Proterozoic Deformation and Metamorphism of Five Points Gulch, Colorado

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INTRODUCTION

The Proterozoic felsic and mafic gneisses and schists of Five Points Gulch have experienced polyphase dynamic metamorphism in the amphibolite facies. Consistent penetrative fabrics developed in a broad, N-S striking ductile shear zone. In the eastern half of the field area shear zone rocks consist of sillimanite±garnet gneisses. The sequence west of the shear zone is made up of quartzose to quartzofeldspathic gneisses, amphibole gneisses, and cordierite schist, interpreted to be derived from predominantly metasedimentary protoliths, with some meta-igneous layers. This project focused on 1) mapping the Proterozoic lithologies and structures of an approximately 12 km^2 area that includes Five Points Gulch, a tributary of the Arkansas River in Colorado, and 2) interpreting the deformational and metamorphic history of the area. The metamorphic events recorded in Five Points Gulch likely correspond with broader regional events at approximately 1.7 and 1.4 Ga (Bickford *et al.*, 1987).

METHODS

Six major metamorphic units and a variety of granitic intrusions were distinguished in the field area. A total of ninety-six samples, over three-quarters of which were oriented, were collected. Criteria for sampling gave priority to the presence of mineral assemblages useful for P-T estimation or protolith interpretation, fabrics or textures containing potential kinematic indicators, and to samples representative of specific units. Thirty-seven samples were cut for thin sections, which were prepared by Wagner Petrographic in Provo, UT. Petrology, microscopic metamorphic textures, and kinematic indicators were examined in thin section. A total of 486 structural orientations of foliation planes, lineations, fold axial surfaces and hinge lines, and brittle joint surfaces were measured in the field using a Brunton compass. Structural data was recorded on a map and plotted on stereonet graphs using the Stereonet computer application. Maps and figures were created using the Canvas application, and empirical data was recorded on Microsoft Excel spread sheets.

LITHIC UNITS AND PETROLOGY

The Proterozoic metamorphic gneisses and schists in the Five Points Gulch field area were separated into six major lithologic units. The sequence west of the shear zone (western units) includes: quartz gneiss association (QGA), calc-silicate gneiss, cordierite schist, interlayered felsic and mafic gneisses (IFMG), and the amphibole gneiss association (AGA). The shear zone consists predominantly of sillimanite-quartz gneisses (SQG), with interlayered bands of the AGA. In general felsic gneisses are gray to pink, very hard and fine- to medium-grained with millimeter to centimeter compositional layering. Two intrusive units also crop out along the Arkansas River Canyon; Boulder Creek Granodiorite (1.7 Ga), which does not appear in the field area, and Silver Plume Granite (1.4 Ga) (Bickford *et al. 1987).* Felsic pegmatites associated with 1.4 Ga plutonism cut the lithologic units throughout the field area.

The mineral composition of the shear zone gneisses and the western units is very similar; however, no cordierite, staurolite, or andalusite is present to the east in the shear zone sequence. Within the western sequence, garnet, cordierite, staurolite, sillimanite, biotite, amphibole, plagioclase, quartz, muscovite, potassium feldspar, and epidote predate S_2 foliation (see following section). Compositional layering and aligned biotite, muscovite, or amphibole formed the foliation. In the shear zone-associated gneisses, sillimanite, biotite, quartz, plagioclase, potassium feldspar, and garnet formed before the S_3 foliation (see below). Aligned biotite and sillimanite defines the foliation, and muscovite crosscuts the fabric in thin section.

