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

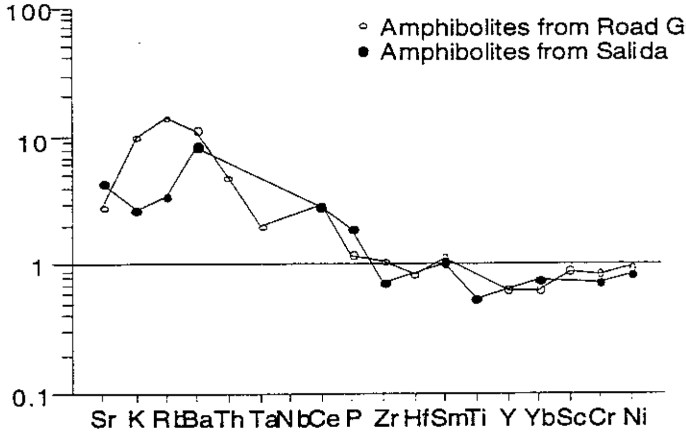

Fig. 4. N-MORB-normalized trace element distribution average diagram for amphibolites from the Salida (n=6) and Road Gulch areas (n=5) . Normalizing values from Pearce (1983).

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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to the external schistosity illustrates this observation (Figure 1). The average orientation of the external schistosity in cordierite schist is N80W, 65NE. Paralleling this orientation of the schistosity are quartzose layers less than 1m thick within the cordierite schist unit. This is an indication that original compositional layering is parallel to the foliation which later developed in the schist.

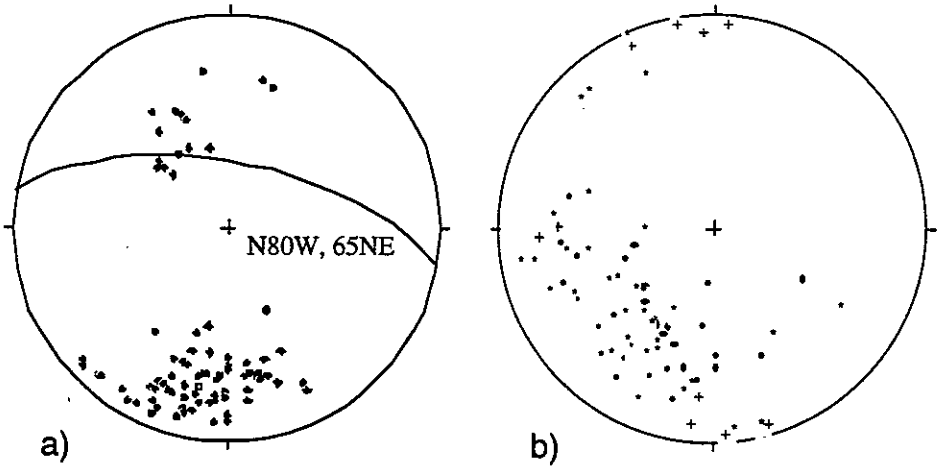

Figure 1 -- a) Equal area stereonet of poles to foliation (•) in cordierite schist; n=83. Average foliation plane is N80W, 65NE. b) Equal area stereonet of poles to foliation planes measured inside the cordierite porphyroblasts. Internal layering consists of alternating bands of opaques and quartz-feldspar minerals. Outcrop 3 measurements have been rotated into alignment with the average regional foliation. Symbols: + outcrop 1 (n=27); * outcrop 2 (n=11); • outcrop 3 (n=36).

In thin section, the relationships between minerals is apparent, and help to clarify observations made in the field. Observing the cordierite crystals in thin section reveals that there are in fact two fabrics present. The first is a microscopic layering of quartz, feldspar and opaque minerals. The second internal fabric is a crenulation cleavage that lies at an angle to the external schistosity. Both internal fabrics can be seen in Figure 2, a photomicrograph of the internal portion of a cordierite crystal.

The minerals sillimanite and biotite are also present in the schist, showing no preferred orientation. Sillimanite is found as overgrowths on the cordierite along grain boundaries and fractures in crystals. Biotite crystals overgrew the foliation in both the schist and the cordierite porphyroblasts. In addition, there are a few small garnets present in the schist and viridine (Mn-andalusite) exists within a quartzose qneiss layer bordering the schist.

INTERPRETATIONS

The microscopic layering of quartz-feldspar and opaque minerals preserved within the cordierite porphyroblasts strongly resembles primary sedimentary layering (S_0, Figure 2). Such fine-scale bedding indicates the protolith was a clay-rich sedimentary rock which originated in a low energy environment. The thin quartzose layers in the schist were probably interbeds of sand rich material. Deposition may have occurred within a volcanosedimentary rock association between 1780-1717 Ma, most likely in a marginal basin on a complex dynamic margin (Bickford et al., 1989).

