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

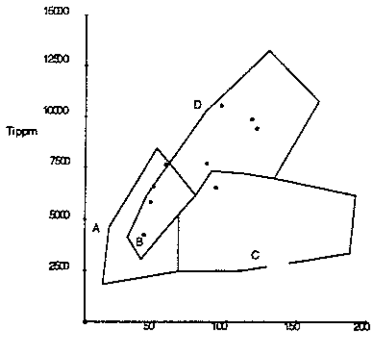


Figure 1: Discrimination diagram using Ti and Zr for the Howard and Jack Hall region. Ocean floor basalts plot in fields D and B and calc-alkali basalts in fields C and B. (Pearce and Cann, 1973).

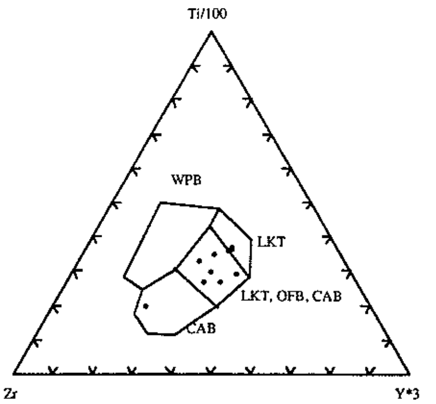


Figure 2 : Discrimination diagram using Ti, Zr and Y for the Howard and Jack Hall region. The samples plot in the low-potassium tholeiite (LKT), ocean floor basalt (OFB), and calc-alkali basalt (CAB) fields. Pearce and Cann (1973).

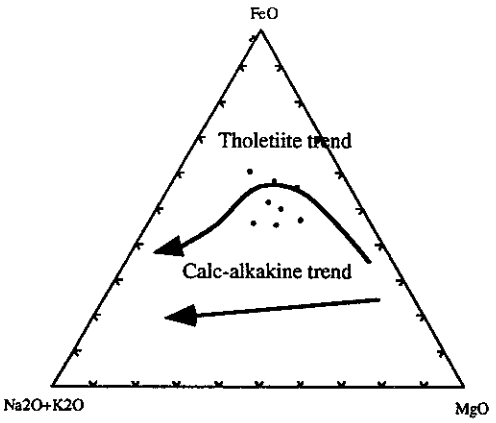


Figure 3: An AFM diagram that shows the Howard-Jack Hall amphibolites to be on the boundry between tholeiitic and calc-alkaline basalt. Boundry after Irvine and Barager (1971)

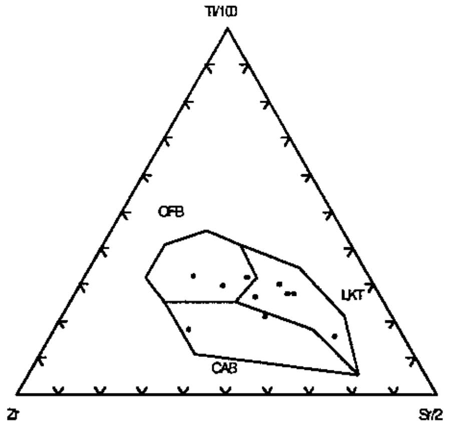


Figure 4 : Discrimination diagram using Ti, Zr and Sr for the Howard and Jack Hall region. The samples plot in the low-potassium (LKT) and ocean floor basalt (OFB) fields. (Pearce and Cann, 1973)

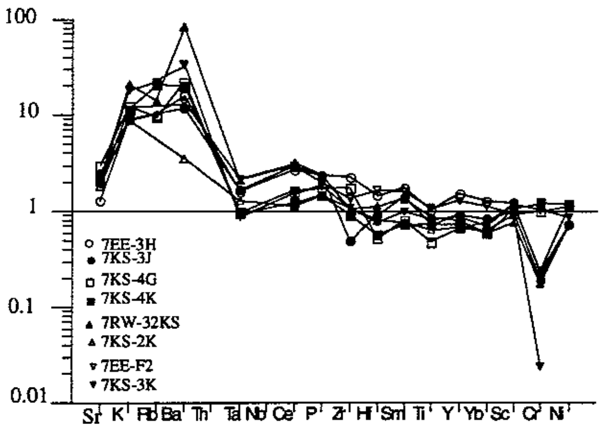


Figure 5: MORB normalized (Pearce, 1983) spider diagram plotting the amphibolites from the Howard and Jack Hall region.

