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.

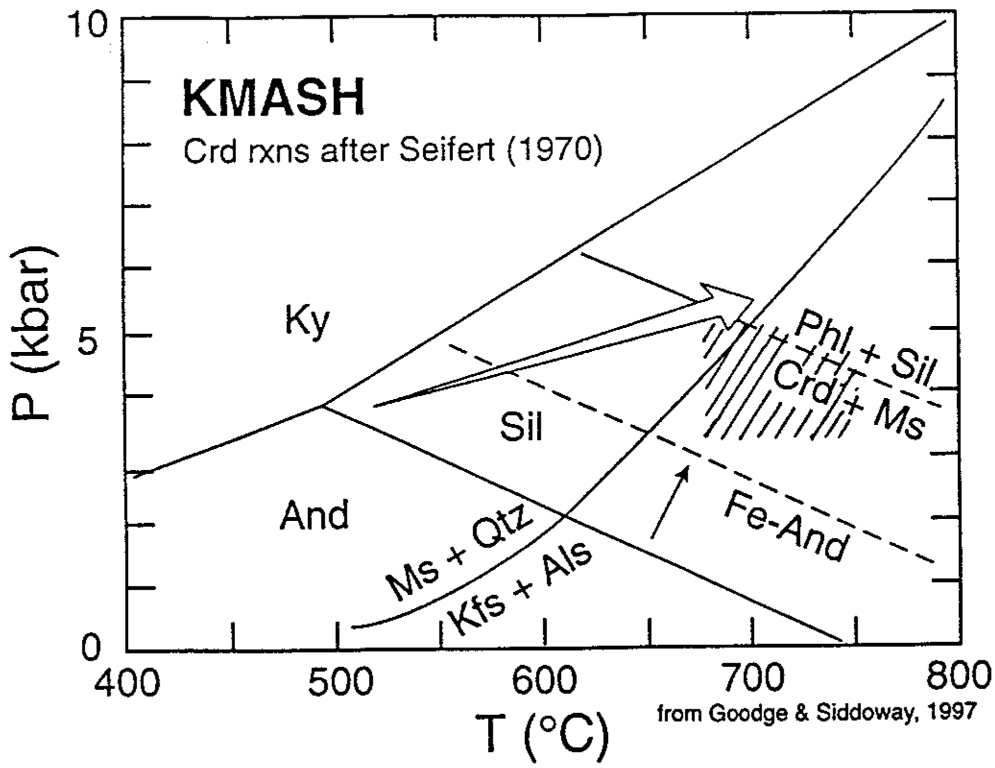

Figure 3 -- Pressure-temperature diagram for conditions of sillimanite (Sil) and biotite (Phl-phlogopite) growth (cross-hatched area in diagram) at the expense of cordierite (Crd). Sillimanite and biotite, as well as Mn-Fe andalusite (Fe-And) in adjacent cordierite-free rocks, show no preferred orientation 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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Meta-Volcaniclastic rocks:

Rocks interpreted in the field by Reinhard Wobus and the author as metamorphosed volcaniclastics occur throughout the area. They are interbedded with both the amphibolites and the quartz-mica schists. The number and size of clasts in the volcaniclastic lithology varies along some transects of the area. They contain clasts of pelitic schist and highly altered clays and mica, which are angular and randomly oriented in the metamorphic fabric. These clasts are matrix supported and are altered and broken down by metamorphism, creating diffuse edges around the clasts.

Quartz is the dominant mineral within the volcaniclastic lithology, feldspars comprise less than 25% of the total rock, muscovite and biotite are the main accessory minerals, with some biotite being altered to chlorite. The micas tend be strongly aligned, but they do not create a strong foliation throughout the lithology. In many cases the volcaniclastic lithology grades into the quartz-mica schist. This gradation could be the result of a finer ash layer being reworked by ocean currents and mixed with clay-rich sediment. In the Kiln Gulch region located south of the main study area, turbidites and volcaniclastic sediments are well-preserved. The turbidites show fine lamination and bed forms, including ripple marks and possible cross laminations. In outcrop, the turbidites are green and composed of sand sized and smaller grains. These grains range in composition from mafic lithic fragments to quartz grains. The amount of metamorphism makes it difficult to interpret the cross laminations. Well preserved volcaniclastic sediment with angular clasts are found on top of these clastic debris flows. Boardman's (1986) study of the Salida area approximately 10 km to the west, shows similar features and sequences which are also interpreted to be turbidites.

GEOCHEMISTRY:

Methods:

Eleven samples (9 amphibolite and 2 felsics) were sent to Oregon State University for Instrumental Neutron Activation Analysis (INAA). The analysis done by the test determines trace element, including Rare Earth Element (REE), content. Fifteen samples (9 amphibolites, 5 felsics and 1 pelitic schist) were sent to ActLabs (Activation Laboratories LTD.) in Ontario, Canada for major and trace element data using the Inductively coupled plasma (ICP) method.