The original sediment then underwent lithification and small scale folding as a result of burial followed by deformational strain. This created the crenulation fabric (S_1) visible inside the cordierite porphyroblasts, which is the first noticeable product of metamorphism. The presence of magnesium, iron and aluminum components in the shale bed as well as changing temperature and pressure conditions promoted the growth of cordierite. The cordierite crystals overgrew the crenulated layering during this early stage of metamorphism, allowing the preservation of two fabrics, S_0 and S_1, within the cordierite porphyroblasts.

Figure 2 -- Fine-scale alternation of opaque minerals and quartz-feldspar bands, preserved within an individual cordierite porphyroblast. The separation of "heavy" minerals, and variability of the thickness and spacing of layers, strongly indicate that primary sedimentary layering, S_0, is preserved within the cordierite. Crenulation cleavage defines S_1, an early deformational fabric.

Dynamic metamorphism occurred at or after 1.67 Ga. by correlation with deformed intrusive bodies of that age (Boulder Creek granodiorite). This period of deformation saw development of the schistose fabric surrounding the rigid porphyroblasts. The cordierite porphyroblasts were rotated during this time and some were stretched and elongated so that the crenulation fabric is not recognizable in hand sample. The difference in orientation between the layering preserved in the cordierite porphyroblasts and the surrounding schistosity reflects this event.

Biotite and sillimanite in the cordierite schist unit have no preferred orientation indicating growth during a stage of relatively high temperate and static conditions. Mn-Fe-andalusite in a nearby quartz-gneiss layer is in a similar textural setting (Goodge and Siddoway, 1997). This growth is very likely a result of regional heating or regional contact metamorphism at 1.4 Ga. related to Silver Plume magmatism (Bickford et al., 1989). Figure 3 is a pressure-temperature diagram showing a possible heating trend and the probable conditions of sillimanite and biotite growth. The increase in temperature caused the prograde reaction of cordierite and muscovite to sillimanite and biotite.

CONCLUSIONS

From observations made in the field and from thin sections, we interpreted a series of events for the cordierite schist unit. Clay rich sediments, recorded in the fine-scale layering seen in thin section, were deposited in a low energy environment. A likely tectonic setting was a marginal basin on a complex dynamic margin as the sediments were deposited within a volcanosedimentary rock association between 1780-1715 Ma (Bickford et al. 1989). Lithification of the sediment then occurred, followed by crenulation noticed in thin section (Figure 2). The cordierite porphyroblasts overgrew this fabric during an early stage of metamorphism, preserving the fabric inside them. A new foliation developed in the surrounding rock turning it from shale to schist. This dynamic metamorphism occurred at or after 1.67 Ga. by correlation with deformed intrusive bodies of that age ("Boulder Creek" granodiorite). There is also evidence that the cordierite porphyroblasts were rotated during this event as some preferred orientation was seen in the field. During a regional heating event due to Silver Plume intrusions at 1.4 Ga. (Bickford et al., 1989), sillimanite and biotite grew at the expense of cordierite and muscovite. These minerals show no preferred orientation and cut foliation, in contrast to cordierite which is wrapped by foliation. Thus, sillimanite and biotite are more likely to have grown under the sort of static, "contact metamorphic" conditions envisioned in earlier interpretations of the cordierite growth (Travis, 1956).

