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Crystallization and melt extraction of a garnet-bearing charnockite from South China: Constraints from petrography, geochemistry, mineral thermometry, and rhyolite-MELTS modeling

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Abstract

Since granitic rocks in high-grade terranes commonly undergo amphibolite-granulite facies metamorphic overprint, recovering magmatic records from the metamorphic modification remains a major challenge. Here, we report an early Paleozoic, garnet-bearing Yunlu charnockite that outcropped in the Yunkai terrane of the Cathaysia block from South China and underwent amphibole-grade metamorphic overprint in the late Devonian. Field observation, micro-texture, and mineral geochemistry combined with diffusion modeling constrain that the metamorphic overprint with an extremely short duration of ~0.2–0.5 Ma only influences a narrow rim of <100 μm for most minerals. The magmatic information can be retrieved by combining rhyolite-MELTS modeling with mineral thermobarometry using mineral core compositions to quantitatively estimate magmatic pressure, temperature, and melt H_2O contents. Rhyolite-MELTS modeling results are evaluated by comparison with experimentally determined phase relations for a peraluminous granite with ~69.83 wt% SiO_2 at a pressure of ~500 MPa. The comparison suggests that the modeling reproduces phase relationships of feldspars and quartz within 20–60 °C when the melt H_2O contents are below 7.0 wt%, but fails to account properly for all the phases when the melt H_2O contents are higher than 7.0 wt%. The modeling results using reconstructed primary magma composition of the Yunlu charnockite combined with the orthopyroxene-garnet-plagioclase-quartz thermobarometry and fluid inclusion analyses suggest that the magma was emplaced at a pressure of ~600 MPa, a temperature of >900 °C, and an initial H_2O content of ~4.0 wt% with rare CO_2 components. The orthopyroxene-garnet, biotite-garnet, and biotite-orthopyroxene thermometers yield a consistent temperature range of 770–820 ± 60 °C, which is significantly higher than the H_2O-saturated solidus temperature of ~630 °C estimated from experimental results and two-feldspar thermometry. These results indicate that the early crystallized minerals (e.g., garnet, orthopyroxene, and some euhedral biotite) of the Yunlu charnockite equilibrate at higher temperatures with crystallinities of ~30–45%, rather than the H_2O-saturated solidus conditions. We thus propose a hypothesis of melt extraction at 780–820 °C in a deep-seated, slowly cooling, partially crystalline magma reservoir. The melt extraction physically segregates the early crystallized minerals from residual interstitial melts, which inhibits element diffusion equilibration between these minerals and interstitial melts. Granite thermometry commonly yields a large range of temperature estimations, which may be related to melt extraction events. Our study shows that melt extraction recorded in granites can be identified by combining micro-texture, mineral thermometry and rhyolite-MELTS modeling, which further provides quantitative insights into the fractionation process of silicic magmas.

Keywords: Garnet-bearing charnockite, rhyolite-MELTS modeling, mineral thermometer, melt extraction, metamorphic overprint