DYNAMIC HIGH-TEMPERATURE METAMORPHISM AND DEFORMATION DURING EMPLACEMENT OF THE SAN ISABEL PLUTON, WET MOUNTAINS, COLORADO

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INTRODUCTION

Distinctive within the Mesoproterozoic plutonic belt of North America, the San Isabel pluton of the southern Wet Mountains has a notably young emplacement age of 1.365 Ga and its depth of emplacement was substantially deeper than the other Mesoproterozoic plutons (Cullers et al., 1992). Thus, the gneisses hosting the pluton offer a unique and informative site to explore the "anorogenic controversy" of Mesoproterozoic magmatism (e.g., Nyman et al., 1994). A heterogeneous assemblage of felsic and mafic gneisses host the San Isabel pluton and are well exposed in the drainages of Bear Creek and Williams Creek in the southern Wet Mountains. The gneisses are known to have sustained contractional tectonism and calc-alkaline plutonism at ~1.67 Ga.

In the Southwest, structural studies of other 1.4 Ga plutons (e.g., Mt. Evans, CO, Sandia, NM, and Needle Mtns, CO) have provided evidence for regional NW-SE shortening (Nyman et al., 1994). In the northern Wet Mountains, the Mesoproterozoic West McCoy Gulch and Oak Creek plutons are associated with ductile shear zones (Siddoway et al., 2001). In contrast to these sites, the Bear Creek-Williams Creek region is unique in the mid-crustal depths of 17-23 km now exposed, based on hornblende barometry and magmatic epidote in the San Isabel pluton (Cullers et al., 1992). The goals of this project are to distinguish Paleoproterozoic and Mesoproterozoic fabrics and textures through mapping, lithologic description and relative chronology of units, and petrographic and textural analysis.

METHODS

Structural mapping of an 11 km^2 area of the Bear Creek quadrangle (USGS 1:24000) revealed five major igneous and metamorphic lithologies, distinguishable by mineral assemblages and development of dynamic fabrics. Forty-two samples, many oriented, were collected for kinematic analysis and lithologic description. Geometrical analyses of 179 mineral lineations, 332 foliation planes, and 3 fold axial surfaces were plotted on Stereonet 6.0 (Allmendinger, 2001). Twenty samples were cut for thin-section petrography, with focus on structural and metamorphic textural relationships. Petrographic analysis also addresses questions of the protoliths for the felsic and mafic gneisses.

GEOLOGICAL RELATIONSHIPS

Strongly foliated granitic gneisses and amphibolite characterize the Williams Creek and Bear Creek drainages, interfoliated at outcrop and smaller scales. Units of interlayered amphibolite and biotite-plagioclase-quartz gneiss considered to be Paleoproterozoic in age represent oceanic and arc materials (Folley and Wobus, 1997) in the accretionary belt sutured against the Wyoming Craton during convergent tectonism. Basaltic protoliths probably contained pyroxene and plagioclase in an aphanitic groundmass. Mineral assemblages in the amphibolite gneisses include hornblende, plagioclase, titanite, pyroxene, ilmenite, magnetite, and pyrite. Generally pyroxenes form relict grains appearing as granular, equant 0.1 mm inclusions within hornblende, as narrow rims surrounding opaques, and as symplectites with titanite. Plagioclase composition ranges from labradorite to oligoclase, determined by the Michel-Levy method. Amphiboles are optically aligned, within alternating amphibole-rich and plagioclase-rich bands defining the foliation at microscopic scale. Garnet is absent from amphibolite gneisses, but biotite-plagioclase-quartz gneiss sample GP-18-4 includes garnets embayed by quartz, plagioclase, and biotite. Migmatites and gneisses are widespread within the field area, marked by alternating mafic and felsic layers, with proportions of felsic and mafic bands varying between the end members of megacrystic granite to that of a biotite-plagioclase-quartz gneiss.

Three granitoid phases exist in the area. Foliated Paleoproterozoic tonalite forms concordant layers. Megacrystic granitic augen gneiss, equivalent to G2 of Siddoway et al. (2000), locally crosscuts the Paleoproterozoic units, but many contacts are parallel with foliation. This granitic augen gneiss (G2) is strongly foliated and lineated, and consists of abundant quartz, feldspars, and biotite, with accessory titanite, zircon, apatite, allanite, and sericite. Composition based on Q-A-P mineral abundances varies from granite to quartz syenite and quartz monzonite. The Granite of Williams Creek and Granite of Bear Creek are fine-grained aplitic granites, rich in quartz and microcline with lesser proportions of plagioclase and biotite, and trace muscovite, zircon, and apatite. Streaked biotite defines foliation and lineation within these units. Fabrics are poorly defined in outcrop and thin section, in biotite-poor phases of the granitoids. The crystallization age of the granite of Williams Creek is 1.486±.036 Ga (U-Pb zircon, Bickford et al., 1989).

