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.

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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PETROGRAPHY

The metabasalt units from Road Gulch have all been recrystallized within the amphibolite facies. Blue-green to brown hornblende (45-60%) and intermediate plagioclase (25-40%) are the dominant minerals in the unit, although biotite is found as a replacement mineral. Samples also contain minor amounts of quartz (2-10%), sphene, diopside, and opaques. The foliation appears as aligned hornblende and biotite minerals.

GEOCHEMISTRY

For general comparison and discussion the amphibolites were grouped into four basic groups: the southern Front Range, the northern Wet Mountains, Salida, and Road Gulch (Figure 1). Determination of protoliths was made by using a discriminant formula developed by Shaw and Kudo (1965). The samples were grouped by the logarithmic function that uses 8 trace elements (in ppm):

$$\mathbf{X}_1 = -2.69 \log Cr - 3.18 \log V - 1.25 \log Ni + 10.57 \log Co + 7.73 \log Sc + 7.54 \log Sr - 1.95 \log Ba - 1.99 \log Zr - 19.58$$

All of the Road Gulch units produce positive values, which fall outside the margin of error, discriminating them as ortho-amphibolites. The samples tested by Folley (1997) also produce values indicative of igneous parent materials.

The discrimination of origins was further defined by the total alkalis versus silica diagram (Le Bas et al., 1986) as shown in figure 1. Five amphibolites from Road Gulch plot between 46-50% and all of the mafic samples compared plot between 46% and 52%. The Road Gulch samples plot between the more alkali rich Wet Mountain samples and the southern Front Range units. Boardman and Condie's (1986) samples plot in the middle of the basalt field and one borders on the basaltic andesite field. The distinct basaltic character of the three bimodal successions is evident in this plot. This study compares the rocks of known tholeiitic basalt origins to those samples also known to have basaltic to basaltic andesite origins.

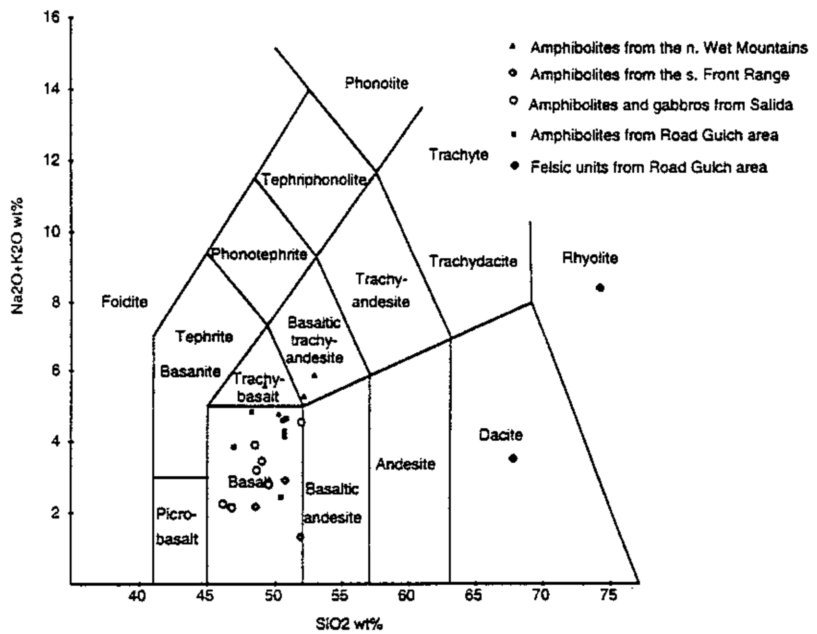

Fig. 1. Total alkali versus silica plot showing the distribution of amphibolites from the four compared areas. After Le Bas et al. (1986). Road Gulch data are previously unreported.

MORB-normalized diagrams from Pearce (1983) show the distrbution of trace elements in amphibolites from the four designated areas. Amphibolites from each area display a distinct enrichment of large ion lithophiles (LILs) and a general flattening trend in the high field strength and rare earth elements. The relative abundances of each area can be seen in figure 2a) which compares the averages from each location. The enrichment in Th and Ba are indicative, but not diagnostic, of basalts that have experienced crustal contamination.

Chondrite-normalized spider diagrams (Fig. 2b) illustrate that the northern Wet Mountains are more enriched in light rare earth elements. These units produce a negative slope following the trend of the Road Gulch and Salida amphibolites. The positive slope from La to Nd displayed by the southern Front Range units suggests that this terrane could be derived from a different parent material (Folley, 1997). Plotting the samples in the TiO_2*MnO*P_2O_5 discriminant diagram (Fig. 3) yields consistent results: all of the units fall within the volcanic island arc fields, plotting mainly as island arc calc-alkaline basalts and island arc tholeiites (Mullen, 1983: Folley, 1997).

