Geochemistry and tectonic setting of Proterozoic amphibolites from the southern Front Range and northern Wet Mountains, central Colorado

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INTRODUCTION

The majority of the Early Proterozoic supracrustal rocks of south-central Colorado are complexly interlayered metasedimentary and metavolcanic units -- especially pelitic schists, felsic gneisses, and amphibolites – which have been punctuated by both syn- and anorogenic granitic intrusions (Fig. 1). The whole wall-rock package has undergone regional amphibolite-grade metamorphism at about 1.7 b.y. as well as multiple intrusive and deformational events (Tweto, 1987). This study incorporates field, petrographic and geochemical evidence from selected amphibolite units along a 100-km north-south transect from the southern Front Range through the Arkansas River Canyon to the northern Wet Mountains in order to determine their origin and to use them as a guide to the tectonic history. Previous studies of this area in south-central Colorado have focused on regional geologic mapping and on the various generations of plutonic activity; little is known about the amphibolites due to a general lack of geochemical data.

FIELD INVESTIGATION

Data for this investigation came from 29 individual sample localities of amphibolites, some of which are associated with felsic volcanic rocks, ultramafic rocks, and calc-silicates. All were chosen for their likely igneous heritage. The amphibolites collected in the southern Front Range occur closely with the pelitic metasedimentary rocks as concordant layers or pods, as xenoliths within granitic plutons, and, less frequently, as discordant intrusive bodies. Most of the samples are well-foliated and generally fine to medium grained. In the Arkansas Canyon, the amphibolites occur as pods and xenoliths within granitic plutons and as layered units associated with felsic gneiss and metasedimentary units. In the Wet Mountains, the samples were taken from concordant bodies within the layered gneiss complex and from larger pods and xenoliths in the plutons. In most cases, the units are foliated, fine to medium grained, and contain amphibole and plagioclase phenocrysts of about equal abundance.

Unlike similar bodies of amphibolite in the Salida and Gunnison areas to the west (Boardman, 1986), such features as pillow structures, amygdules, or flow breccias indicative of a volcanic protolith have been obliterated due to the high grade of regional metamorphism. Geochemical analyses along with field and petrographic relationships have been required to form any conclusions about previous history.

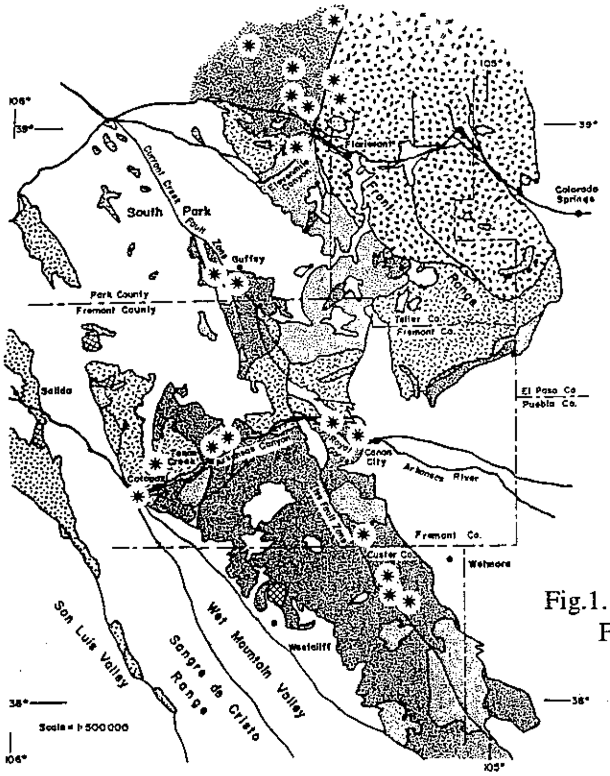
PETROGRAPHIC FEATURES

The amphibolite units from the southern Front Range, Arkansas Canyon, and northern Wet Mountains have all been recrystallized under amphibolite grade metamorphic conditions. They are composed mainly of blue-green and brown-green hornblende and intermediate plagioclase. Quartz is usually present in low amounts, but at some localities can be up to 20%. Some samples also contain minor biotite, diopside, and opaques. The recrystallization of these units is evident in the thin sections; most have a moderately developed crystalloblastic fabric, with a weak to moderate foliation defined by the alignment of hornblende and biotite.

