METAMORPHISM OF PRECAMBRIAN ROCKS IN THE SOUTHERN HIGHLAND MOUNTAINS, SOUTHWESTERN MONTANA

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INTRODUCTION

A diverse Precambrian sequence of garnet-rich gneisses and schists with lenses of marble, quartzite, iron formation, amphibolite, orthoamphibolite, serpentinite, garnet amphibolite, and aluminous schist occurs in the thin and discontinuous X(A)g map unit (O'Neill et al., 1996) in the southern Highland Mountains of southwestern Montana. This distinctive unit is lithologically similar to sequences in the adjacent Precambrian basement of the Tobacco Root Mountains that were affected by the 1.78 Ga Big Sky orogeny described by Burger, Brady, Cheney and Harms (2004). These similarities may provide a link between these two ranges and offer insight into the extent of the Big Sky orogeny.

This project focuses on the distinctive orthoamphibolites from the X(A)g unit of the Highland Mountains; most of the data used by Cheney et al. (2004a) to construct the P-T-t path for the Tobacco Root Mountains came from orthoamphibolites in the Spuhler Peak Metamorphic Suite (SPMS) and the Indian Creek Metamorphic Suite (ICMS).

Additionally, metamorphic monazites from the Tobacco Root Mountains yield bimodal ages: 2.45Ga and 1.78 Ga, the latter being assigned to the Big Sky orogeny (Cheney et al., 2004b). ICMS rocks have both ages, whereas SPMS rocks only contain the 1.78 Ga monazite.

FIELD RELATIONSHIPS

The X(A)g map unit (O'Neill et al., 1996) of the Highland Mountains is exposed in two places: one informally called O'Neill's Gulch (ONG) and the other along Nez Perce Creek (NPC). ONG offers a spectacular, nearly continuous, across-strike outcrop of unit X(A)g. NPC, although it contains fewer outcrops, has a greater diversity of rock types. Figure 1 is a measured column of the X(A)g unit in ONG. Because of its excellent exposure, ONG offers an opportunity to compare the metasupracrustal rocks of the X(A)g unit with the metasupracrustal rocks of the SPMS and the ICMS.

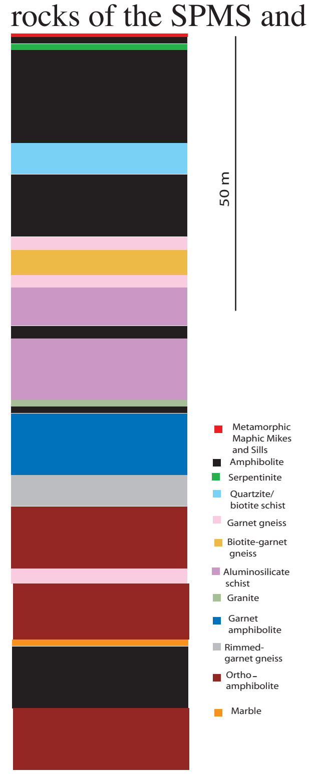

Figure 1. Measured column of the X(A)g map unit in O'Neill's Gulch, from the southern Highland Mountains, south-western Montana.

The metasedimentary rocks in the ICMS are marbles, quartzites, aluminous schists, and iron formation (Harms et al., 2004). The metasedimentary rocks in the SPMS are limited to silicious schists and quartzite; marble is notably absent (Harms et al., 2004). The metasedimentary rocks of the X(A)g unit are more similar to the ICMS: aluminous schists, marbles, quartzites, and iron formation.

PETROGRAPHY

Ninety samples were collected from NPC and ONG, 36 of which were described petrographically. Mineral compositions were determined on the SEM/EDS at Amherst College for five thin sections: two orthoamphibolites, ONG-E1 and NPC-G9; sillimanite-biotite-garnet schist, ONG-H15; fibrolite-biotite-garnet gneiss, ONG-H27; and corundum-sillimanite-phlogopite schist, XR-C1.

The orthoamphibolites from the Highland Mountains have complex textures and mineral assemblages and contain primarily gedrite, garnet, plagioclase, and quartz. In this way, they are similar to the Tobacco Root Mountain rocks. Samples ONG-E1 and NPC-G9 also contain rutile, kyanite, or partial to complete sillimanite pseudomorphs after kyanite. Cordierite is rare and occurs as rims separating aluminosilicates and gedrite (Fig. 2). NPC-G9 contains delicate sapphirine-cordierite-spinel symplectites (Fig. 3). Garnet has quartz inclusions in the core and quartz-absent rims.