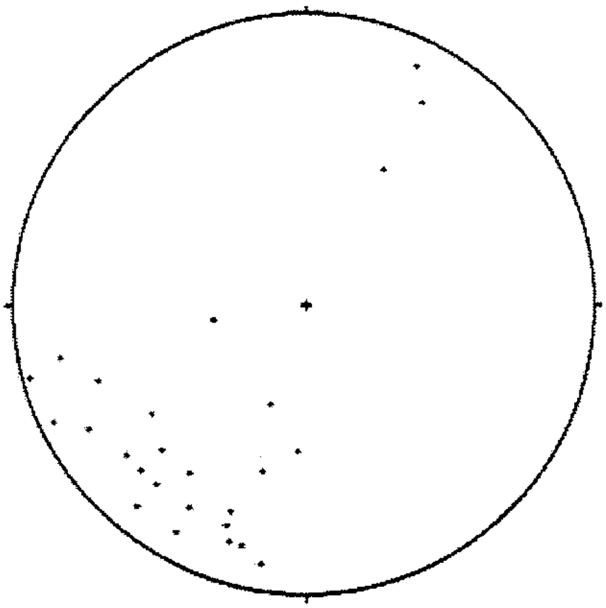

Fig.2 : Equal area projection of poles to planes of Boulder Creek foliation.

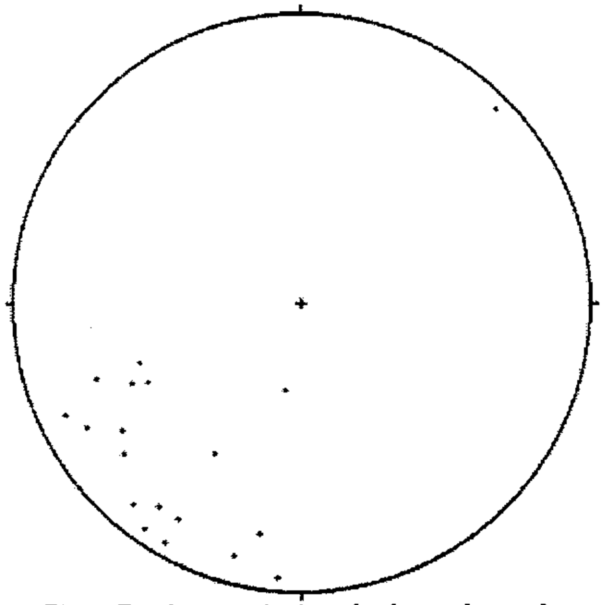

Fig. 3: Equal area projection of poles to planes of Amphibolite foliation.

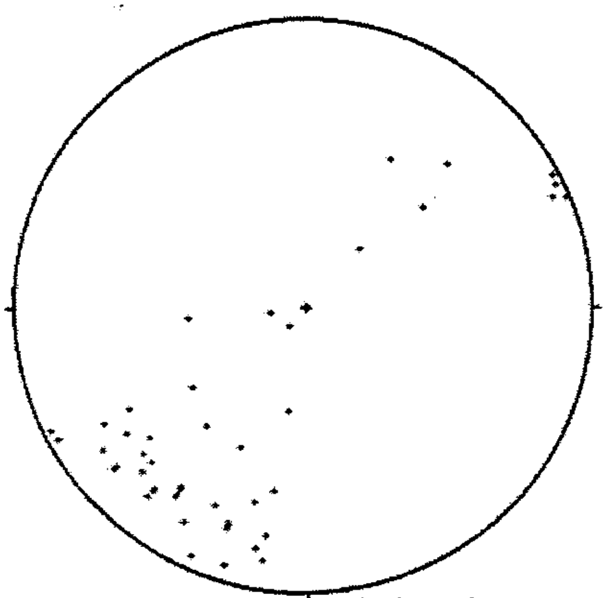

Fig. 4: Equal area projection of poles to planes of grey gneiss foliation.