GEOCHEMICAL ANALYSES

Twenty-five amphibolites were selected for geochemical analyses on the basis of composition as identified in the field, freshness of the sample, relationship to other units within the metamorphic package, location, and relevance to the region as a whole. Fifteen samples were sent to Oregon State University for Instrumental Neutron Activation Analysis (INAA) to obtain the amounts of the trace elements Sc, Cr, Co, Ni, Zn, Rb, Cs, Sr, Ba, La, Ce, Nd, Sm, Eu, Yb, Zr, Hf, Ta, W, Hg, Th, U in each. Other trace elements, (Nb, Y, Ga, Pb, Cu, V,) were obtained by X-ray fluorescence (XRF) from Activation Laboratories, LTD, in Ontario, Canada. Major elements were also determined by XRF at the University of Massachusetts at Amherst.

In the following figures and discussion, the amphibolites are grouped into four regions: the southern Front Range, the Guffey area west of the Currant Creek/Ilse Fault, the Arkansas River Canyon (from Royal Gorge upstream to Cotapaxi,) and the northern Wet Mountains. Interpretations about the units and their tectonic histories have been made by comparing the characteristics of the amphibolites individually as well as among the four regions.



EXPLANATION

Phanerozoic rocks, undivided

Proterozoic Y

Pikes Peak Granite

Granitic rocks of Berthoud (Silver Plume) intrusive suite (1360-1460 m.y.)

Proterozoic X

Granitic rocks of Routt (Boulder Creek) intrusive suite (1665-1705 m.y.)

Metavolcanic rocks and associated metasediments (1710-1740 m.y.)

Metasedimentary rocks, undivided (derived primarily from pelitic sediments; volcanic components minor)

Fig.1. Map of geology and sample localities in south-central Colorado. From Cullers and Wobus (1986).

It is first important to identify a protolith for each sample. The discriminant function developed by Shaw and Kudo (1965) was employed to characterize the 16 amphibolite units for which INAA data exist. The function uses a combination of 8 trace element values (in ppm) to distinguish between ortho- and para-amphibolites:

$$X_1 = -2.69 \log Cr - 3.18 \log V - 1.25 \log Ni + 10.57 \log Co + 7.73 \log Sc + 7.54 \log Sr - 1.95 \log Ba - 1.99 \log Zr - 19.58$$

All of the samples produce a positive value, characterizing them as ortho-amphibolites. This identification of an igneous protolith for the amphibolites in this study allows for further interpretation of the units by methods appropriate for mafic igneous rocks.

As shown on the total alkalis vs. silica diagram (Le Bas et al, 1986) all of the amphibolite samples plot between 45-55 weight % SiO_2. There appears to be a distinction between amphibolites in the northern Wet Mountains, with relatively high alkalis, and those in the southern Front Range and Guffey area, which plot lower in the basalt and basaltic andesite fields. Some of the amphibolites in the Wet Mountains lie in the fields of trachy-basalt and basaltic trachy-andesite, as well as the high-alkali range of the basalt field. The samples collected in the Arkansas River Canyon cluster in the middle of the basalt field.

In this study, more emphasis has been placed on the discrimination of amphibolite samples by means of diagrams which plot minor and trace elements, specifically the high field strength elements and rare earth elements that are relatively immobile during metamorphic processes, than on those plotting major element compositions.

MORB-normalized spider diagrams (Pearce, 1983) show the distribution of trace elements in amphibolites from the southern Front Range and the northern Wet Mountains (Fig. 3). Amphibolites from both regions show an appreciable enrichment of large-ion lithophile elements and a slight depletion of high-field strength and rare-earth elements in relation to MORBs. Differences between the two regions can be seen when looking at the magnitude of enrichment/depletion for each. Rocks from the Wet Mountains are more enriched in the lithophile elements, many at 10-30 times the amount found in MORBs, than those in the Front Range, most of which are no more than 10 times greater. The Ta-Nb trough for rocks in the Front Range plots below the MORB-normalized value, while the rocks in the Wet Mountains show Ta-Nb values 2-3 times MORB. A few samples from both regions show noticeable Cr-depletion.