The dominant foliation in the area is defined by compositional layering in biotite-plagioclase-quartz gneiss, aligned hornblende in amphibolite, and aligned biotite in G2 and Granite of Williams Creek. Mesoscopic, isoclinal folds and rootless small-scale folds indicate that the foliation is a second deformational layering, S_2. In granitic gneisses, dynamic textures in thin section include bent Carlsbad twins in orthoclase grains, biotite alignment, and lobate grain boundaries of quartz and feldspars. Strong north-plunging mineral lineations have an average orientation of 35, 354. S_2 strikes NE with intermediate dips to the NW. A single foliation is expressed in the younger granitoids, whereas S_2 overprints a previously existing foliation in the older units. Evidence for an earlier foliation (S_1), probably of Paleoproterozoic age, is suggested by rootless folds of leucosomes within amphibolites. Three planar zones ~300 m wide have a differing foliation (S_3) attitude, with average strikes of 011, dipping ~60W, with stronger fabric development. Lineations in these zones trend to the north and exhibit shallower plunges. Map relationships suggest the zones are high strain zones that crosscut the regional S_2 foliation in all rock types. Thus, they postdate development of the compositional layering.

Observed parallel to lineation and perpendicular to S_2 in G2 augen gneiss, asymmetric kspar porphyroclasts with tails and S-C fabrics indicate dominant top-to-the-south reverse kinematics. An additional (sinistral) strike-slip component is suggested by shallow-plunging lineations associated with the NNE-striking foliation in the 011 shear zones. Kinematic shear sense has not been determined with confidence, because conflicting indications of shear sense have been observed.

Informative mineral textural relationships suggest upper amphibolite facies conditions for metamorphism. In the amphibolites, hornblende grains exhibit 120° interfacial angles and straight grain boundaries, a granoblastic polygonal texture indicative of annealing and textural equilibrium recrystallization at high temperatures approaching the granulite facies (Yardley et al., 1990). Symplectitic intergrowth of pyroxene and titanite in sample WC-1 attest to high temperature metamorphism at the amphibolite-granulite facies transition (Spear, 1993, p. 425). In amphibolite sample GP-7-5, pyroxene grains overgrow foliation defined by aligned hornblende. Symplectitic intergrowths of opaques and pyroxenes probably developed at the same time as the titanite.

INTERPRETATIONS

Textural characteristics of the interfoliated amphibolite and quartzofeldspathic gneisses suggest dynamic metamorphism under uppermost amphibolite conditions. The following factors suggest high-temperature metamorphism at the granulite facies transition. In some samples, there is textural evidence for breakdown of hornblende to clinopyroxene with ilmenite and magnetite present, requiring temperatures of 750 ºC or higher (Spear, 1993, p. 425). Mineral assemblages of WC-1 and GP-7-5 include metamorphic clinopyroxene and titanite. Metamorphic temperatures in excess of 500 °C are required for titanite growth. Assemblages offer little control on metamorphic pressures; however, the absence of garnet in amphibolites may indicate that pressures were less than 6 kbar, or the protolith was aluminum-poor (Spear, 1993, p. 445). These values are comparable to the 5-7 kbar pressure of the San Isabel pluton at 17-23 km depths, based on the occurrence of igneous epidote and highly aluminous hornblende (Cullers et al., 1992).

Indications of dynamic conditions during Mesoproterozoic events are strong fabric development in Mesoproterozoic granitoids and growth of aligned titanite in felsic and amphibolite gneisses. The Granite of Williams Creek has a crystallization age of 1486±36 Ma (Bickford et al., 1989). Strong foliation and lineation coincide with high temperature fabrics in amphibolites and G2, suggesting that dynamic metamorphism occurred at or after ~1486 Ma. A preliminary U-Pb age on metamorphic titanite within G2 augen gneiss is ~1.364 Ga (unpublished data, Jones and Connelly, UT Austin 2002). Titanite in G2 sample GP-13-2 is aligned with foliation and exhibits lobate grain boundaries, indicating syntectonic mineral growth. Assuming that titanite growth in amphibolites and G2 augen gneisses were contemporaneous, the metamorphism is interpreted to have occurred at ~1364 Ga.

A texture in sample WC-1 is of symplectitic intergrowths of titanite and clinopyroxene, unlikely to have been preserved through an event of penetrative deformation. The texture might be an indication that elevated temperature conditions outlasted deformation.

Based on the development of discrete shear zones, strong foliation fabric, and reverse shear sense, synplutonic contraction is recorded at midcrustal depths, effectively dispelling the notion of an anorogenic setting for emplacement of the San Isabel pluton. Deformation at Bear Creek along 011 strain zones is consistent with transtension at Newlin Creek and Five Points shear zones (Siddoway et al. 2001) in the central and northern Wet Mountains.

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