DISCUSSION

Like the orthoamphibolites in the SPMS and in the ICMS (Cheney et al., 2004a), the orthoamphibolites of the X(A)g have several different reaction textures. Sample NPC-G9 contains kyanite and sillimanite pseudomorphs after kyanite, both phases are separated from gedrite by rims of cordierite. The cordierite

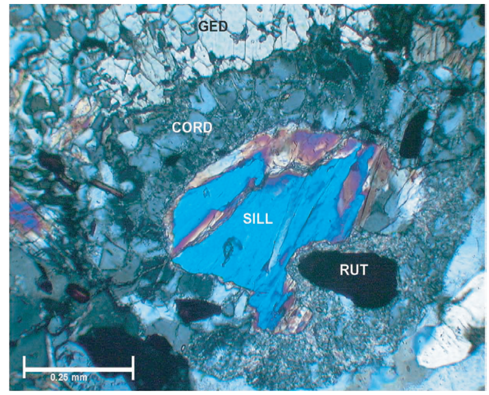

Figure 2. Cordierite growth at the expense of gedrite and sillimanite as a result of nearly isothermal decompression. Photomicrograph, crossed polars, NPC-G9.

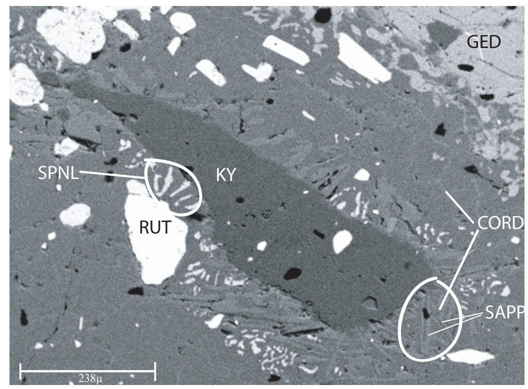

Figure 3. Sapphirine-cordierite-spinel symplectite separating kyanite and gedrite. Scanning electron microscope image, NPC-G9.

composition plots on a line between gedrite and aluminosilicate compositions on an AFM diagram. This texture occurs in orthoamphibolites in Tobacco Root Mountains, results from the reaction

gedrite + aluminosilicate ---> cordierite [1]

and is interpreted as resulting from nearly isothermal decompression (Cheney et al., 2004a). Figure 2 shows that cordierite grows directly between aluminosilicate and gedrite indicating that the reaction is localized.

Intergrowths of cordierite and orthopyroxene occur adjacent to quartz along the rims of garnet indicating the reaction garnet + quartz ---> cordierite + orthopyroxene. [2]

Similar intergrowths are reported in Tobacco Root orthoamphibolites by Cheney et al. (2004a). Cordierite requires a volume increase to grow (Spear, 1993), again consistent with decompression.

Perhaps most striking, however, are the delicate symplectite textures that occur in the aluminosilicate-bearing orthoamphibolites, shown in Figure 3. Sample NPC-G9 has cordierite-sapphirine-spinel symplectite bands that separate kyanite and gedrite. Sapphirine and spinel occur as elongate intergrowths, perpendicular to kyanite, in a cordierite matrix.

Sapphirine symplectites have been reported in many regions worldwide, but are commonly found in rocks without amphibole and that contain corundum or garnet (e.g. Harley, 1985; Kihle and Bucher-Nurminen, 1992; Harley, 1998), and typically surround sillimanite instead of kyanite. The only other known occurrence of sapphirine symplectites in the Wyoming province is in the Tobacco Root Mountains (Cheney, et al., 2004a). As in the Highland Mountains sapphirine-spinel symplectites, the Tobacco Root Mountains sapphirine-spinel symplectites occur with gedrite and surround kyanite. Cheney et al. (2004a) interpreted the sapphirine-spinel symplectite textures, (fine grain size, rimming texture, volume increase) as resulting from rapid mineral growth, consuming aluminum in locally silica under-saturated conditions.

Orthoamphibolites in the X(A)g map unit of the Highland Mountains have mineral assemblages and reaction textures that are similar to assemblages and textures described in the ICMS and SPMS in the Tobacco Root Mountains. Cheney et al. (2004a) interpreted these distinctive textures as being indicative of isothermal decompression from the kyanite stability field to the sillimanite stability field, between 700 and 800 °C.

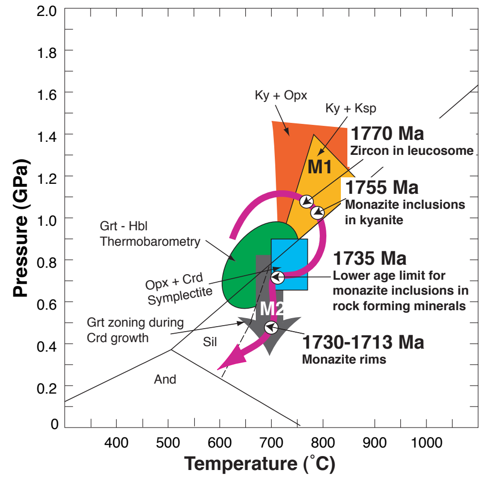

Figure 4. Clockwise P-T-t path for the Tobacco Root Mountains modified from Cheney et al. (2004a). The Highland Mountain orthoamphiboltes are consistent with this path.