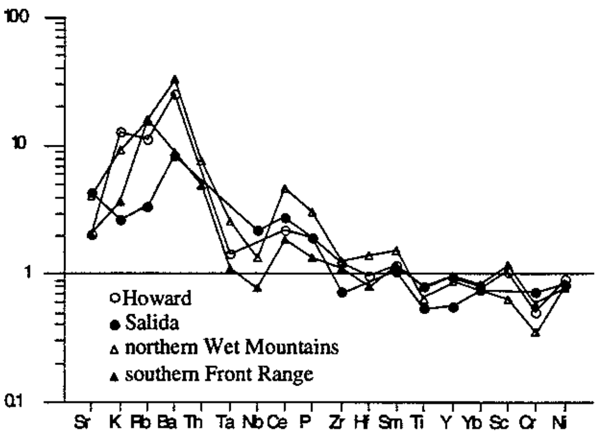


Figure 6: MORB normalized (Pearce, 1983) spider diagram plotting the averages of the amphibolites from the different regions under comparison.

field and petrographically. Twelve felsic samples were sent to Oregon State University for Instrumental Neutron Activation Analysis (INAA) to obtain trace element data, and additional trace elements were analyzed by X-ray fluorescence (XRF) at Activation Laboratories, Ltd., in Ontario, Canada. Major and minor elements were obtained using XRF at the University of Massachusetts at Amherst. Additional data for amphibolites are from Folley and Wobus (1997).

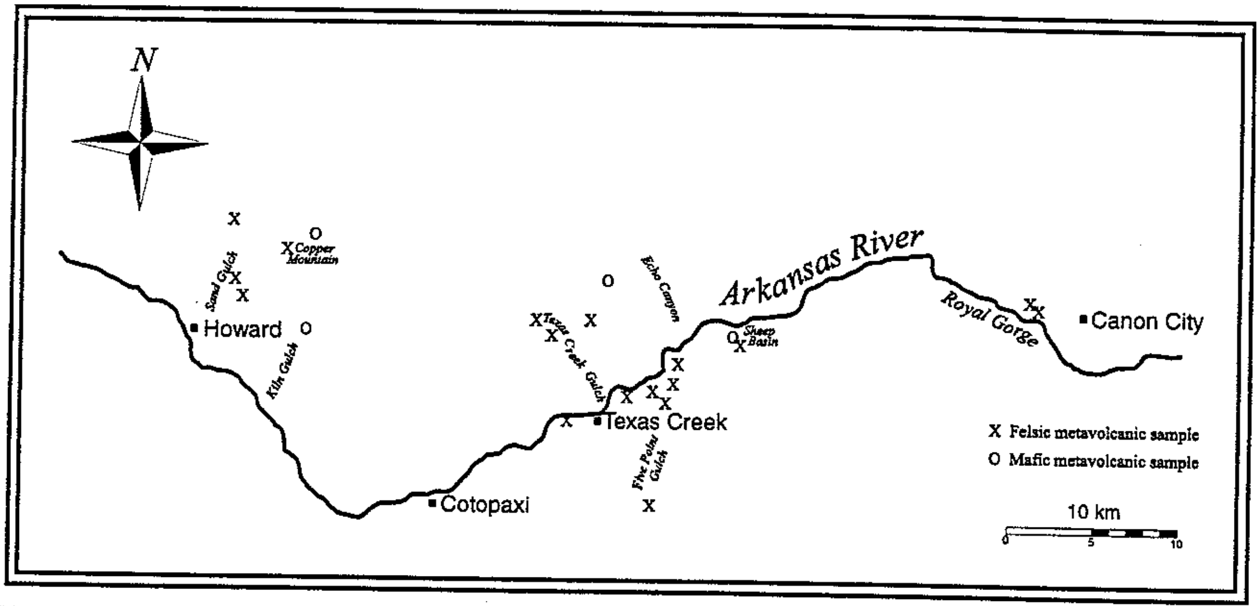


Fig. 1. Map of sample localities.