Results:

The amphibolites in Howard and Jack Hall area plot in basalt and basalt related fields on a total alkalis-silica (TAS) plot and a silica versus K_2O plot (not pictured). A plot of Ti verses Zr (Pearce and Cann, 1973) places a majority of the samples in the ocean floor basalt field (Figure 1). On a ternary plot of Ti/100-Zr, and Y*3 (Pearce and Cann, 1973), the samples plot as ocean floor, low-potassium tholeiites and calc-alkali basalts (Figure 2). On an AFM diagram, the samples plot along the trend line for tholeiites (Figure 3). A ternary diagram plotting, Ti/100, Zr, and Sr/2 show the amphibolites falling mainly into the fields for low-potassium tholeiites and ocean floor basalt (Figure 4).

The Howard-Jack Hall samples show a MORB affinity when plotted on a MORB normalized spider diagram (Figure 5). This spider diagram, when compared to studies of modern backarc basins, indicates both an island arc tholeiite and backarc basin basalt affinity for the Howard-Jack Hall samples (Clift, 1995). This ambiguity in the interpretation of this graph makes the specific tectonic setting difficult to pin down. Backarc basins are typically associated with an adjacent active island arc, where rifting and volcanism are contemporaneous (Taylor, 1995). If the Howard-Jack Hall region was between the rifting basin and the active island arc it could have been influenced by both magmatic sources, which could account for the ambiguity of the spider diagrams.

The tectonic setting of central Colorado has been hypothesized as a succession of backarc basins and volcanic island arcs (Condie, 1986). The Howard-Jack Hall region fits in with this theory. When the geochemistry of the Wet Mountains, Front Range and Salida are compared to Howard-Jack Hall on a spider diagram they all exhibit similar trends. The data for the other areas are interpreted as originating from a volcanic arc (Boardman, 1986; Boardman and Condie, 1986 and Folley, 1997). The Howard-Jack Hall area correlates with the tectonic setting for central Colorado.

DISCUSSION:

Petrography:

Some rocks within the Howard area have undergone metamorphism to anthophyllite-cordierite schists. The region would have to be enriched in magnesium and iron for the anthophyllite to have the chemistry for development. One likely source of the parent rock is altered sea floor volcanic or volcaniclastic rocks, from volcanic vents on the ocean floor which can react with seawater to form minerals. One well documented example of such vent enrichment are volcanic massive sulfide deposits (VMS) (Franklin *et al.*, 1981). There is a VMS deposit approximately 45 km to the southeast of the Howard area in the Green Mountain Mine area. Cotopaxi and

Salida both have outcrops of these shists suggesting an environment conducive to the formation of VMS deposits. The presence of these deposits indicates that hydrothermal alteration occurred near the Howard-Jack Hall region.

Field Relations:

The field relations among the different lithologies are key to understanding the geologic history of the area. The first event recorded in the Howard-Jack Hall region was the collection of volcaniclastic material from a volcanic island arc. This material includes both fine ash and clastic tuff. This material was subsequently altered by the incorporation of sediment from the nearby continent. Detrital material was transported by ocean currents and mixed with the volcanic material in the basin. This detrital sediment is likely the source of the abnormally high concentrations of biotite and muscovite in the volcaniclastic deposits and the similar geochemical composition of the two rock lithologies.

Three factors help to support the hypothesis of a backarc basin/immature island arc system for the formation of the region. The clasts in the volcaniclastic lithology are graded in the hypothesized up direction. This fining upwards is consistent with a subaqueous depositional environment for the lithology. Due to the rapid deposition of subaerial pyroclastic flows distinct fining upwards sequences would be rare. A unit with bedforms indicating turbidites also supports the subaqueous deposition. The rocks also underwent alteration that produced the bulk chemistry suitable for the production of anthophyllite-coriderite rocks during metamorphism. This chemical alteration was likely caused by hydrothermal vents on the ocean floor and took place around the time the rocks were being deposited. These factors, subaqueous deposition and the likely existence of hydrothermal vents points to a system that had a extensional environment or magma body underneath the source region. The observations for the Howard and Jack Hall regions are consistent with the theory of a subaqueous depositional environment for central Colorado Proterozoic rocks proposed by Bickford and Boardman (1984).

