Crustal evolution and age relationships in a Proterozoic high grade gneiss terrane, Wet Mountains, Colorado

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INTRODUCTION

The ≈ 1.7 Ga rocks of the Wet Mountains in south central Colorado are a ductilely-deformed, high-grade gneiss terrane with a pervasive planar fabric. The purpose of this study is to characterize a six km^2 area of this terrane through detailed lithologic mapping and observation of structural style. Similar information from four other regions will be combined with work from this project to create a detailed composite map of this little understood, but important Proterozoic suite. In the study area, four major lithologic units and their cross-cutting relationships were defined. Sixty one samples were collected from these lithologies, thirty-one of which were thin sectioned for petrographic research and eleven geochemically analyzed. Detailed examination of the oldest of these units - the biotite-amphibole gneiss and grey, quartz rich gneiss - utilizing field relations, petrography, and geochemical analysis, aid in the definition of their possible protolith and provenance and the tectonic setting in which they originated.

LITHOLOGIC DESCRIPTIONS

The study area is bounded to the south by Route 96 which provides an ≈ 3 mile long section of road cut ideal for studying lithologies and defining age relationships. Combining map scale characterization of lithologic units with petrographic study provides a guideline by which to identify units in the field and in handsample.

Biotite-amphibole gneiss (BAG). This unit includes biotite, ± amphibole, plagioclase feldspar, quartz, alkali feldspar, ± opaques, ± zircon, and ± apatite and contains an augen end member with augen of plagioclase ranging from 1 mm to 1 cm. Unit thickness varies from millimeters in interlayered sequences to tens of meters and is everywhere foliated parallel to layering with mafic minerals primarily defining foliation. In some areas, interpreted as high strain zones, this unit forms boudins interlayered with both the grey, quartz rich gneiss and less commonly with the foliated granitoids. Compositional banding of the BAG is more common within these zones. In many places, the biotite-amphibole gneiss is visibly folded on outcrop scale in relatively open to isoclinal folds. The biotite-amphibole gneiss is cross-cut by successive events of intrusion but does not cross-cut any other lithology; in some places, xenoliths of BAG can be found within an intrusive granitoid. From these observations we conclude that BAG is part of the oldest lithologic package in the study area.

Quartz-biotite gneiss (QBG). The very resistant, grey, quartz-biotite gneiss contains quartz, plagioclase feldspar, alkali feldspar, biotite, ± chlorite, ± amphibole, ± sillimanite, ± apatite, and ± opaques. Homogeneous grain size and lack of pervasive compositional banding characterize this unit. Foliation is defined by alignment of mafic minerals and, in some places, by feldspar augen rich layers with augen ranging from 0.5 - 2 cm. This unit occurs mainly as tabular and folded concordant bodies on the order of 2 cm to ~10 meters thick and is, in some places, boudinaged. Shear bands are fairly common and define high strain zones in which segregation of mafic minerals creates characteristic, thin, attenuated, parallel layers. As with the BAG, the quartz-biotite gneiss is cross-cut by later intrusions, but nowhere crosscuts any other unit.

The lithologies of BAG and QBG are intimately interlayered due to the highly deformed character of the region, attributed to at least two and possibly three phases of deformation (Noblett, Cullers, and Bickford, 1987). In places, the lithologies are layered on such a fine scale that differentiation into individual units is impossible. Although the previous definitions are appropriate guidelines by which to classify individual units, in reality, the contact between these lithologies is commonly gradational and not distinct. Due to the intimate relationship of these lithologies and the observation that, as a package, neither unit cross-cuts any other lithology, both the BAG and the QBG can be defined, together, as the oldest assemblage in the project area. (Figure 1)

Amphibolite. The amphibolite contains amphibole, plagioclase, ± biotite, ± quartz, ± opaques. Grain size of the lithology varies from fine to course grained, in places attaining an almost gabbroic texture with characteristic salt and pepper coloring. In some areas, fine-grained, dark green calc-silicates occur in association with the amphibolite as well as a pyroxene bearing rock in a singular location. Amphibolite was rare in my area and is, therefore, not considered in the detailed petrographic and geochemical analysis.

Granitoids. Three distinct intrusive phases characterized as granitoids can be distinguished on the basis of both petrology and fabric. The following descriptions are given in order of emplacement as determined by cross-cutting relationships.

(G1) A granitoid containing quartz, moderately deformed alkali feldspar augen ranging in size from 2 mm to 3 cm, plagioclase, biotite, ± opaques, ± apatite. This unit is tentatively associated with the Boulder Creek intrusive phase (Wobus, 1996, personal communication) which is dated between 1705-1665 Ma (Bickford, et al., 1989). It is everywhere foliated with foliation defined by mafic minerals and, in some places, quartz ribbons. In regions of high strain, mineral segregation creates dramatic bands of biotite up to 0.5 cm thick, separating thicker quartzo-feldspathic layers. G1 is found in the north-west corner of the study area and lacks abundant outcrops.

