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 ± 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

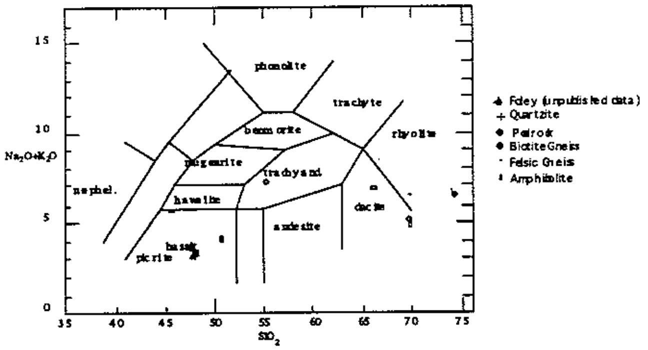
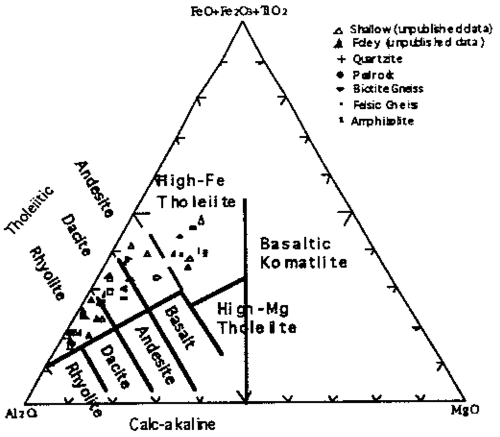


Figure 2



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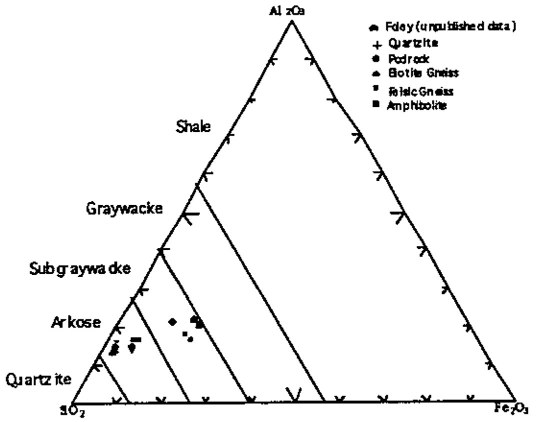

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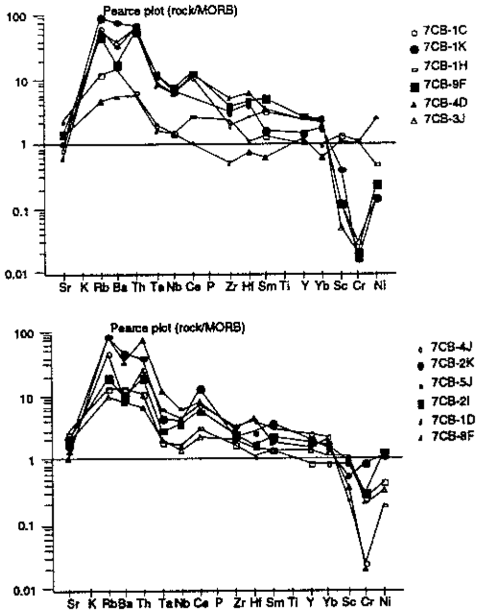

Figure 5

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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of plagioclase can be seen in both the MEM and MCZ. These crystals, which originate from the host material, appear to have fallen into the mafic enclave. The MCZ contact with the FCZ is wavy under thin section. Chutes of MCZ material inject up to 1 cm into the FCZ. In several thin sections, what appears to be a flow alignment is visible. However, many textures in the thin sections may be due to post-crystallization metamorphic overprinting.

The FEM is composed of plagioclase, microcline, quartz, and biotite, with accessory sphene, zircon, and apatite. The grain sizes range from 0.1-0.5 cm for quartz, microcline, and biotite, while plagioclases range from 0.4-0.5 cm. Most of the quartz and plagioclase show undulatory extinction under crossed-polars. Epidote and chlorite occur as alteration minerals.

The FCZ is composed of plagioclase, biotite, hornblende, and microcline ± quartz with accessory sphene, zircon, and apatite. The sizes of the crystals dramatically increases in the FCZ. Plagioclase ranges from 0.6-2.0 cm, and hornblendes reach lengths of 0.7 cm. The feldspars in the FCZ are show considerable serissite and clay alteration. It is important to note the presence of hornblende in the FCZ, where as it is not present within the FEM.

