemblages,” those containing all three Al$_2$SiO$_5$ minerals in stable equilibrium, because they potentially represent valuable fixed $P$-T reference assemblages for calibration of thermobarometers (e.g., Hodges and Spear 1982), stable isotope fractionations, and a range of other geochemical parameters.

This paper argues that except under exceptional circumstances, such triple-point assemblages cannot represent a stable association in common metapelitic rocks. Common metapelitic rocks are defined as those containing muscovite, biotite, quartz, and water (Fig. 1). The arguments presented are purely phase-equilibrium arguments that, if correct, make moot the related debates about the “unlikelihood” of metapelites forming at exactly the conditions of the triple point, or how different nucleation and growth kinetics of the polymorphs make their simultaneous growth unlikely. Implications of the “invisibility” of the triple point to common Ms+Bt+Qtz-bearing metapelites are discussed with respect to the metapelitic petrogenetic grid, the bathozone/bathograd scheme of Carmichael (1978), and the possibility of prograde kyanite → andalusite → sillimanite sequences.

THEORETICAL CONSIDERATIONS

Whether Al$_2$SiO$_5$ triple-point assemblages are possible as a stable association in Ms+Bt+Qtz-bearing metapelites (abbreviations of Kretz 1983) boils down to a simple question: do reactions that introduce an Al$_2$SiO$_5$ mineral to these bulk compositions occur at higher or lower temperature than the triple point (Fig. 2)? In the ensuing discussion of reactions, interested readers may wish to refer to Figures 32–33 and 36–39 of Pattison and Tracy (1991).

The lowest temperature reaction that introduces coexisting Al$_2$SiO$_5$+Bt to metapelites is the model K$_2$O-FeO-MgO-Al$_2$O$_3$-SiO$_2$-H$_2$O (KFMASH) univariant reaction:

$$\text{Muscovite} + \text{Staurolite} + \text{Chlorite} + \text{Quartz} = \text{Al}_2\text{SiO}_5 + \text{Biotite} + \text{H}_2\text{O}$$

(Thompson and Norton 1968; reaction 2 of Pattison and Tracy 1991). In rocks lacking staurolite, the relevant reaction is the model KFMASH divariant reaction:

$$\text{Muscovite} + \text{Chlorite} + \text{Quartz} = \text{Al}_2\text{SiO}_5 + \text{Biotite} + \text{H}_2\text{O}$$

(Thompson and Norton 1968; reaction 9 of Pattison and Tracy 1991) whereas in rocks lacking chlorite, the relevant reaction is the model KFMASH divariant reaction: