Coexisting andalusite, kyanite, and sillimanite: Sequential formation of three Al$_2$SiO$_5$ polymorphs during progressive metamorphism near the triple point, Sivrihisar, Turkey

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ABSTRACT

Regionally metamorphosed, muscovite-bearing quartzites from Sivrihisar, Turkey, contain coexisting andalusite, kyanite, and sillimanite. Kyanite is the most abundant polymorph and defines a lineation along with prismatic sillimanite, andalusite, staurolite, and elongate quartz. Andalusite is the most Fe-rich of the polymorphs (0.9–1.6 wt% Fe$_2$O$_3$, compared with 0.6–0.9 wt% for kyanite and sillimanite), and was ductilely deformed. Staurolite has partially pseudomorphed kyanite, and occurs intergrown with sillimanite. Garnet occurs in some metaquartzites and interlayered mica schists. Mica schists lack Al$_2$SiO$_5$ polymorphs. Porphyroblasts in mica schists are chloritoid, chloritoid + staurolite ± garnet, or staurolite ± garnet with inclusions of chloritoid and staurolite.

Textural relations and relative deformation features among the three polymorphs suggest the crystallization sequence andalusite → kyanite → sillimanite, with growth of staurolite primarily in the sillimanite stability field. Results of garnet-biotite thermometry and estimates of peak $P$-$T$ conditions from petrogenetic grids are ~540–560 °C. Maximum pressure is not known, but there is no evidence for the high-pressure – low-temperature conditions that affected similar rocks to the northwest in the Sivrihisar massif. The stable coexistence of staurolite + sillimanite at peak metamorphic conditions suggests a maximum pressure of 5.5 kbar. The three polymorphs grew sequentially along a clockwise $P$-$T$ path that looped around the Al$_2$SiO$_5$ triple point during incipient subduction of a continental margin sequence (burial: andalusite → kyanite), followed by collision (heating and/or decompression: kyanite → sillimanite).

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INTRODUCTION

Metamorphosed aluminous rocks such as metapelitic schist and micaceous quartzite commonly contain Al$_2$SiO$_5$ polymorphs: andalusite, kyanite, and/or sillimanite. These phases are of great importance in metamorphic studies, as they provide information about pressure-temperature ($P$-$T$) conditions and, in rocks containing more than one polymorph, $P$-$T$ paths.

In most rocks that contain more than one polymorph, the Al$_2$SiO$_5$ phases typically represent a crystallization sequence, with incomplete reaction of the early formed polymorphs, rather than nucleation and growth at a particular pressure and temperature, such as at the triple point. Coexisting kyanite + sillimanite commonly occur in rocks that were regionally metamorphosed at moderate to high $P$-$T$ conditions and indicate heating and/or decompression from the kyanite to the sillimanite zone. Coexisting andalusite and sillimanite is indicative of low-$P$-high-$T$ metamorphism, such as occurs during progressive heating without a major pressure increase in the contact aureoles of plutons (Pattison and Tracy 1991), and, regionally, in the upper midcrust of arc terrains (Lux et al. 1986). The assemblage andalusite + kyanite is less common, but occurs in rocks metamorphosed at pressures below the Al$_2$SiO$_5$ triple point (kyanite → andalusite; Holdaway 1978) or in metamorphic terranes that experienced burial but initially were not accompanied by significant heating (andalusite → kyanite; Evans and Berti 1986).

Coexisting kyanite, sillimanite, and andalusite are more rare than two-polymorph assemblages, but have been reported in a number of localities (e.g., Hietanen 1956; Holdaway 1978; Grambling 1981; Mottana et al. 1990; Hiroi and Kobayashi 1996; García-Casco and Torres-Roldán 1996). Some of the most extensively studied sites have been shown to have complex tectono-thermal histories. At the so-called triple-point locality near Mt. Moosilauke, New Hampshire, no single rock contains all three polymorphs (Thompson and Norton 1968; Rumble 1973). In the Boehls Butte area, Idaho (Hietanen 1956), rocks containing three Al$_2$SiO$_5$ polymorphs experienced an early, relatively high-pressure event that produced kyanite + sillimanite, followed by low-pressure (contact) metamorphism that produced andalusite (Carey et al. 1992; Grover et al. 1992). Al$_2$SiO$_5$-bearing quartzites in Proterozoic terranes in New Mexico are particularly intriguing because textures and thermobarometric results suggest that the assemblage andalusite + kyanite + sillimanite equilibrated near the Al$_2$SiO$_5$ triple point (Holdaway 1978; Grambling 1981; Grambling and Williams...