Petrologic and geochronological constraints on the polymetamorphic evolution of the Fosdick migmatite dome, Marie Byrd Land, West Antarctica

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Summary Microstructures and monazite geochronology suggest that the peak metamorphic assemblage of sillimanite+biotite+quartz+plagioclase+ilmenite+melt±garnet±magnetite in the metasedimentary rocks from the Fosdick migmatite dome correspond to Carboniferous metamorphism. Constraints on the conditions of peak metamorphism are hindered by reequilibration of mineral compositions, but preliminary estimates based on mineral equilibria modeling suggest peak temperatures of 700-860°C and pressures of 5-10 kbar. Presence of coexisting garnet+magnetite is a function of bulk composition and constrains peak temperatures to 720-800°C using an assumed peak pressure of 8 kbar. Evidence for Cretaceous decompression includes cordierite replacing sillimanite and biotite, and cordierite rimming garnet. Estimates for Cretaceous metamorphism are P = 5.3-5.5 kbar and T = 700-740°C (Siddoway et al., 2004). Future studies will consider the effects of melting and melt loss, and localized compositional domains on the mineral equilibria, and the use of average thermobarometry and trace element thermometers.

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Introduction

The Ford Ranges of Marie Byrd Land preserve a record of the Paleozoic and Mesozoic development and subsequent fragmentation of the Pacific margin of Gondwana. Marie Byrd Land preserves evidence for subduction-related calc-alkaline magmatism in the Devonian and the Cretaceous. In western Marie Byrd Land, Cretaceous extension/transtension is recorded by mafic dike swarms (Mukasa and Dalziel, 2000; Siddoway et al., 2005), alkalic magmatism (e.g. Weaver et al., 1994), and exhumation and rapid cooling of mid-crustal rocks, including the Fosdick Mountains migmatite dome (Richard et al., 1994; Siddoway et al., 2004). The high-grade metamorphism and melting associated with dome formation coincide with regional extension across the proto-Pacific margin of Gondwana at 125-95 Ma (Richard et al., 1994; Siddoway et al., 2004, 2006; McFadden et al., 2007). Recent field work and related geochronological studies (e.g. Siddoway et al., 2004, 2006) have revealed exciting new evidence of Carboniferous metamorphism and melting suggesting that the migmatites and the granites within the Cretaceous dome are the products of a polymetamorphic evolution. We have begun a project to unravel this polymetamorphic history. Preliminary petrologic and (U-Th)-Pb monazite results are summarized here.

Geological setting

A late Neoproterozoic to Cambrian marine turbiditic sequence known as the Swanson Formation is the oldest unit exposed in the Ford Ranges (Bradshaw et al., 1983; Adams, 1986). The Swanson Formation is intruded by a number of granites, including the Devonian-Carboniferous I-type Ford Granodiorite (Weaver et al., 1991), emplaced between ca. 380-350 Ma (Adams, 1987), and the mid-Cretaceous A-type Byrd Coast Granite (Weaver et al., 1991, 1994). Minor S-type granitic magmatism occurred between ca. 340-320 Ma (Pankhurst et al., 1998). A Swanson Formation protolith for metasedimentary rocks in the Fosdick Mountains was suggested by Bradshaw et al. (1983) and Adams (1986). The plutonic rocks also occur within the dome as orthogneiss, but they are pervasively deformed and metamorphosed. SHRIMP U-Pb zircon data suggest anatexis of Ford Granodiorite constituents during Cretaceous regional heating (Siddoway et al., 2004, 2006). This model is also supported by preliminary geochemistry (Saito et al., this volume). The detailed petrologic study reported here examines mineral assemblages and microstructures from metasedimentary gneisses collected from Mt. Avers (see Fig. 1 in McFadden et al., 2007).

Migmatite petrography

The outcrops at Mt. Avers are dominated by metatexite with a vertical thickness and lateral extent exceeding 1000 m. The metatexite is characterized by the development of discrete stromatic mesosome and leucosome ranging in thickness from a few millimeters to several centimeters. Leucosome networks occupy layers concordant to metamorphic foliation, which may be folded, and occur in fold limbs, extensional shear surfaces, and interboudin partitions. Discrete melanosomes are rare to absent.