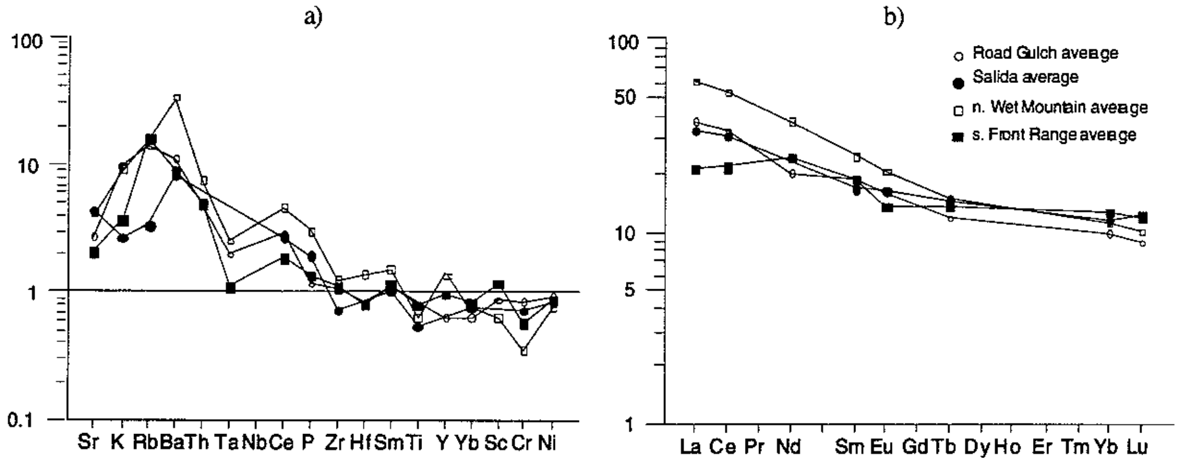

Fig.2. a) MORB-normalized trace element average distributions for amphibolites from Road Gulch (n=5), Salida (n=6). the northern Wet Mountains (n=4), and the southern Front Range (n=4). Normalizing values taken from Pearce (1983). b) Chondrite-normalized average trace element distributions.

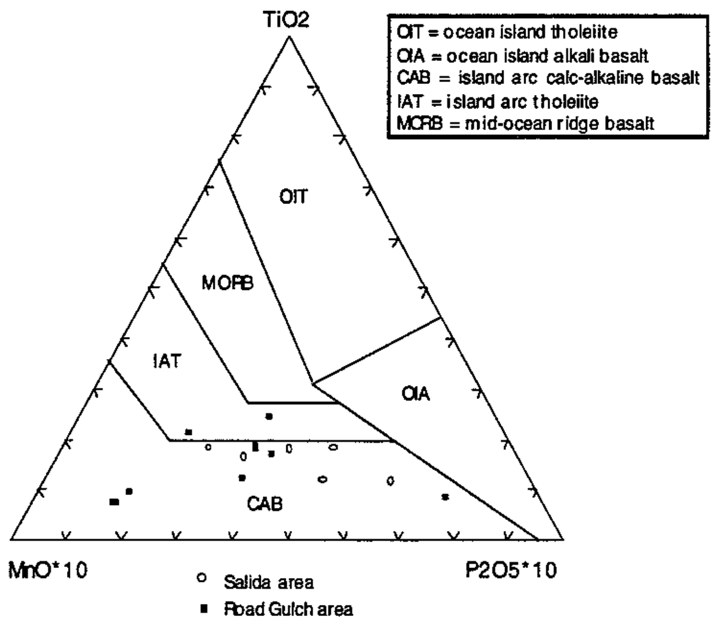

Fig. 3. TiO2*MnO*P2O5 diagram after Mullen (1983).showing the distribution of amphibolites from Road Gulch and Salida. Data taken from Boardman & Condie (1986) for Salida.

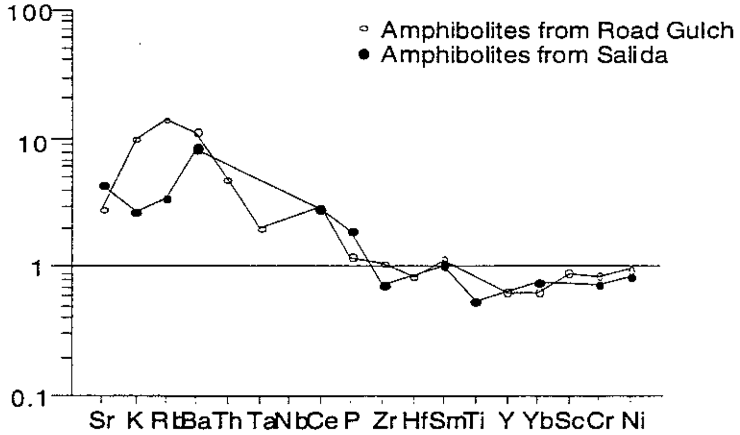

Fig. 4. N-MORB-normalized trace element distribution average diagram for amphibolites from the Salida (n=6) and Road Gulch areas (n=5) . Normalizing values from Pearce (1983).

