Structural and geochemical analysis of Proterozoic metamorphic rocks near Texas Creek, Colorado

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INTRODUCTION

All of the rocks in the study area are Proterozoic with the exception of younger intrusions and Tertiary-Quaternary alluvium. The area consists of a bimodal sequence with other rock units interlayered. These rocks are intruded by several different types of younger dikes, including pegmatitic, granitic, and mafic dikes that crosscut foliation. Most of the rocks have undergone amphibolite grade metamorphism, which is defined by the appearance of foliations and small and large scale folding within the rock units. Structural and geochemical analysis of these rocks will provide data for understanding the deformation that occurred in the area.

PETROGRAPHY

The analysis of 30 thin sections was conducted to determine the mineralogy of the rocks collected in the field. Identification of minerals along with microstructures and textures were noted. The major rock units found in the study area include amphibolite, felsic gneiss, and biotite gneiss and will be described below. The bimodal sequence is composed of the biotite gneiss and felsic gneiss. The other rock units that were distinguished in the field and through thin section analysis include Boulder Creek granodiorite, cordierite schist, quartzite, podrock, sillimanite schist, and epidosite.

Amphibolites in the study area have a unit thickness that varies from meters to tens of meters, are usually bounded by felsic gneiss or biotite gneiss, and occasionally are found in other units as large xenoliths. Rocks of the amphibolite units contain 25-50% xenoblastic to hypidioblastic amphibole (cummingtonite), 25-30% xenoblastic quartz, and varying amounts of plagioclase, microcline, chlorite, biotite, muscovite, epidote, sphene, zircon, hematite, and opaques. They are usually fine to medium grained, foliated rocks containing larger phenocrysts with inclusions, and some poikiloblastic minerals.

Felsic gneiss units vary from meters to hundreds of meters, are usually bounded by biotite gneiss or amphibolite and occasionally have amphibolite xenoliths. Felsic gneiss are fine to medium grained foliated rocks containing 15-40% xenoblastic to hypidioblastic microcline and/or plagioclase, 20-40% xenoblastic quartz, 15-20% hypidioblastic biotite, and varying amounts of muscovite, sphene, chlorite, epidote, garnet, zircon, hematite, apatite, and opaques.

Biotite gneiss units vary from meters to hundreds of meters and are usually bounded by felsic gneiss or amphibolite. These fine to medium grained rocks contain 20-40% hypidioblastic biotite, 15-25% xenoblastic to hypidioblastic microcline and/or plagioclase, 40% xenoblastic quartz, and varying amounts of muscovite, hematite, garnet, apatite, and zircon.

STRUCTURE

Structural measurements of foliations, lineations, and folds were taken. Field criteria and stereographic analysis of structures indicate that two generations of folding can be distinguished from the data.

First Generation Structures

The oldest structures in the study area are tight to isoclinal F_1 folds and are associated with S_1 layering, and a possible S_0 layering. S_1 is defined by the axial planar alignment of biotite and quartz. S_0 is defined as primary sedimentary or igneous layering. Thin section analysis has shown there is little or no preserved S_0 layering present in the rocks of the study area. The F_1 folds produced the prominent foliation and lineations associated with the rocks in the study area.

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Second Generation Structures

F_2 folds are the next of the folding events. The F_2 folds are generally larger than the F_1 folds. The amplitudes and wavelengths of these folds are meters to tens of meters. These folds consist of open to tight folds in which the axial planar surface of the S_1 was folded. This event resulted in the folding of F_1-generation foliations and lineations. The new layering is therefore referred to as S_2. The appearance of 'S' and 'Z'-shaped folds are common in some outcrops of F_2 folds. 'M'-shaped folds were never found in the study area. The 'S' and 'Z'-shaped folds formed on the fold limbs by interlayer shear (e.g. a 'flexural-slip' fold model). Crenulation folds of S_1 are common, and form in the hinges of folds to compensate for the shortening that occurred during the deformational event.