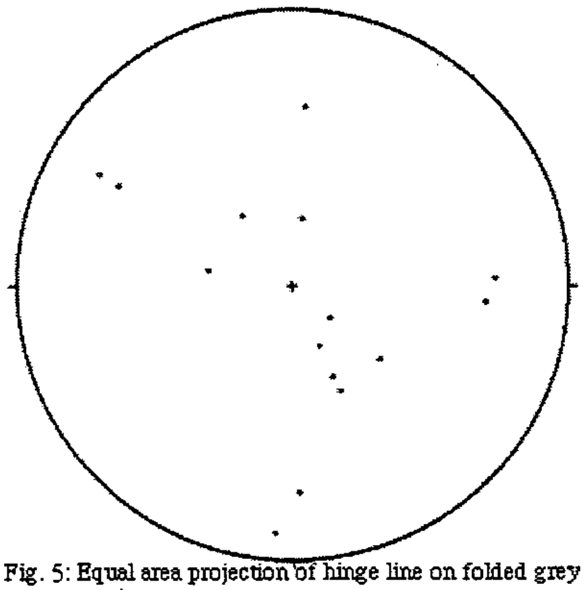

Fig. 5: Equal area projection of hinge line on folded grey gneiss.

The felsic gneisses in the western units are quartz-rich, and fine-medium grained. The QGA and IFMG are distinguished by centimeter-meter wide interlayering of amphibole gneisses and the presence of potassium feldspar in the IFMG. Pre-S_2 cordierite within QGA gneisses includes staurolite, and in other layers staurolite is in equilibrium with garnet, biotite, and amphibole. The calc-silicate gneiss records two stages of epidote; the first is included in plagioclase, and the second is in equilibrium with plagioclase and hornblende. The cordierite schist contains 5-10 cm cordierite porphyroblasts wrapped by aligned muscovite. Cordierite porphyroblasts contain inclusions of biotite, plagioclase, and aligned quartz and opaques. The cordierite is in equilibrium with garnet and muscovite (Fig. 1b). This assemblage aids in estimating P-T conditions of formation, discussed later. Augen in a felsic layer of the IFMG preserve two stages of garnet growth. The first is inclusion-rich and has an embayed texture. The second garnet growth is inclusion-free and idioblastic to hypidioblastic. It is in equilibrium with epidote and plagioclase. The mafic gneisses of the IFMG are characterized by an augen texture. Layers within the AGA contain amphibole porphyroblasts wrapped by foliation defined by a later growth of amphibole. Differing amounts of opaques, apatite, tourmaline, zircon, and sphene occur as accessory minerals in the western units.

The SQG in the shear zone contain plagioclase, potassium feldspar, quartz, biotite, sillimanite, muscovite, and garnet, with accessory apatite and zircon. The equilibrium assemblages of sillimanite, biotite and potassium feldspar, and in another location, sillimanite, biotite and garnet were identified in thin section (Fig. 1a).

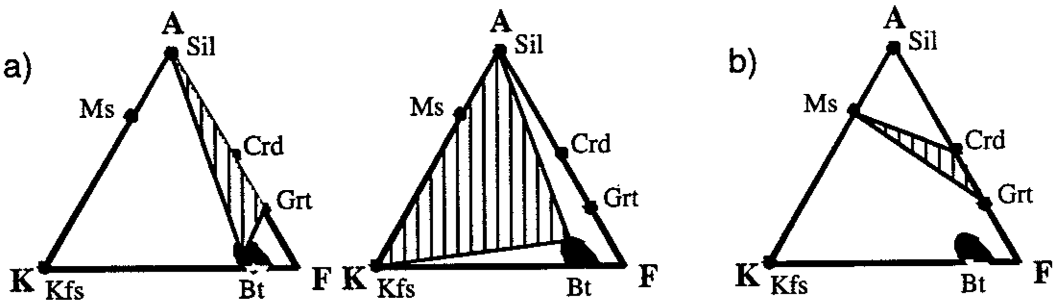

Figure 1. a) Ternary diagrams of equilibrium assemblages in two samples from the SQG. A=Al_2O_3, K=K_2O, and F=FeO for a) and b).

b) Ternary diagrams of an equilibrium assemblage in the cordierite schist.