Fig. 2. Float boulder of metarhyolitic pyroclastics in Texas Creek Gulch showing two large volcanic bombs surrounded by felsic matrix.

According to the total alkalies vs. silica (TAS) classification of LeBas and others (1986), thirteen of fifteen felsic samples plot as rhyolites (SiO_2 = 71-80%, total alkalies = 6-8%) and two as trachydacites (SiO_2 = 65-67%, total alkalies ~ 9%). Three of four amphibolites plot in the basalt field and one may be classified as a basaltic trachyandesite. This geochemistry confirms the bimodality of the Arkansas canyon volcanic suite.

Many trace elements are considered to be less mobile than major elements under conditions of metamorphism and deformation; thus, considerable attention was given to their abundances. MORB-normalized spider diagrams (Fig. 3) show the felsic samples to be relatively enriched in the large ion lithophile elements (LILEs). High field strength element (HFSE) concentrations are also relatively high, and a moderate Ta - Nb trough is present.

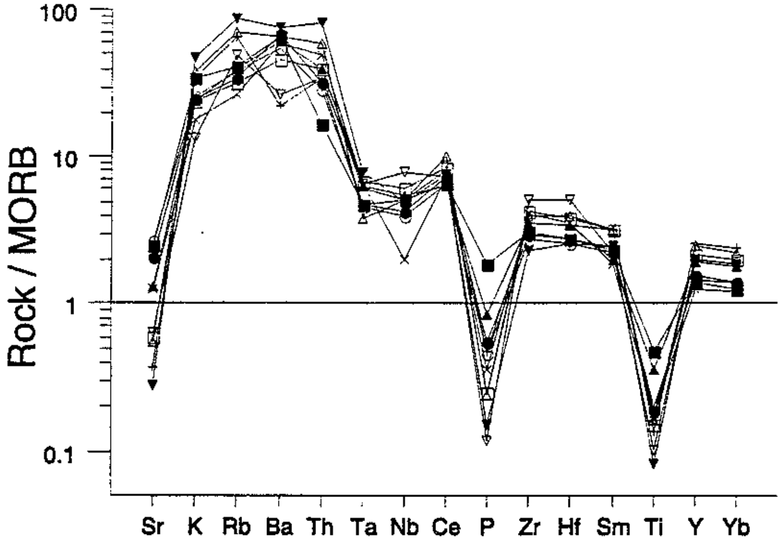
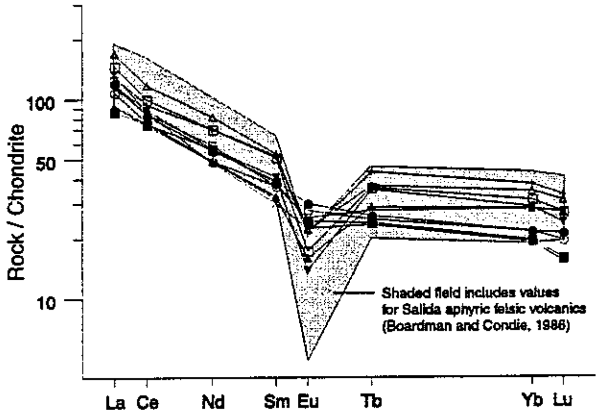


Fig. 3 MORB-normalized trace element abundances in Arkansas River canyon felsic meta-volcanics. Normalizing values are from Pearce (1983).

Rare earth element (REE) diagrams (Fig. 4) show light REEs at about 100x chondrite and only slightly enriched over heavy REEs, with $La_N / Yb_N < 5$. Small to moderate negative Eu anomalies punctuate otherwise relatively flat rare earth trends.