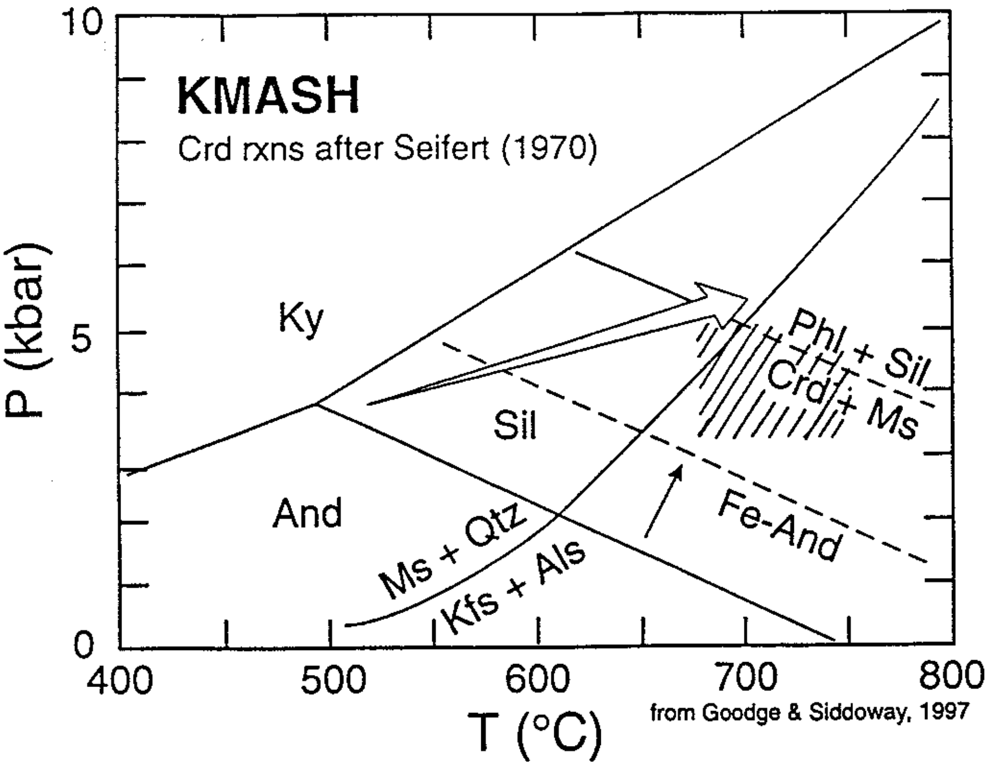

Figure 3 -- Pressure-temperature diagram for conditions of sillimanite (Sil) and biotite (Phl-phlogopite) growth (cross-hatched area in diagram) at the expense of cordierite (Crd). Sillimanite and biotite, as well as Mn-Fe andalusite (Fe-And) in adjacent cordierite-free rocks, show no preferred orientation and are interpreted to have grown during a static heating event related to emplacement of plutons at 1.4 Ga. The arrow indicates the interpreted heating trajectory for the region. Other mineral abbreviations as follows: Als - aluminosilicate, Kfs - Kfeldspar, Ky - kyanite, Ms - muscovite, Qtz - Quartz.

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Petrology and geochemistry of the Proterozoic rocks from the Howard and Jack Hall Quadrangles, Fremont County, Colorado: implications for tectonic setting

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INTRODUCTION:

The main goal of this study is to determine the early Proterozoic tectonic setting of the rocks in the Howard-Jack Hall region, and place that setting into the context of the crustal evolution of the southwestern United States. Field relationships, petrographic examination, and geochemical analysis will be used to compare the rocks from the Howard-Jack Hall region to the Wet Mountains (Folley, 1997) and the Salida area (Boardman, 1986; Boardman and Condie, 1986).

Geologic Setting:

The Proterozoic rocks that are the focus of this study are located north of the Arkansas River in the Howard and Jack Hall 7 1/2 minute quadrangles. They are truncated on the west by the Pleasant Valley fault, intruded by the 1.65 Ga Garell Peak batholith to the east and bounded to the north and south by Tertiary volcanics (Scott *et al.*, 1978). These rocks consist of felsic volcaniclastics, mafic igneous dikes and sills, and siliceous sedimentary rocks. The area underwent metamorphism up to amphibolite grade, which produced a weak foliation parallel to inferred primary layering.

LITHOLOGIC DESCRIPTIONS:

There are three main rock types in the field area, including amphibolite, quartz-mica schist, and volcaniclastic. There are also minor outcrops of felsic intrusions and pelitic schist.

Amphibolite

The main mafic unit found in the Howard-Jack Hall region is a hornblende-plagioclase amphibolite, which crops out as randomly oriented dikes. At one location, one dike intrudes and crosscuts another dike. The younger dike has a fine grained margin along the contact with the older dike, indicating that it cooled against the older dike. At other locations, the amphibolites crosscut the foliation, which is hypothesized to be parallel to bedding. The crosscutting relations of the outcrops to other rock lithologies also leads to the conclusion that the amphibolites started out as shallow dikes and/or sills. The field relations of the outcrops to other lithologies also support the hypothesis that the amphibolites began as shallow dikes or sills and were subsequently metamorphosed. The mineralogy is also now a metamorphic not igneous mineralogy.

The dominant minerals in the amphibolite are hornblende, plagioclase and biotite, with minor sphene and apatite. In thin section, many samples show a diabasic texture with recrystallized tabular plagioclase and possible conversion of pryoxene to hornblende. The plagioclase has been partially altered to sericite. The diabasic texture and large crystal size (4 to 10 mm) is consistent with a shallow gabbro intrusion that has been metamorphosed, although metamorphism has not completely destroyed the original igneous texture.

Quartz-mica schists (Sedimentary origin)

Quartz-mica schists crop out over a large percentage of the area. These schists generally contain greater than 75% quartz. They also contain biotite and muscovite with minor chlorite, garnet and anthophyllite. The biotite typically occurs in semi-round clusters, which are anywhere from 1-15 cm long. Biotite is altered to chlorite in many samples. The high (>75%) quartz and mica content indicates a probable sedimentary protolith for the quartz-mica schists.

The quartz-mica schist grades into metamorphosed felsic volcanic rocks. As it does so the biotite clusters become more abundant and contain other minerals, such as garnet. In some cases, white reaction rims have formed around the clusters. The clusters could form in either quartz-mica schists or felsic volcanics. In a quartz-mica schist, they could form from concentrations of clay in the sedimentary protolith. However, sedimentary clasts or concentrations of detrital material in a volcaniclastic rock could also produce the clusters in the felsic volcanic rocks. These ambiguous lithologies are classified as felsics, although they could be volcanic in origin.