Mesosomes

Mesosomes typically contain cordierite, biotite, sillimanite, quartz, plagioclase, and rare oxides, with or without garnet. Garnet in the mesosome is not common, but where present it typically forms poikiloblasts ranging in size from 2-5 mm. Grain edges adjacent to quartz are commonly straight, whereas grain edges adjacent to cordierite are commonly embayed. Garnet may contain aligned inclusions of fibrolitic sillimanite needles and minor biotite, and rounded lobate inclusions of optically discontinuous quartz (Fig. 1a). The macroscopic foliation is defined by aligned sillimanite and 1-2 mm long brown biotite, and may wrap around garnet and quartz grains 2-4 mm across. Finer quartz and plagioclase (0.5-2 mm) occur throughout the mesosome, and biotite may also be present as randomly distributed flakes.

Cordierite commonly forms anhedral poikiloblasts 2-5 mm across containing aligned inclusions of sillimanite and biotite (Figs. 1b, d). In some samples, cordierite with abundant inclusions of sillimanite and biotite are interstitial to coarse embayed quartz grains (Fig. 1c). The interstitial cordierite is optically discontinuous and may connect with foliation-parallel poikiloblasts. Sillimanite needles in this microstructure may be up to 1 mm in length, and are coarser than the sillimanite inclusions shown in Figure 1b. Magnetite is more abundant in these assemblages and occurs with sillimanite and biotite as inclusions in cordierite (Fig. 1d). Garnet is absent from samples with magnetite inclusions in cordierite. Cordierite may also occur as anhedral to euhedral grains with or without inclusions, and as irregular rims around garnet with rounded to lobate to vermicular quartz inclusions and minor biotite (Fig. 1a). Cordierite rims around garnet may be optically continuous with cordierite poikiloblasts. Cordierite is variably pinitized. K-feldspar is rare, but may occur as a thin rim around cordierite poikiloblasts.

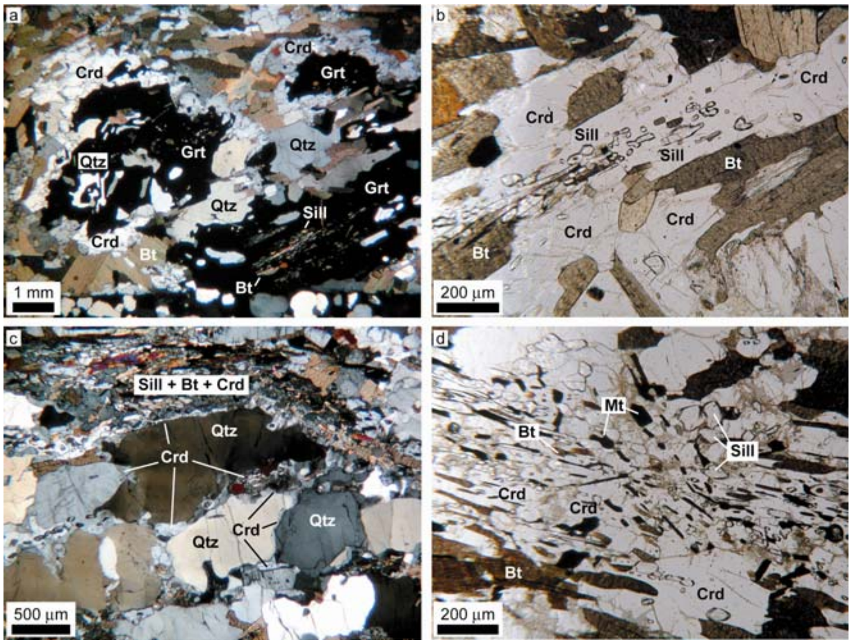

Figure 1. Photomicrographs. (a) Grt with aligned inclusions of Sill and Bt (lower right), and Crd rims around Grt (upper left). (b) Crd poikiloblasts with aligned Sill and Bt. (c) Interstitial Crd commonly connects with foliation-parallel poikiloblasts. (d) Crd poikiloblasts with Sill, Bt and Mt. Grt is absent from samples with this microstructure.

Leucosomes

Leucosomes are coarser-grained than the mesosomes and are dominated by quartz, antiperthite and rare biotite, with or without garnet. Garnet forms porphyroblasts ranging in size from 1 to 3 mm, and may contain rare rounded quartz inclusions that are commonly optically continuous. Inclusions of biotite and sillimanite in leucosome garnet are rare to absent. Garnet may be rimmed by an optically continuous and uniform network of cordierite that encloses subhedral matrix quartz grains up to 1 mm across. A thin rim of plagioclase commonly separates garnet and quartz. Garnet is rarely associated with biotite, but the replacement of adjacent garnet and biotite by plagioclase has been observed in some samples. Plagioclase in some leucosomes is partially sericitized. Muscovite is rare.