GEOCHEMISTRY

Transects from MEM to FEM were taken for XRF and INAA analysis. On a total alkali-silica (TAS) diagram, enclaves plot as basaltic andesites, andesites, or basaltic trachyandesites. FEM and FCZ samples plot as trachydacites or dacites (Figure 1). A large compositional gap exists between enclaves and host in silica-alkali content.

Harker diagrams (Figure 3) show linear positive trends for Na_2O and K_2O vs. silica, while CaO, MgO, and P_2O_5 show negative curved trends. These trends are especially visible when amphibolites from the Howard area, which is located immediately south of the pluton, are plotted with enclave and host data. These curved trends are indicative of fractional crystallization rather than magma mixing.

Spider diagrams for three separate rocks plotting FEM, FCZ, MEM, and MCZ as separate samples show several similarities (Figure 2). All samples are strongly enriched in Sr, Rb, and Th compared to MORB, possibly due to crustal contamination of the parent magma. Remaining elements show a general enrichment except for Sc and Cr, which show strong depletions. These depletions can possibly be accounted for by fractional crystallization.

Data shows that little interaction has taken place between the enclave and host. Harker diagrams show distinct groupings between mafic samples and felsic samples. MCZ and FCZ samples plot with their respective end members rather than in intermediate ranges. FEM and FCZ samples show nearly identical plots for both major oxides and trace elements. MEM and MCZ samples show similar patterns. Had mixing taken place a linear trend should be visible between the end members, either gradually increasing or decreasing moving from MEM to MCZ to FCZ to FEM.

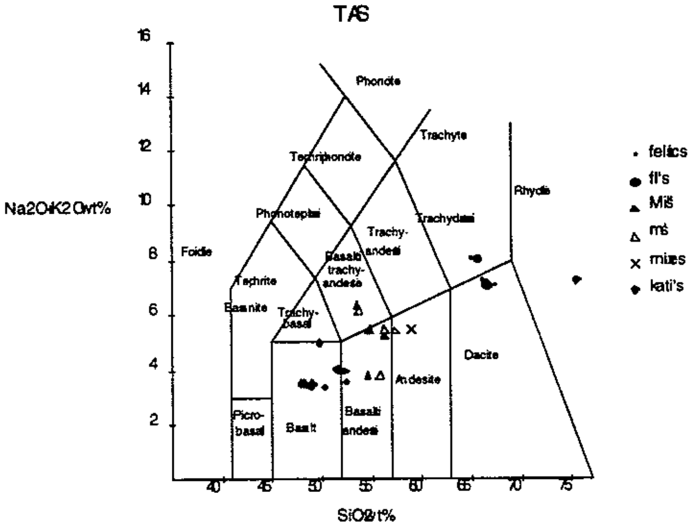

Figure 1. TAS diagram for FEM, FCZ, MCZ, MEM, and Howard amphibolites.

DISCUSSION

The data presented indicates that magma mingling has taken place within the pluton. The lobate-cuspate shape of the enclaves is similar to that of other mingled enclaves examined in other plutonic bodies throughout the world. The concentration of hornblende in the MCZ and the subsequent decrease in plagioclase suggest chilled margins within the enclaves. The large grain size of the feldspars in the FCZ can be attributed to the close proximity of the enclaves. An enclave of basaltic-andesitic composition would have a temperature of over 1000°C. The felsic host would be at a temperature several hundred degrees lower than this. Upon injection into the felsic magma chamber, the enclaves would rapidly cool, resulting in a chilled margin. Still, these enclaves would be much hotter than the host, and in an attempt to reach thermal equilibration, the FCZ would warm, resulting in the coarse texture observed in the FCZ. This rapid chilling of the mafic constituent may also prevent large scale mixing from taking place. Viscosity and density contrasts can also prevent migration of elements between enclave and host.

The presence of hornblende in the FCZ, while it is absent in the FEM, indicates that some interaction has taken place between the enclave and host. This interaction could be related to fluids migrating from enclave to host, temperature, viscosity differences, as well as mineral site availability. Which factor is most important in determining overall element distribution is unknown, however.