Structural Analysis of Ductile Structures

From the field and lab data collected, it appears that the rocks in the study area have experienced superposed folding, resulting in folding of early-formed foliations and lineations. Stereonet plots (Figure 1) show the axial surfaces of F_1 folds and folded S_1 layering to share the same great circle and fold axis. Therefore, the area has been folded at least twice. The poles to the planes of the foliations of the four major rock units, show that the fold axis (F_2) is plunging NE. The axial surface and fold limbs also show the same F_2 fold axis plunging NE.

The superposed folds in the study area can be classified as Type 3 as described by Ramsay and Huber (1987). Type 3 superposed folds consist of a convergent-divergent pattern. This particular fold morphology arises when the differential movement direction of the second phase (a_2) lies at a high angle to the first fold axial planes (Ramsay and Huber 1987). According to Ramsay and Huber (1987) these relationships show that although the first fold axial surfaces become curved, the first fold hinges are not markedly deflected.

Analysis of Microstructures

Evidence of crystallographic strain of the rocks in the study area was not abundant. The rocks in the study area have been annealed through high pressure and temperature metamorphism destroying most of the microstructures. All of the rock units have pretectonic to post-tectonic minerals. Evidence that the rocks have been deformed is apparent by the undulose extinction of quartz, sutured boundaries, and dislocation glide of the feldspars. Other textures in thin section include myrmekite, sericite, and topotactic transformation of biotite to chlorite. All of these features formed as a result of the amphibolite grade metamorphism that occurred throughout the area.

GEOCHEMISTRY

Twelve samples of the different rock units in the study area were used for geochemical analysis. Other data used included two of Martha J. Foley's (unpublished data) samples that were taken from the study area during the 1996 Keck project and 27 samples from research conducted in the study area by American Copper and Nickel Co. (John Shallow, unpublished data).

Possible Protolith Compositions

The protolith of the rocks in the area were hard to determine. There were no primary textures or features in outcrop or thin section that points to an igneous or sedimentary protolith. Therefore, the rocks were plotted as igneous and sedimentary protoliths.

Possible igneous protoliths for the rocks in the study area plotted as a combination of basalts, trachyandesites , dacites, and rhyolites on a total alkalis vs. silica (TAS) diagram (Figure 2). The rocks plot as tholeiitic rhyolites, dacites, andesites, and high-Fe tholeiites on the Jensen cation plot (Figure 3). The amphibolites plot as basalts with the felsic gneiss, biotite gneiss, and podrock plotting as dacites, rhyolites, and andesites.

Using the ternary diagram taken from Moore and Dennen (1970) the rocks of the study area plot in the arkose and subgraywacke fields for possible sedimentary protolith (Figure 4). The appearance of sillimanite in some of the samples and may indicate a sedimentary origin for those rocks.

REE and Trace Element Analysis

The REE and trace element signatures of the rocks in the study area appear to resemble a continental margin arc or evolved oceanic arc as described by Condie (1986). The MORB normalized spider diagrams show an enrichment of the large-ion lithophile (LIL) elements and a slight depletion of the high field strength (HFS) elements. Almost all of the samples exhibit a noticeable Cr-depletion (Figure 5).

CONCLUSION

Thin section analysis revealed very little structural evidence that was useful in determining the deformational history of the study area. Most of the primary textures and features have been obliterated through high pressure and temperature metamorphism. Structural evidence shows that the area has undergone two major folding events producing a NE plunging fold axis. Geochemical analysis supports an arc environment for the formation of these rocks. Possible protoliths include an igneous or sedimentary parentage. If igneous, the rocks were either basalts, trachyandesites, dacite, or rhyolites. If sedimentary, the rocks were either arkoses or subgraywackes. Continued study in the southwestern United States will further the understanding of how the southwest was accreted and deformed.