Discussion of metamorphic evolution

Peak metamorphic assemblages

In the metapelitic rocks, inferred peak metamorphic assemblages involve sillimanite, biotite, quartz and plagioclase, with or without garnet and magnetite. Common accessory phases include zircon, monazite, apatite, and sulfides. K-feldspar is rare in the peak assemblage and is more common as a retrograde phase, as is cordierite. However, bulk composition has a strong control on the distribution of minerals in many samples. Mesosomes are commonly characterized by garnet-rich and biotite + sillimanite-rich zones, suggesting a domainal bulk compositional control on the peak assemblage. Mineral compositions are typically homogeneous. Mineral equilibria modeling suggest that these compositions were reequilibrated during post-peak metamorphic events, complicating the application of conventional thermobarometry to the peak assemblage.

Preliminary results of in-situ monazite geochronology

In this study, four monazite grains were mapped for Y, Th, and U using electron probe microanalytical techniques to delineate chemical domains (Fig. 2). *In situ* (U-Th)-Pb monazite dates were then obtained with a JEOL JXA-8900 Electron Probe Microanalyzer at the University of Maryland following the protocol of Pyle et al. (2005) using a beam diameter of 5 μm. Two grains occur in cordierite poikiloblasts with abundant sillimanite and biotite inclusions, a similar microstructure as shown in Figures 1b and 1d. These grains show compositional zoning that yield Carboniferous (ca. 320-290 Ma) cores and Cretaceous (ca. 160-120 Ma) rim ages (Figs. 2a, b). A monazite inclusion in the outer rim of garnet on the margin of a 5 mm-thick leucosome has a very small (< 10 μm) high-Y core and a low-Y rim (Fig. 2c). These domains correspond to a Carboniferous core and a Cretaceous (ca. 120-110 Ma) rim. Monazite included in a cordierite + biotite reaction rim around garnet yields only Cretaceous ages (Fig. 2d). These results are consistent with Carboniferous peak metamorphism to produce sillimanite + biotite + quartz + plagioclase + ilmenite + melt ± garnet ± magnetite assemblages, and the formation of cordierite after sillimanite and biotite (Figs. 1b, d), and cordierite after garnet (Fig. 1a) during Cretaceous metamorphism. The initial growth of garnet after biotite and sillimanite (Fig. 1a) is likely Carboniferous in age, but it is currently unknown whether the Cretaceous overgrowth in the monazite inclusion in leucosome garnet represents a second generation of garnet crystallization in the presence of melt.

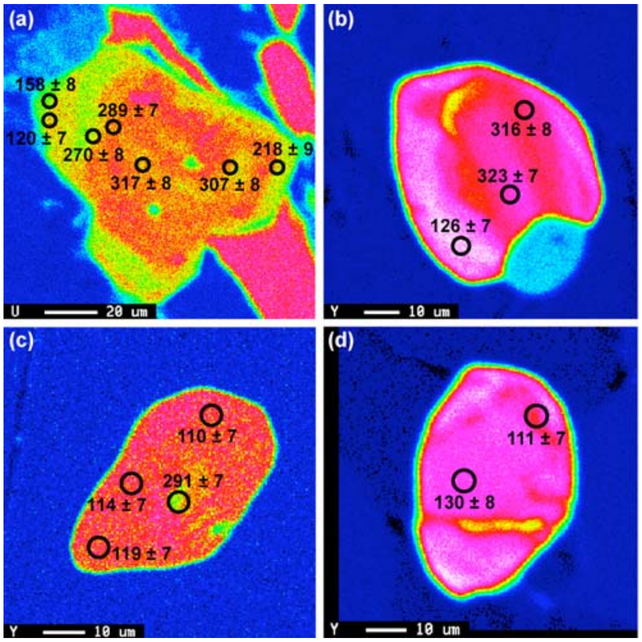

Figure 2. Monazite (Mnz) x-ray maps and dates of chemical zones. (a), (b) Mnz associated with Crd poikiloblasts with Sill and Bt inclusions. (c) Mnz included in rim of Grt. (d) Mnz associated with Crd + Bt reaction rim around Grt.