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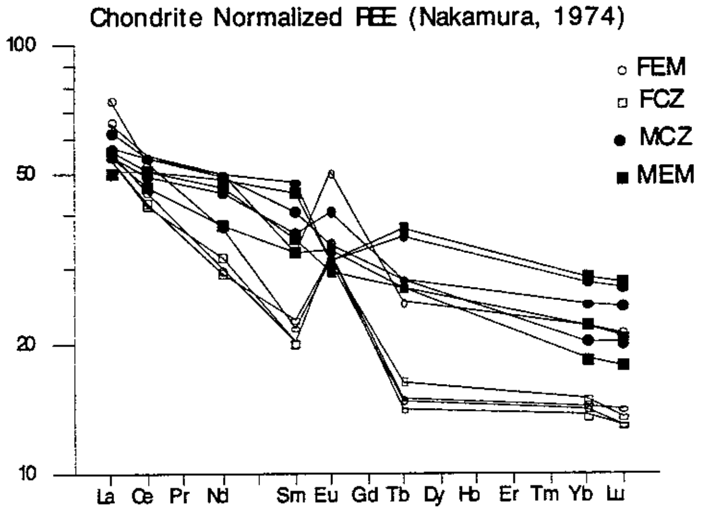

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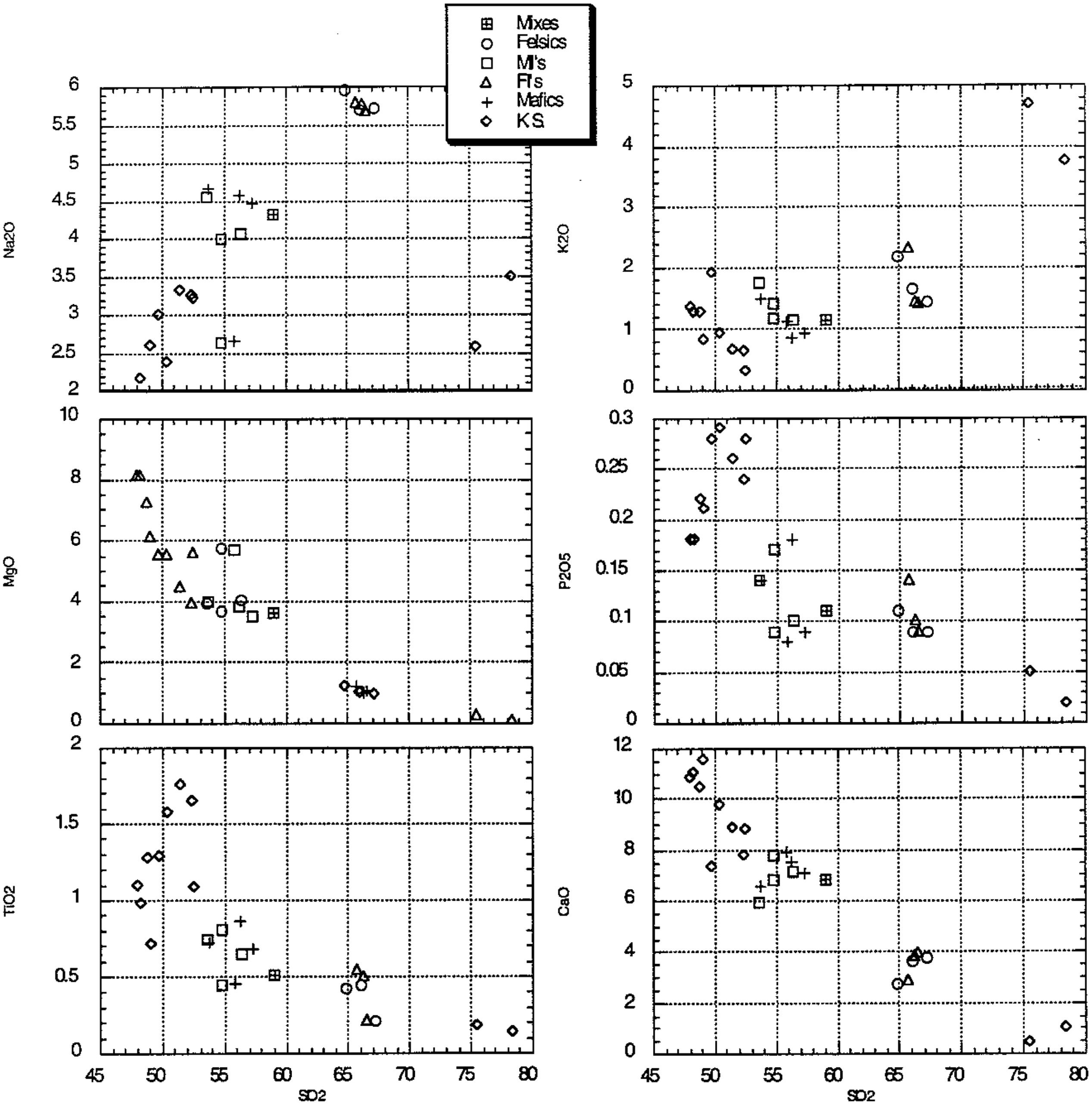