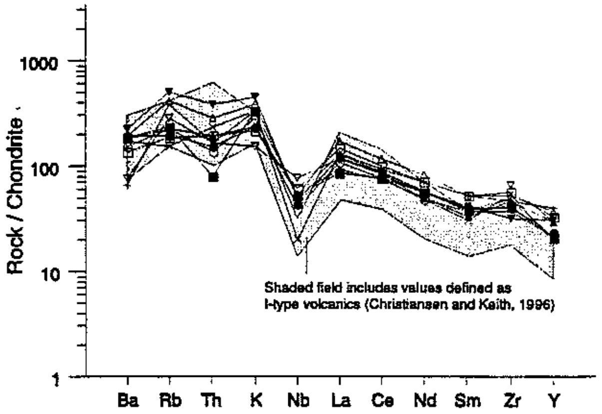


Fig. 4. REEs of Arkansas canyon felsic volcanics compared with those of Salida after Boardman and Condie (1986)

Fig. 5. Trace elements of Arkansas canyon felsic volcanics compared with standard I-type rhyolites, after Christiansen and Keith (1996)

TECTONIC SETTING

Discriminant diagrams which employ minor and trace element abundances to determine tectonic settings yield somewhat ambiguous results when applied to the Arkansas River felsic suite. On Nb vs. Y and Ta vs. Yb diagrams (Pearce and others, 1984), felsic samples are tightly clustered across field boundaries dividing volcanic arc petrogenesis from within-plate petrogenesis. Results are more definitive when plotted using the method of Christiansen and Keith (1996), who distinguish trace element patterns normalized against chondrite for four principle types of silicic igneous rocks: I-type rhyolites, A-type rhyolites, S-type rhyolites and granites, and Ocean Ridge-type granites. This comparison shows the Arkansas River felsic suite to have strong affinities with I-type rhyolites (Fig.

5), particularly in their high LILE abundances and high Ba/Nb and Rb/Nb ratios. I-type silicic magmas are mostly found at convergent plate margins, including oceanic and continental magmatic arc settings (Christiansen and Keith, 1996). The nearby, and presumably not much younger, Boulder Creek-age plutons are characteristically I-type granodiorite and tonalite, also suggestive of arc settings. Finally, comparison with an extensive numerical data set for subalkalic silicic obsidians shows the ranges and averages of most trace elements in the Arkansas River rocks are consistent with those for mature island arcs and active continental margins (MacDonald and others, 1992).

While not the major emphasis of this study, the four mafic volcanic samples analyzed all plot as calc-alkaline basalts from a volcanic arc setting using the TiO_2 - P_2O_5 - MnO discriminant diagram of Mullen (1983).

DISCUSSION AND CONCLUSIONS

The nearest well studied sequence of bimodal metavolcanic rocks occurs approximately 15 km west of the westernmost samples in the present report, near the town of Salida (Boardman and Condie, 1986). The felsic units of the Arkansas canyon strongly resemble those of Salida (Fig. 4), dated at 1728 +/- 5 Ma, with REE values falling almost entirely within the spread of the Salida aphyric felsic volcanic data. As in the Salida suite, Sr values are too low and heavy REEs are too enriched to suggest a petrogenetic origin involving partial melting of continental crust (Boardman, 1986). The 1770 - 1760 Ma Dubois Greenstone volcanic belt, located approximately 130 km to the west near the town of Gunnison, also has similar trace element abundances, and is compositionally comparable to bimodal volcanics found in continental margin arcs and associated back-arc basins (Condie, 1986). Comparisons with the Salida and Gunnison Early Proterozoic volcanics and with I-type rhyolites defined by Christiansen and Keith (1996) suggest that the bimodal Arkansas canyon suite is a remnant of a young back-arc basin developing on or near continental crust. The extent of bimodal volcanics within the region is much greater than previously thought: clearly these rocks have a significant role in the geologic history of the Arkansas River canyon and in the geologic assembly of southwestern North America.

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Archean Rocks of the Tobacco Root Mountains, Montana

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