(G2) A regionally dominant, commonly migmatitic, pink quartzo-feldspathic gneiss containing quartz, alkali feldspar, plagioclase feldspar, ± biotite, ± opaques, ± apatite with garnet-bearing and augen-rich phases. Compositional bands differentiating more plagioclase rich layers (white) from potassium rich layers (pink) are common and range from 1 - 3 cm but the lithology is, in places, massive with foliation grading from weak to pronounced and defined by mafic minerals. G2 occurs most commonly as concordant or subconcordant layers ranging in width from a few centimeters to 6 meters. G2 occurs also as large, discordant, clearly intrusive bodies that cut across all pre-existing lithologies. In some places, mafic mineral segregation creates 1-3 mm thick layers of biotite separated by 2-10 cm thick quartzo-feldspathic layers that, in places, take on the form of incipient augen; this is interpreted to be a high strain zone.

(G3) Unfoliated dikes and sills of similar composition to G2 but cross-cutting all lithologies including G2.

Figure 1. Intimately interlayered biotite-amphibole and quartz-biotite gneiss. Note boudinaged BAG layer and pencil for scale.

STRUCTURE

Due to the clearly apparent shear strain on outcrop scale in the form of augen and shear bands, we expected to see similar microsturctures in petrographic analysis. As these microsctructures are not evident, we attribute their disappearance to textural overprinting possibly from a regional reheating event that has destroyed most evidence for shear deformation in thin section. Deformation structures are still abundant, however, as most thin sections do display a majority of undulatory quartz and sutured grain boundaries due to strain induced grain boundary migration, as well as subgrains concentrated on grain boundaries. Subgrains in G2 comprise up to 40% of the slide. Within all samples of BAG and most samples of QBG and G2, biotite and opaque minerals are aligned parallel to foliation and mineral segregation is common in BAG, QBG, and G2, mimicking field relations in which quartzo-feldspathic layers alternate with more mafic layers. Feldspar grains in all samples are subhedral to anhedral with twinning apparent in places. Microcline comprises up to 80% of the alkali feldspar in G2 samples. Interstitial myrmekite is common in G2 as well. Very few examples of replacement can be observed with the exception of chlorite replacing biotite in samples of biotite-amphibole gneiss where the characteristic Berlin blue interference colors are observed. Modal biotite in the BAG ranges from 10-20% and pleochroism ranges from tan to bright red in samples of both the BAG and the quartz-biotite gneiss.

Poles to foliation in the study area define a moderately southwest dipping girdle that defines a moderately plunging, northeast trending fold axis.

GEOCHEMISTRY

Eleven samples chosen from the BAG and QBG were analyzed for major and trace element geochemistry using the XRF labs at the University of Massachusetts and Franklin and Marshall College. Two samples of the BAG and one sample of the QBG were also sent to the Radiation Center at Oregon State University for INAA analysis. Major element geochemistry reveals a range of 46 - 54% SiO_2 for the six BAG samples and 71 - 85% SiO_2 for the QBG with four of the five samples falling within the range 71 - 73%. The goals of this geochemical analysis are to characterize the oldest assemblage and to determine its possible protoliths. For this purpose, major element data are plotted on a total alkalies versus silica plot. In order that both an igneous and sedimentary protolith be considered, data from the eleven samples are shown on two types of diagrams, one that assumes a sedimentary protolith (Figure 2) and another that assumes an igneous origin (Figure 3). Results show that if the assemblage has an igneous protolith, the BAG plots within the trachybasalt, basaltic trachy-andesite, and basaltic andesite fields; the QBG plots within the field designated as rhyolite. If sedimentary, both the QBG and the BAG plot in the field designated as greywacke. The use of the TAS, however, is always suspect when dealing with metamorphic lithologies due to mobility of alkalies. Consequently, these diagrams cannot alone be used as reliable indicators of tru protolith composition. Further analysis of major and trace element geochemical data and incorporation of data from other regions mapped will provide a more comprehensive determination of provenance and lithologic characterization.