STRUCTURAL GEOLOGY

The prominent foliation of the western sequence strikes E-W to ESE-WNW (Fig. 2a). This penetrative foliation represents a second stage deformational fabric, S_2. Evidence of earlier fabrics, S_0 and S_1, was observed in cordierite porphyroblasts wrapped by the S_2 foliation in the cordierite schist (discussed in detail by Stevens and Wilson, this volume). The S_1 foliation was isoclinally folded, and transposed by the prominent penetrative S_2 foliation in the area (Fig. 2a). Mesoscopic isoclinal folds are evident in heterogenous units such as the IFMG and in the calc-silicate gneiss. Biotite, amphibole, and sillimanite mineral lineations trend generally NE (Fig. 3a). Z-, S-, and M-parasitic folds were observed in the QGA and the cordierite schist. Fabric asymmetries wrapped by S_2 give a kinematic sense of top down to the north. However, fabric asymmetries are not widespread.

The ductile shear zone strikes roughly north-south. The presence of this deformation zone is evident by 1) the truncation of the western units, 2) a distinct and abrupt change in foliation orientation, and 3) contrasting metamorphic grades between shear zone Sil-Grt-Kfs gneisses and western units including Grt-Crd-Ms and Grt-St-Bt gneisses. Within the shear zone, penetrative foliation strikes predominantly NNW-SSE, subparallel to the shear zone boundary, and dips steeply in both directions. This foliation represents S_3 (Fig. 2b). Evidence of isoclinal folding has been obliterated in the shear zone gneisses. NNE-plunging sillimanite and biotite lineations (Fig. 3b) are strongly developed in localized high strain zones. Fabric asymmetries in the motion plane indicate motion of top down to the northeast.

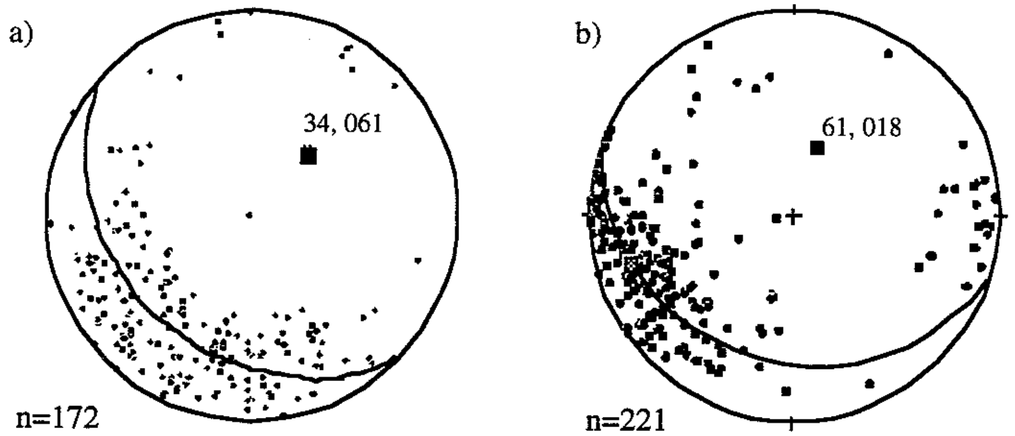

Figure 2. a) Equal area projection of poles to planes of S_2 foliation in the western units. b) Equal area projection of poles to planes of S_3 foliation in the shear zone gneisses.

The eastern boundary of the shear zone does not lie within the field area, but reconnaissance mapping suggests it could be as distant as 3 km to the east. Late syntectonic mafic dikes cut foliation in the shear zone at a low angle but contain a concordant foliation. The shear zone is cut by unfoliated pegmatites that may be of Silver Plume age (~1.4 Ga).

The S_2 foliation in the western units and the S_3 foliation in the shear zone have been folded about NE axes (Fig. 2). An axial planar crenulation fabric is locally developed. Hinge lines of open folds plunge to the northeast, sub-parallel to the mineral lineations associated with S_2 (Fig. 3).