GEOTHERMOMETRY

A clockwise P-T path for the Tobacco Root Mountains (Fig. 4) was described by Cheney et al. (2004a) using critical mineral assemblages and textures, as well as calculated temperatures and pressures.

Garnet-biotite temperatures of 700-800°C from two samples in the X(A)g unit, ONG-H15 and NPC-G9, were calculated with Kohn and Spear's (2006) *Program GTB: Geothermobarometry* using Ferry and Spear's (1978) calibration and Berman's (1990) garnet solution model. These temperatures are consistent with the temperatures reported for the Tobacco Root Mountains. The absence of calcic plagioclase in the Highland Mountains rocks precludes useful geobarometry.

AGES

X-ray mapping and wavelength-dispersive spectrometric analyses of monazite were performed at the Electron Microprobe/SEM Facility at the University of Massachusetts-Amherst, USA. Electron microprobe Th/Pb chemical ages of monazite were determined in

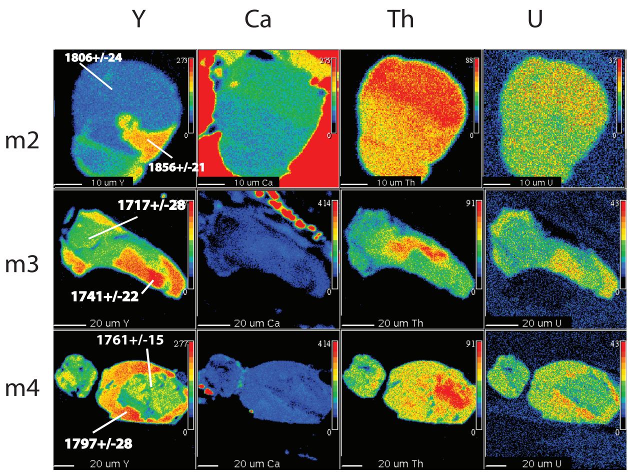

Figure 5. Y-Ca-Th-U maps of monazite grains from O'Neill's Gulch. Sample ONG-E1 (m2) and sample ONG-H27 (m3 and m4).

two ONG samples (ONG-E1 and ONG-H27).

X-ray maps (Fig. 5) show that the monazite grains from ONG are chemically zoned, and have particularly strong Y variation from core to rim. Garnet growth can be correlated with Y zoning in monazite, as garnet is one of the few silicate minerals that incorporates Y into its crystal structure as it grows; as garnet is broken down, Y is released and concentrated in monazite (Mahan et al., 2006). Garnet has been moderately to significantly resorbed in both sample ONG-E1 and sample ONG-H27. High Y monazite rims overgrow low Y monazite cores (Fig. 5). Low Y monazite cores could indicate monazite growth during initial garnet growth. High Y monazite rims could indicate younger overgrowth on monazite syn- or post- garnet resorption, possibly due to in situ reaction crystallization.

Eight to ten spots in each of two domains of differing Y concentration were dated on one monazite grain (m2, Fig 5.) from sample ONG-E1, a symplectite-bearing orthoamphibolite. The ages obtained from the low Y region of m2 were averaged and reported as 1806±24Ma; similarly, the high Y region ages of m2 were averaged and reported as 1856±21Ma. Six to nine spots in each of two domains of differing Y concentration were dated on two monazite grains (m3 and m4) from a garnet-biotite gneiss, ONG-H27, just below the X(A)g unit in ONG. Grain m3 is not concentrically zoned, but has regions of varying Y concentration. The ages obtained from the low Y region of m3 were averaged and reported as 1717±28Ma; similarly, the high Y ages from m3 were averaged and reported as 1741±22Ma. Grain m4 is concentrically zoned. The low Y core of grain M4 yielded an age of 1761±15Ma. Curiously, the high Y rim of the m4 grain was older than the core, but still within the error. The ages from monazite in the Highland Mountains are consistent with age spectrum from the Tobacco Root Mountains (Cheney et al., 2004b) and thus these Highland Mountains monazites also grew during the Big Sky orogeny.

SUMMARY

Orthoamphibolites in the X(A)g map unit of the Highland Mountains contain mineral assemblages and reaction textures that are similar to the orthoamphibolites found in the Tobacco Root Mountains, particularly the ICMS. Additionally, field relationships, consistent Th/Pb chemical ages, and corresponding geothermometry, taken altogether, suggest that the orthoamphibolites in the Highland Mountains, like those in the Tobacco Root Mountains, were affected by the Big Sky orogeny.

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