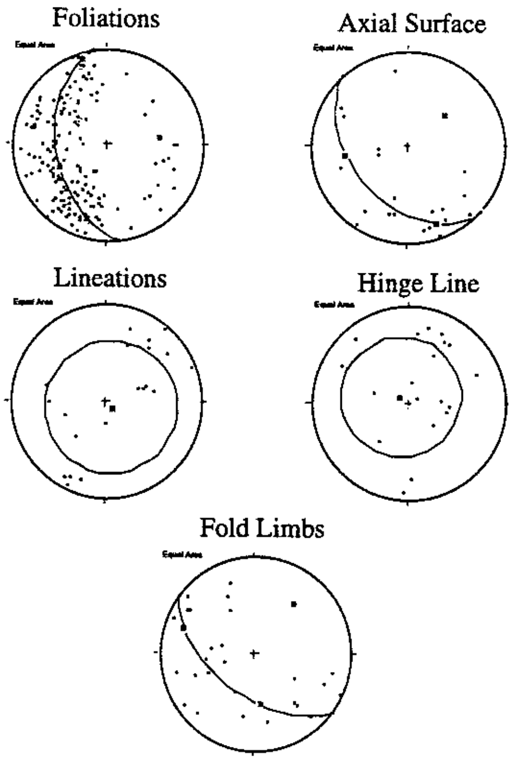

Figure 1. Stereoplots of foliations, lineations, and fold data recorded from the rocks in the study area. Note the general northeast plunge in all of the plots.

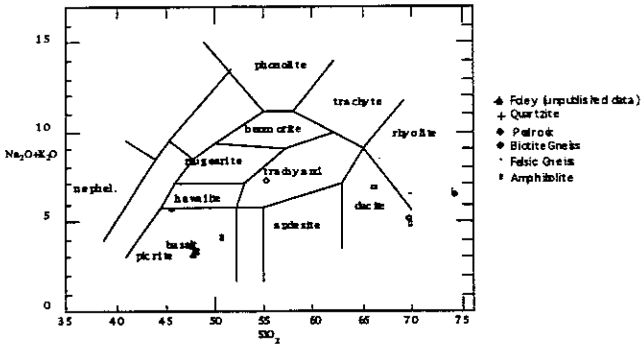

Figure 2

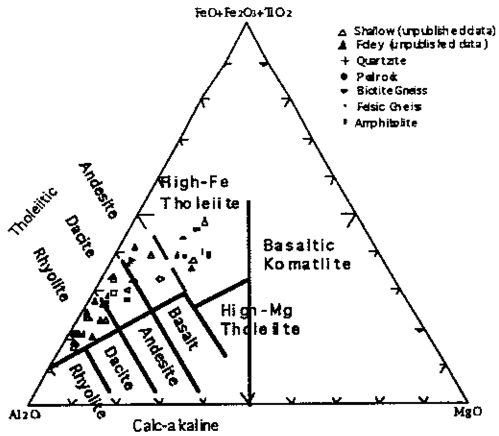

Figure 3

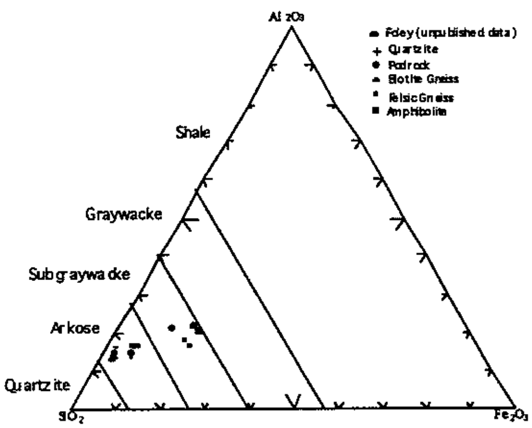

Figure 4

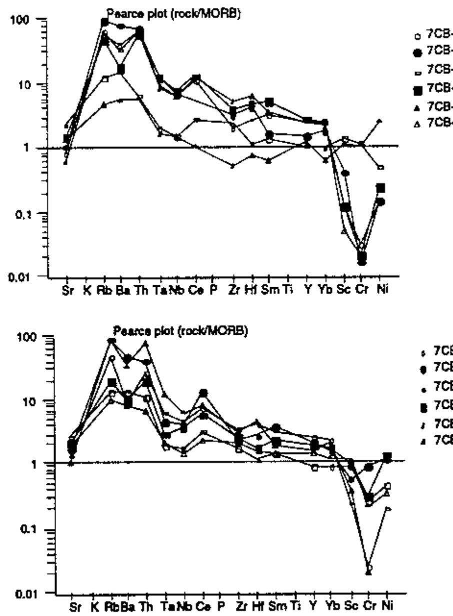

Figure 5

Figures 2, 3, 4 and 5. 2)Jensen (1976) plot showing possible igneous protolith, 3)TAS diagram showing possible igneous protoliths, 4)Moore and Dennen (1970) plot showing possible sedimentary protoliths, 5)REE and trace element spider diagrams, MORB normalized from Pearce (1983).