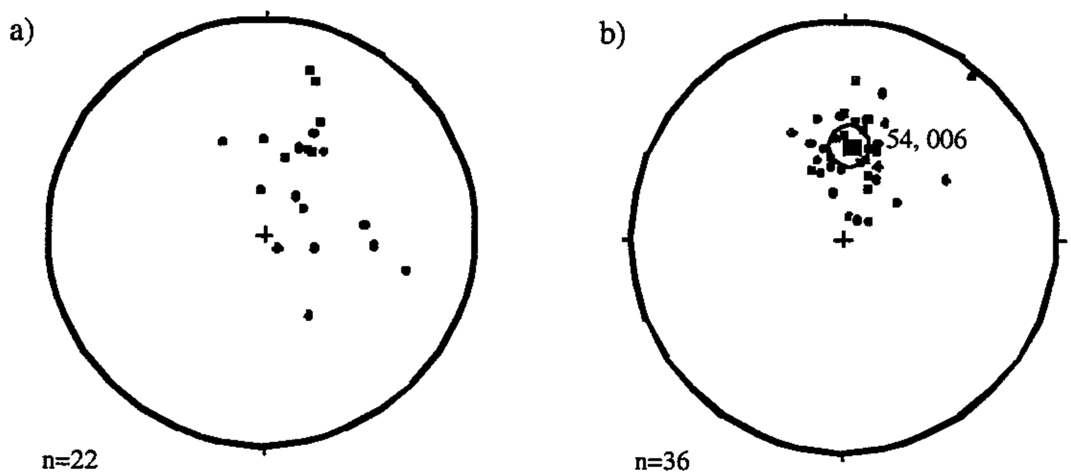

Figure 3. a) Equal area projection of mineral lineations in the western units. b) Equal area projection of mineral lineations in the shear zone gneisses.

DISCUSSION

At least three episodes of progressive dynamic metamorphism are recorded in the metamorphic sequence of the Five Points Gulch field area. Relating field observations, structural information, microscopic mineral textures, and equilibrium assemblages observed in thin section helped define metamorphic events and their relative timing. The first dynamic event involved crenulation (S_1) of primary layering in sediments and cordierite growth. A second dynamic metamorphic event caused isoclinal folding and transposition of S_1. The resulting S_2 foliation represents the prominent foliation in the region. Local development of asymmetrical augen wrapped by this foliation indicate that deformation involved a component of non-coaxial simple shear with top-to-northeast transport. The Five Points ductile shear zone truncated and transposed S_2 in a third deformational event. The shear zone may be up to 3 km in width, based on consistent N-S to NNW-SSE striking foliation, and NNE plunging sillimanite lineation in the SQG gneisses eastward for 3 km. The uniform texture, fabric, and mineral composition of the shear zone gneisses is in distinct contrast with the western units. A fourth deformational event caused open, upright folding about a NE axis and development of a macroscopic crenulation fabric throughout the entire sequence.

The presence of sillimanite, biotite, potassium feldspar, and garnet, and the absence of cordierite, staurolite, and andalusite in the shear zone gneisses reflects a much higher metamorphic grade than that of the western units. Cordierite, garnet and muscovite associated with biotite inclusions within the cordierite possibly reflect the reaction: aluminosilicate + biotite + quartz = garnet + cordierite + muscovite, and relative high temperature of metamorphic conditions, although no aluminosilicate is present in the schist. Cordierite and garnet in equilibrium restrict the pressure of formation to less than 5 kbar (Spear 1993). Studies of Proterozoic sequences in the central Wet Mountains to the south of Five Points Gulch constrained temperature and pressure of formation to 500-700° C and 2-6 kbar (McCloskey 1997) and 610-620° C and <5 kbar (Rosenweig 1997).

Garnet-biotite-staurolite is a typical assemblage of metapelites (Spear 1993). High aluminum content, revealed by the presence of cordierite, staurolite, and sillimanite, and the low percentage of potassium feldspar also suggest that the protolith for the majority of the lithologies present in Five Points Gulch are metasedimentary. The metapelites (QGA) are interfoliated with felsic and mafic meta-igneous units, represented by potassium feldspar-biotite-plagioclase-quartz gneisses and amphibole gneisses in the IFMG.