Discriminant diagrams that use minor and trace element compositions to determine tectonic settings are also used in this investigation to further characterize the amphibolites. When the samples are plotted on the Y/15-La/10-Nb/8 diagram (Fig.4, Cabanis and Lecolle, 1989) all fall within the field of volcanic arc basalts. There are no oceanic basalts and only a few values border the field of continental basalts. Most of the amphibolites of the southern Front Range plot in the field of volcanic arc tholeiites and in the overlap field, while some of those from the Wet Mountains and from west of Guffey plot as calc-alkali basalts. The use of the TiO_2-$MnO*10$-P_2O_5*10 diagram (Fig.5, Mullen, 1983) is consistent: all of the samples again plot as island arc volcanics, with those from the northern Wet Mountains concentrated within the calc-alkaline field, while the rest of the samples plot in both the calc-alkaline and tholeiitic fields.

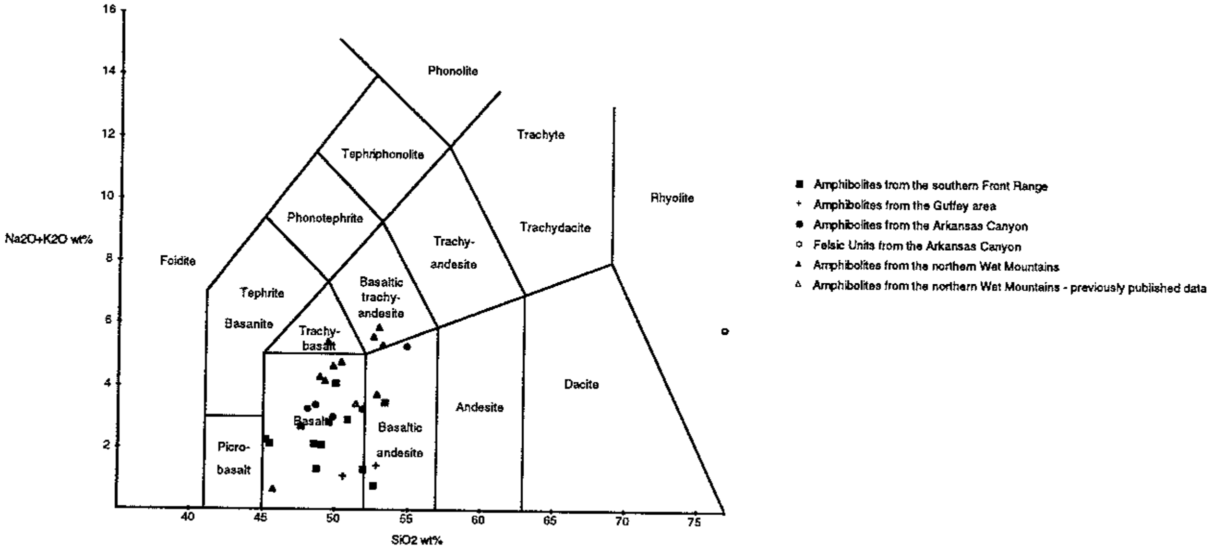


Fig.2. Total alkalis vs. silica classification showing distribution of amphibolites and felsic units. After Le Bas, et al. (1986). Unless otherwise noted, all plots show unpublished data from this project.