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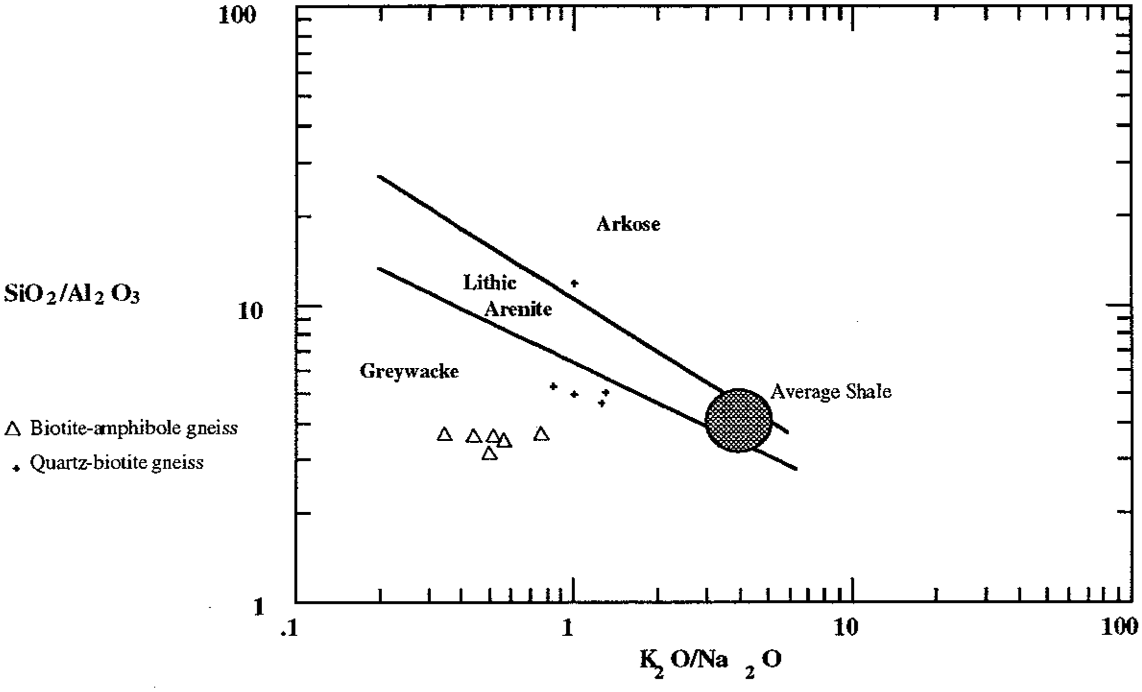

Figure 2. Major element ratio diagram showing potential protolith of BAG and QBG if their origin is sedimentary. (Fields modified from Creaser et al., 1997)

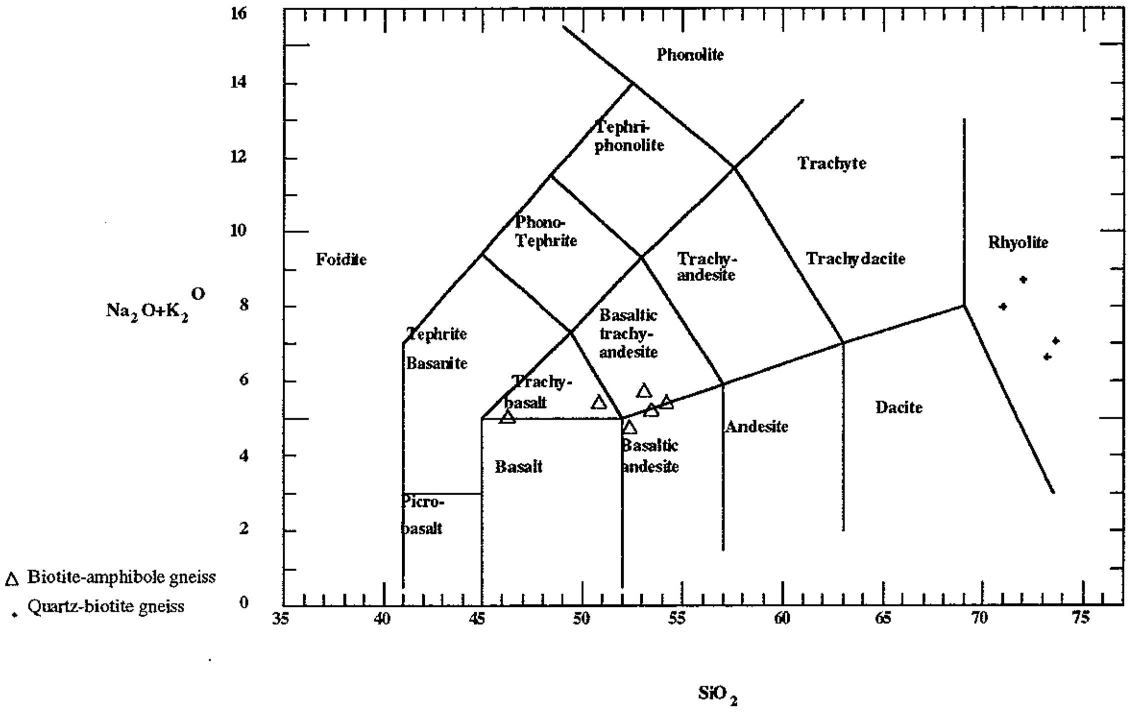

Figure 3. Total alkalies versus silica (TAS) diagram (modified from Rollinson, 1993) showing potential protolith for the BAG and QBG if their origin is igneous.