CONCLUSIONS:

The rocks of the Howard and Jack Hall region are likely the result of the accretion of a volcanic island arc and backarc basin succession to the growing Proterozoic North American continent. Field relations, petrologic data, and geochemical data all help to support this theory. The bimodal nature of the region limits the timing and the types of tectonic settings that can create this suite. An immature island arc could produce this bimodal suite. The presence of anthophyllite-coriderite schist is supportive of the backarc basin setting due to the hydrothermal vent origin hypothesis, however, mid-ocean ridges also have associated vents. Studies on modern backarc basins all show hydrothermal activity causing enrichment of the surrounding sea floor (Taylor, 1995). The geochemical data show the mafics to be of MORB affinity with characteristics of both island arc basalts and backarc basin basalts. The Howard-Jack Hall area probably evolved in a transition zone between the rift and arc. This idea holds with the regional understanding of central Colorado, specifically the Salida area and the northern Wet Mountains and the southern Front Range.

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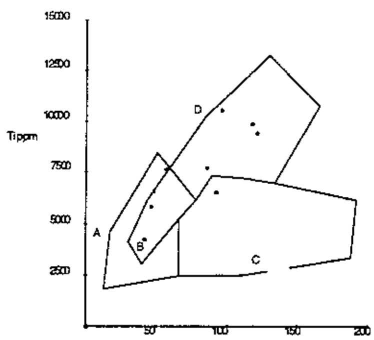

Figure 1: Discrimination diagram using Ti and Zr for the Howard and Jack Hall region. Ocean floor basalts plot in fields D and B and calc-alkali basalts in fields C and B. (Pearce and Cann, 1973).

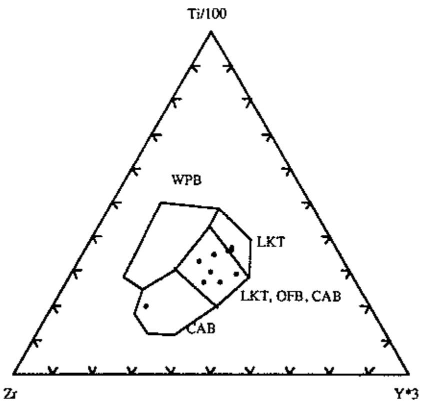

Figure 2 : Discrimination diagram using Ti, Zr and Y for the Howard and Jack Hall region. The samples plot in the low-potassium tholeiite (LKT), ocean floor basalt (OFB), and calc-alkali basalt (CAB) fields. Pearce and Cann (1973).

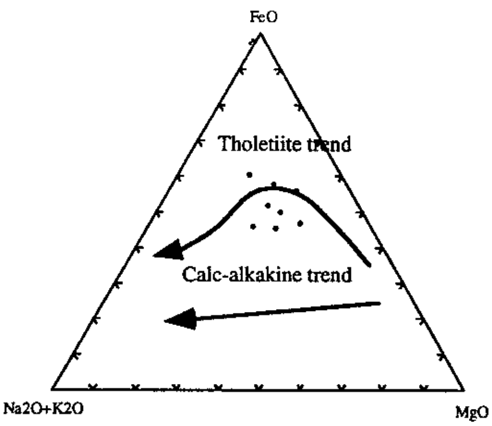

Figure 3: An AFM diagram that shows the Howard-Jack Hall amphibolites to be on the boundry between tholeiitic and calc-alkaline basalt. Boundry after Irvine and Barager (1971)

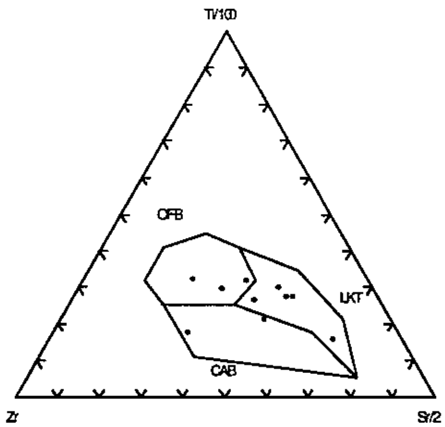

Figure 4 : Discrimination diagram using Ti, Zr and Sr for the Howard and Jack Hall region. The samples plot in the low-potassium (LKT) and ocean floor basalt (OFB) fields. (Pearce and Cann, 1973)

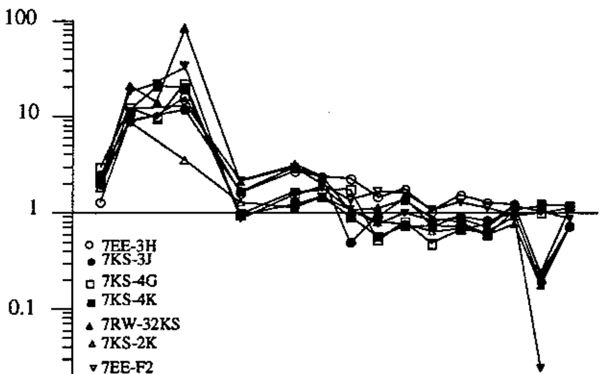

Figure 5: MORB normalized (Pearce, 1983) spider diagram plotting the amphibolites from the Howard and Jack Hall region.