CONCLUSIONS

Geochemical analyses and trace-element discriminant diagrams indicate that the amphibolites sampled in this project are all volcanic arc basalts and basaltic andesites, some even trachy-basalts. There appears to be a distinction between rocks from the northern Wet Mountains more of which plot as calc-alkaline basalts, and the samples from the southern Front Range which plot more as island arc tholeiites. Amphibolites from the northern Wet Mountains appear to be part of a more mature, highly evolved arc setting than those to the north. They have more of a "continental" affinity, as seen by their enrichment in alkalis and large-ion lithophile elements: some of them even plot in a continental-margin arc setting on other discriminant diagrams. Amphibolites from the southern Front Range are generally more "primitive" than those to the south, with tholeiitic signatures. These points are compatible with the conclusions of previous investigations which suggest that the supracrustal rocks of south-central Colorado result from the collisions of successive volcanic arcs onto the North American craton. The southern Front Range and northern Wet Mountains could thus represent two arcs having different tectonic histories which are now juxtaposed along side each other.

Karlstrom, Bowring, and Conway (1987) are working to characterize the tectonic boundary separating the Yavapai and Mazatzal provinces in central Arizona, and to extend it further to the northeast. They have proposed that in central Colorado, the continuation of this boundary extends between the northern Wet Mountains and southern Front Range. While the geochemical data presented in this study point to a difference between amphibolites from the Front Range and the Wet Mountains, the exact location of this boundary may have to be defined in different terms.

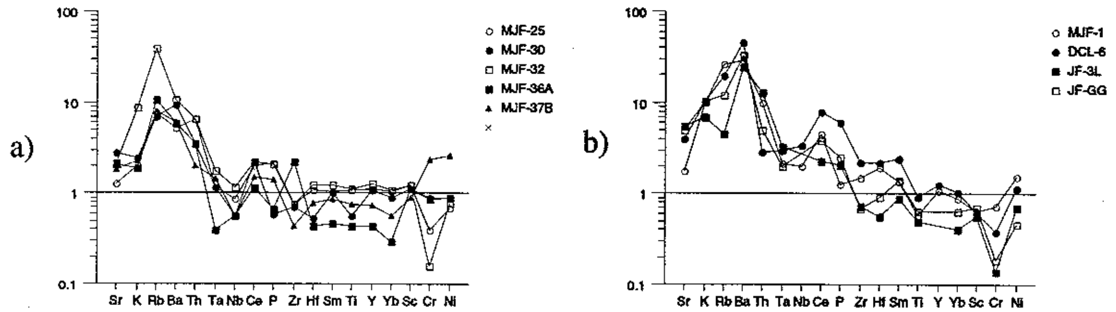


Fig.3. MORB-normalized trace element distributions for amphibolites in a) the southern Front Range and b) the northern Wet Mountains. Normalizing values from Pearce (1983).

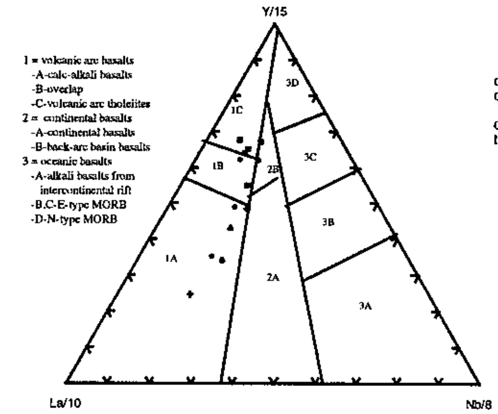


Fig.4. Y/15-La/10-Nb/8 diagram showing distribution of amphibolites. Fields after Cabanis and Lecolle (1989). Symbols as in figure 2.

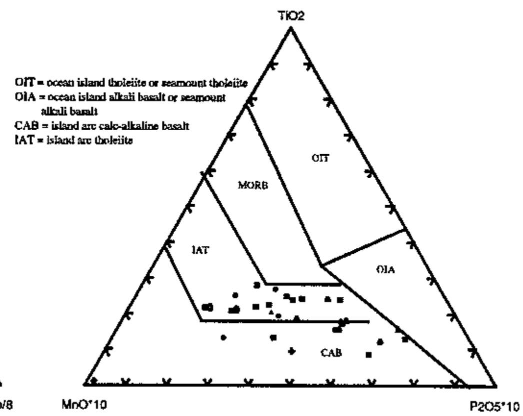


Fig.5. TiO2-MnO-P2O5 diagram after Mullen (1983) showing the distribution of amphibolites and felsic units. Symbols as in figure 2.

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