Figure 3. Harker diagrams for FEM, FCZ, MCZ, and MEM.

Kinematic indicators and structural characteristics of the Road Gulch area, Colorado

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INTRODUCTION

The purpose of this project was to identify and map the rock units and record the structural characteristics of an area in the northern part of the Wet Mountains in Colorado. The area lies near the Arkansas River Canyon about sixty miles southwest of Colorado Springs, between Turkey and Rogers' Gulches (see figure 1.) It is bounded by the BLM/private land border to the East, and Texas Creek to the West. The Wet Mountains are part of a 1,500 km belt of Proterozoic crust affected by several periods of convergent tectonism with accompanying prograde metamorphism [Karlstrom, 1990.]. Peak metamorphism occurred during each tectonic pulse at 1.74, 1.70, and 1.65-1.60 Ga. The deformational fabrics resulting from these tectonic phases are compressional. Different metamorphic grades resulted from differential block uplifts [Karlstrom, 1990.] Condie, 1982, described the same accretion from Wyoming to Arizona as successive basin closures and Andean-type orogenies. He noted that in each province bimodal volcanic assemblages, a quartzite-shale assemblage, and granitic plutons are present [Condie, 1982.]

ROCK UNITS

The area of this study is underlain by a grey biotite gneiss, an amphibolite gneiss, and two metamorphosed plutonic formations. The grey, biotite gneiss consists of approximately 30% biotite, 60% quartz, and 10% K-feldspar. A layer of fining-upward feldspars in one outcrop of the grey gneiss appears to be a graded layer. If this interpretation is correct the grey gneiss is a meta-sedimentary gneiss. The amphibolite gneiss consists of roughly 70% hornblende and 30% plagioclase, with varying amounts of quartz and pyroxene. These amphibolite grade gneisses have been intruded by granitoid magmas during two phases of igneous activity.. The Boulder Creek formation, a well-foliated granodiorite gneiss covering most of the map area, intruded at 1.6 Ga. It can be characterized by its coarse grain size, big augens, and biotite laminations. The Silver Plume formation, a weakly foliated granitic gneiss, intruded the older gneisses around 1.4 Ga. Only a few scattered outcrops of the Silver Plume formation occur in this map area. Pegmatites which followed the intrusion of the Silver Plume formation are present throughout the map area. Especially large exposures of these pegmatites are present between Turkey and Road Gulches. Northwest of these gulches, in Howard County, bimodal volcanics are common, although not present in this map area.

FIELD RELATIONSHIPS

The grey gneiss and amphibolite are strongly foliated. The Boulder Creek has a slightly weaker foliation and the pegmatites have virtually none. The most prominent Boulder Creek foliation trends N50-60W and dips northeast (see figure 2.) The amphibolite and grey gneiss have similar trends (see figures 3 and 4.) The compositional layering and foliation of the gneisses was created by the same major deformation that led to isoclinal folding throughout the map area. The axial planes of most of these folds parallel the regional northwest-trending foliation. The axes of these folds plunge steeply, as shown by the plot of the hinge lines in figure 5. This suggests that they may have been formed as a result of a regional shear. A second set of folds trends N60-80E with varying plunge. Shear bands found in the Boulder Creek are all sinistral and trend N45-70E, at a high angle to the dominant foliation direction and the orientation of the earlier isoclinal folds. A third set of poorly developed folds in the foliation trend N10-20E and plunge 50-80 NE.

The rocks in this area have been metamorphosed to a high grade and have undergone at least two folding events. The amphibolites, which occur as elongate, boudin-shaped outcrops in map view, are mainly surrounded by larger fields of pegmatite and Boulder Creek granodiorite . The Boulder Creek