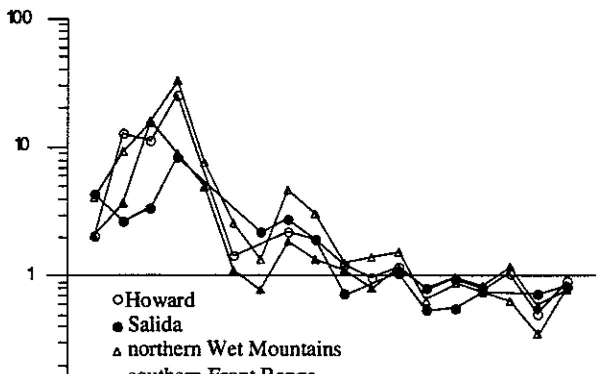

Figure 6: MORB normalized (Pearce, 1983) spider diagram plotting the averages of the amphibolites from the different regions under comparison.

Geochemistry and tectonic setting of the Early Proterozoic metavolcanics of the Arkansas River Canyon, Howard to Royal Gorge, Central Colorado

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INTRODUCTION

The rocks of the Arkansas River canyon extending 50 km upstream (west) from the Royal Gorge to the Pleasant Valley fault near the town of Howard form part of a 1300 km wide Proterozoic orogenic belt reaching southward from the Cheyenne belt of southern Wyoming to northern Sonora, Mexico. Laramide and post-Laramide uplifts and subsequent erosion have exposed a significant and previously overlooked bimodal volcanic suite within the Proterozoic basement of the canyon. The felsic and mafic units occur interlayered with a well exposed series of biotite-quartz-feldspar gneisses, quartzites and metapelites, all of which have been intruded by multiple generations of syn- and anorogenic granitic plutons and pegmatites. Regional sillimanite-grade metamorphism deformed the area prior to the intrusion of the Garrell Peak granitic pluton, which cross-cuts the metavolcanic units and gives them a minimum age of 1.65 Ga. This study provides detailed geochemical analysis especially of the unstudied felsic metavolcanics which occur in this part of the Arkansas River canyon which were previously noted only in reconnaissance maps and reports (Taylor, Scott and Wobus, 1975; Cullers and Wobus, 1986). It also complements research on amphibolites of volcanic petrogenesis from the southern Front Range to the northern Wet mountains by Folley (1997) and Folley and Wobus (1997), and attempts to place the bimodal Arkansas canyon package within a regional tectonic context.

FIELD INVESTIGATION

Felsic and mafic (amphibolite) samples from along a 50 km transect of the Arkansas River and its tributaries were selected in the field on the basis of likely volcanic protolith as determined by texture and mineralogical composition. Locations sampled include the Sand Gulch region north of Howard, upper and lower Texas Creek Gulches, Bull Gulch, East Gulch, Five Point Gulch, Sheep Basin, and the upper part of Royal Gorge (Fig. 1). The felsic and mafic volcanic units are concordant layers in which the felsic units appear to represent air-fall tuffs, pyroclastic flows and breccias and the amphibolites represent mafic flows.

In contrast to the remarkably well-preserved occurrences of Early Proterozoic metavolcanics near Gunnison and Salida, the Arkansas River section has been considerably deformed by regional metamorphism. Some primary structures are still evident, however, most notably relict pumice fragments, volcanic clasts, and remnant volcanic bombs up to 20 cm in length (Fig. 2). No pillow structures have been found in the area of study.

PETROGRAPHIC FEATURES

The felsic units examined are predominantly aphyric, characterized by primary fragmental textures and locally by relict flattened pumice lapilli. Plagioclase, microcline, and quartz, occurring as fine-grained, intergrown, anhedral crystals, dominate the felsic units. Most metabasalts have a moderately developed crystalloblastic texture and contain brown-green hornblende and intermediate plagioclase; some samples also contain diopside.

The regional metamorphism which affected the area subsequent to deposition caused a variety of changes among the volcanics, including recrystallization, possible remobilization of major elements, and metamorphic overprinting. Many samples have a weak to moderate foliation defined by the alignment of minor biotite. Previously studied volanics near Salida show that, of all the units present, the aphyric massive tuffs are most likely to represent the composition of the original magma (Boardman, 1986).

GEOCHEMICAL ANALYSES

Twenty-one samples were selected for geochemical analysis on the basis of freshness of sample, mineralogy, geographic coverage across the transect, and textural evidence of volcanic origin, as identified both in the