The first two episodes of deformation probably occurred within the regional metamorphic and deformational events at 1.7 Ga. Localized deformation in the shear zone may have occurred during latest stages of the 1.7 Ga deformation, but predated emplacement of the crosscutting, unfoliated 1.4 felsic intrusions. Precise timing could be determined by isotopic dating of the syntectonic amphibolite dikes that cross shear zone gneiss layers. Throughgoing shear zones of this type and timing are virtually unstudied in Colorado. Future studies should work to determine the extent and the amount of displacement on the shear zone, and to quantify the metamorphic contrast across the shear zone boundaries.

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Geochemistry and tectonic setting of Proterozoic amphibolites from the Road Gulch area near Texas Creek, Fremont County, Colorado

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INTRODUCTION

The supracrustal Early Proterozoic rocks from the Road Gulch area near Texas Creek, Fremont County, Colorado consist of interlayered amphibolite facies rocks derived from volcanic and metasedimentary protoliths. These units include amphibolites, biotite-rich gneisses, and felsic gneisses, which have all been intruded by two generations of granitic plutons. The Boulder Creek (1700 Ma) and the Silver Plume (1400 Ma) intrusive episodes are the two dominant granitic lithologies in the area along with local pegmatites. Geochemical analyses along with detailed petrographic and field relationships lead to conclusions about the Precambrian tectonics and regional terrane boundaries. This project incorporates other data sets from amphibolites sampled in three surrounding areas: Salida, the northern Wet Mountains, and the southern Front Range- researched by Shelby Boardman (1986) of Carleton College and Martha Folley (1997) of Williams College. These data sets provide useful information for evaluating the relationship of the Proterozoic rocks from Road Gulch to the 1730-1740 Ma metavolcanic terrane in Salida, 40 km to the west and how the Road Gulch area fits into the Precambrian tectonic history of terrane accretion in the region..

FIELD RELATIONSHIPS

A total of five amphibolites were studied for this project from Road Gulch and then compared to six from Salida, four from the Wet Mountains, and four from the southern Front Range (Boardman & Condie, 1986; Folley, 1997). Only samples that were most likely derived from igneous sources were examined. The amphibolites from the Road Gulch area are interfoliated with biotite-rich gneiss and occur as a part of discordant xenoliths within the granitoids. The samples are generally fine grained and moderately to well-foliated. Folley's amphibolites from the Wet Mountains were taken from concordant xenoliths or layered gneiss complexes. The southern Front Range samples, also collected by Folley, are taken from interlayered gneisses, and from concordant or discordant xenoliths within granitic bodies. In most of the areas the amphibolite units are well-foliated and fine to medium grained.

The lower grade amphibolites from the Salida and Gunnison areas directly to the west studied by Boardman (1986) display well preserved primary structures and textures, such as amygdules, and pillow and flow breccias, which are evidence of a volcanic protolith. Such primary structures were obliterated by high grade metamorphism in the northern Wet Mountains, the southern Front Range, and the Road Gulch area. Thus, major, minor, and trace element analyses are employed to compare the regional sites and to determine possible tectonic settings.

ANALYTICAL METHODS

Fourteen rocks were analyzed for major and trace elements (including Ba, Sr, Y, Sc, Zr, Be, and V) using ICP technology at the Activation Laboratories LTD in Canada. The results display two distinct host rock groups: one with silica contents near 45% or below and the other with 50-51% silica content. All the samples in the low silica group are layered biotite-rich metasediments and those in the higher group are amphibole-rich gneisses. Harker plots group the rocks inconsistently. These loose groups suggest that the oxides were relatively mobile during high grades of metamorphism in this area.

Ten of the samples from the ACT Laboratories suite were sent to Oregon State University to be tested by INAA analysis to determine the abundances of Sc, Cr, Co, Ni, Zn, Rb, Cs, Sr, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Zr, Hf, Ta, W, Hg, Th, and U. Since certain rare earth and high field strength elements are immobile during amphibolite grade metamorphism, they serve as key determinants in placing each rock or suite of rocks into a stage of magmatic evolution.