CONCLUSIONS

Geochemical analyses and trace element discrimination diagrams indicate that the amphibolites sampled from Road Gulch are all derived from volcanic arc basalts. The units in the Road Gulch area are tholeiitic basalts and dacites to rhyolites; they exhibit distinctly similar chemical signatures to the rocks found in the Salida-Gunnison area (see fig. 4), and are relatively similar to the northern Wet Mountain samples, located to the west and southeast respectively. The rock units from Road Gulch appear to originate from a immature island arc system. This setting is the same as those determined for the suites found in Salida-Gunnison (Boardman & Condie, 1986) and in the northern Wet Mountains (Folley, 1997). The southern Front Range units display less distinct crustal contamination patterns, as illustrated by the flattened trend from Ta to Y, indicating that this suite may have originated from a different and less evolved arc system.

Condie (1986) has worked to further characterize the extent of terrane boundaries by geochemical analysis throughout the Southwest and central Colorado. He stated that the lateral extent of the Salida-Gunnison 1730-1740 Ma terrane remains in question pending the completion of further research. This project suggests, given the clear geochemical similarities, that the boundary could extend eastward to the Road Gulch-Texas Creek area.

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Structural analysis and metamorphic history of a cordierite schist unit, Fremont County, south-central Colorado

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INTRODUCTION

The Colorado province has been interpreted to consist of a series of magmatic arcs which were accreted to the Archean Wyoming craton during the Early Proterozoic Eon. A 300m thick unit of cordierite schist constitutes part of the belt of high-grade metamorphic rocks, in the Wet Mountains along the Arkansas River. Rock units neighboring the schist include impure quartzite, amphibolite and gneiss. A large granite body and numerous pegmatites intruded the schist and neighboring metamorphic rocks in the study area. We chose to analyze a section of the schist unit which extends from Five Points Gulch to U. S. Highway 50, 2.8 miles east of Texas Creek, Fremont County, Colorado.

This particular unit was selected for study because the unusually large cordierite porphyroblasts preserve an internal fabric distinct from the regional foliation in the surrounding rocks. Cordierite $[(Mg, Fe)_2A_{14}Si_5O_{18}]$ is a bluish-gray colored mineral which commonly occurs in regionally metamorphosed argillaceous rocks. It develops under a wide range of temperature and moderate to low pressure conditions. Inclusions, which potentially represent recrystallized material from the original sediment, are common in cordierite. Thus cordierite crystals can protect and preserve the mineral fabrics present at the time of their growth (Deer et al., 1992). The internal fabrics studied in the Five Points Gulch locality have not previously been researched. However, in 1956 the unit was described in some detail by R. B. Travis, who interpreted the cordierite crystals to have formed by contact metamorphism of quartz-mica schist . We are proposing a different interpretation regarding the conditions of cordierite growth.

The purpose of our study was to analyze both the fabric within the cordierite porphyroblasts and the surrounding schistosity. By noticing the structural relationships between minerals we have attempted to construct a metamorphic history for the cordierite schist unit. We paid particular attention to the fabric within individual cordierite porphyroblasts in order to determine whether the fabric represents S_0, original bedding, or S_1, an early foliation.

RESEARCH METHODS

We spent two weeks in the field mapping the cordierite schist unit from outcrops along Highway 50 in the northwest to the outcrop located in Five Points Gulch to the southeast. A topographic map was used to record external foliations measured throughout the unit. Three outcrops were studied in detail to measure the layered fabric visible within the individual cordierite crystals, and a few samples of cordierite porphyroblasts were taken.

The following week was spent in the laboratory looking at thin sections previously prepared by Christine Siddoway. Mineral textural relationships of cordierite porphyroblasts as well as minerals in the surrounding schist were studied to determine the metamorphic history of the rock unit. Specifically, we interpreted a sequence for crystallization of the minerals and development of the layering fabrics. In addition, stereonet plots were made, for graphic analysis of internal fabrics measured within the cordierite crystals, and of the external foliation in the surrounding schist.

OBSERVATIONS

Cordierite porphyroblasts within the unit of schist are 3-11 cm in length. The foliation of the schist is defined by the alignment of white micas and deformed quartz; the schistosity wraps around the cordierite. There is a prominent internal fabric visible within the cordierite porphyroblasts. In general, a single cordierite porphyroblast contains a fabric with a single orientation. However, a few porphyroblasts preserve an internal fabric which is folded. In the three outcrops studied in detail it is apparent that internal fabrics are cut by external schistosity. The orientations of fabrics present within the cordierite are extremely variable, and do not coincide in orientation with foliation in the surrounding schist. The stereoplot of fabrics measured inside the cordierite porphyroblasts compared