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Magma Mingling in the Proterozoic of Colorado

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INTRODUCTION

The Proterozoic rocks exposed north of Howard, Colorado are a bimodal sequence consisting of quartz-rich gneisses, felsites, and amphibolites similar to the sequence exposed near Salida, Colorado. Plutons of several ages intrude into this package. A small, approximately 1 km^2 pluton exposed in the Jack Hall quadrangle contains numerous mafic enclaves found within a felsic host. The purpose of this study is to determine whether this pluton represents a case of magma mingling. Magma mingling is defined to be injection or introduction of two or more different types of contemporaneous liquid magmas into one body in which the respective magmas retain their primary igneous compositions. Field relationships as well as petrographical and geochemical analysis aid in determining if the enclaves and host of this pluton do represent mingled but unmixed magmas.

FIELD RELATIONS

Field data was obtained by a series of transverses across the pluton and surrounding area. Total area covered was approximately 2 km^2. The pluton is represented by a series of sills which radiate from a central core and interfinger with the local country rock. A variety of country rocks are found in the area, including a silica-rich grey paragneiss and a K-feldspar/biotite rich gneiss. Numerous amphibolitic dikes cross throughout the area, including the mingled pluton. The pluton is truncated by the Garells Peak Pluton in the east, gradually pinches out into country rock towards the west, and is covered by Tertiary aged volcanics to the north. Towards the south, the pluton gradually pinches out, and is only sporadically exposed in the area immediately south of the Little Badger Creek drainage.

The enclaves take the shape of cuspate to lobate ellipses within the pluton. Some ellipses have wispy projections into the host rock. Most of these enclaves have sharp contacts in relation to the host, though occasionally a gradational contact is observed. Locally, an orientation can be seen to the enclaves, though this orientation changes throughout the pluton and appears to be random. Bent and folded enclaves also occur in throughout the pluton. The distribution of the enclaves within the pluton is variable. In some areas, enclaves compose 80-90% of the total rock. In these regions, the host appears as thin ribbons in between the pillow shaped enclaves. In other regions of the pluton, enclaves are entirely absent. The areas of high/low enclave concentration are rare overall, however. The vast majority of the pluton has a uniform concentration of 35-45% enclaves.

PETROGRAPHY

The enclaves and host were divided into four sections for further analysis. A mafic end member (MEM) represents mafic material within the enclaves taken as far away from the mafic-felsic interface as possible. Mafic contact zone (MCZ) represents mafic material taken within 0.5 cm of the contact with the host rock. Felsic contact zone (FCZ) material represents that which is taken within 0.5 cm of the contact with a mafic enclave, and felsic end member (FEM) material represents material taken from the host as far away from an enclave as possible.

MEMs are characterized by dark green pleochloric hornblende and plagioclase $\pm$ biotite. Both hornblende and plagioclase are euhedral to subhedral with lengths of 0.05-0.1 cm. Biotite is conspicuously absent in some thin sections, though is tabular when present. Accessory sphene and zircon are present, while infrequent epidote and chlorite occur as alteration minerals.

The MCZ shows the same basic mineralogy, though distribution of the minerals has changed. Hornblende is concentrated near the contact, while the amount of plagioclase decreases. The size of hornblendes in this region dramatically increases, with some individual crystals as large as 1 cm. When biotite is present, it is concentrated in the MCZ. In several thin sections, biotite is common (>20%) in the MCZ, while it is absent in the interior of the enclave. Several thin sections show large microclines (>2 cm) which appear to have formed interstitially with hornblende inclusions. Occasionally large phenocrysts