Mineral equilibria modeling

Mineral equilibria modeling was undertaken using THERMOCALC 3.26 (Powell and Holland, 1988; June 2006 upgrade) and the internally consistent dataset of Holland and Powell (1998). The calculations were done in the chemical system Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2-Fe_2O_3 (NCKFMASHTO) using the thermodynamic models and *a*–*X* relationships presented in White et al. (2007). Bulk compositions for the Swanson Formation were obtained by XRF analysis. FeO contents were analyzed by Fe^{2+} titration; Fe_2O_3 contents were calculated by difference. A *P*–*T* pseudosection calculated for a Swanson Formation composition can be used to evaluate the conditions of peak metamorphism prior to melt loss and subsequent change in bulk composition (Fig. 3a). However, the inferred peak assemblage of sillimanite + biotite + quartz + plagioclase + ilmenite + melt ± garnet ± magnetite is stable over a wide range of pressure (5-10 kbar) and temperature (700-860 °C; Fig. 3a). A *T*–*X* pseudosection calculated over a range of Swanson Formation compositions also shows this large stability field (Fig. 3b). The absence of garnet in assemblages that contain magnetite (e.g. Fig. 1d) is consistent with differences in protolith bulk composition and suggests peak temperatures of 720-800 °C using an assumed peak pressure of 8 kbar (Fig. 3b). These preliminary results demonstrate the strength of using a pseudosection approach for migmatite gneisses that have undergone polyphase metamorphism. Further modeling will investigate the effects of melting and melt loss, and localized compositional domains, such as grain boundary contacts between specific minerals, which may be more suitable for the modeling of microstructures and reaction rims than a bulk rock pseudosection.

Retrograde assemblages

The continuity (optical and textural) of cordierite rimming garnet and cordierite replacing sillimanite and biotite suggests that these microstructures may be the same generation. The growth of this cordierite is Cretaceous in age based on monazite geochronology. Cordierite replacing sillimanite and biotite (e.g. Figs. 1b, d) has been interpreted by Siddoway et al. (2004) to be evidence for Cretaceous decompression with conditions estimated to be *P* = 5.3-5.5 kbar and *T* = 700-740 °C. Future work will use appropriate pseudosections accounting for melt loss, average thermobarometry, and trace element thermometers to confirm these estimates.

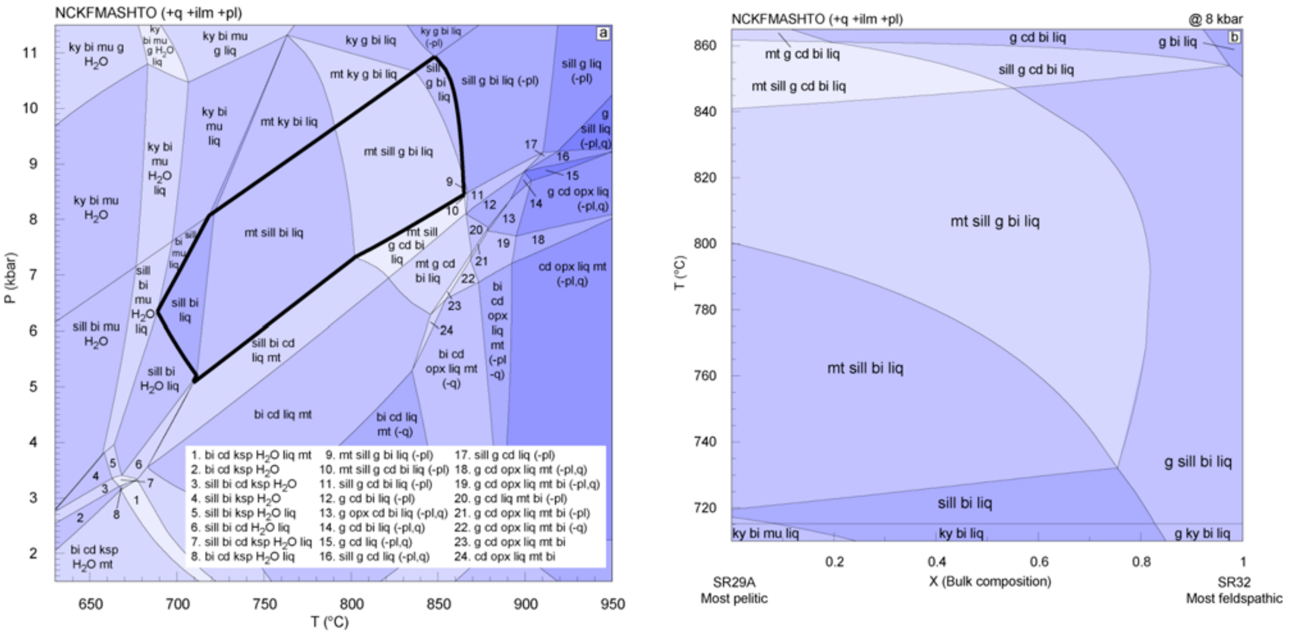

Figure 3. Mineral equilibria modeling. (a) *P-T* pseudosection for a pelitic composition (sample SR29A). (b) $T\text{-}X_{Bulk}$ pseudosection; aluminum decreases, and calcium and sodium increase from left to right.

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