Structure and geochemistry of a portion of the Wet Mountains, Colorado

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INTRODUCTION

The Wet Mountains are a polydeformed intercalation of amphibolite grade gneisses and associated granitoids. Our study emphasized field-based mapping in five, semi-contiguous areas along the eastern flank of the Wet Mountains. The Wet Mountains are located within a 1,300 km. wide, southward younging belt of Proterozoic crust separated from the Archean Wyoming craton by the Cheyenne Belt, a relict suture. The rapid addition of this crust between 1.79-1.66 Ga (Reed *et al.*, 1987) may be explained by a continuous incorporation of arc systems generated in a southward jumping subduction zone or by episodic accretion of two tectonically distinct superterranes. Both crustal evolution models are proposed to explain the succession of lithologically distinct terranes evident in Colorado, New Mexico and Arizona. Locations of tectonic stitching have been difficult to trace, therefore recent work has relied on structural and geochemical discontinuities to delineate terrane boundaries. The Wet Mountains lie in proximity to a tentative terrane boundary but have received little detailed study. This project contributes structural and geochemical observations to assist the classification of the Wet Mountains in terms of previously recognized southwestern terranes.

FIELD LOCATION

The Wet Mountains form a secluded range in the San Isabel National Forest at the southern terminus of the Colorado Front Range. The Wet Mountain range is separated from the northern Colorado Front Range by the 1.0 Ga Pike's Peak batholith and from the Spanish Peaks to the south by the 1.362 Ga San Isabel batholith. Within the Wet Mountains, western 1.694+/-10 Ga granulite facies units are separated from eastern 1.720 Ga amphibolite facies units by the northwest striking Ilse shear zone. A petrologic, geochemical and structural study of amphibolite grade rocks was conducted between July 14 and August 9, 1996 over a 7mi2 field area. Topographic relief approaching 950 m frequently limited outcrop access and therefore required mapping by long traverses.

ANALYTICAL PROCEDURES

A total of 263 structural orientations including foliations, lineations, fold axial planes, hinge lines and fracture planes were recorded. Structural data were plotted and analyzed using the Stereonet computer application. Sixty-four oriented samples were collected for defined linear fabrics and representative or anomalous mineral assemblages. Thirty-four of the less weathered samples were cut for thin sections, then examined for mineralogy, metamorphic texture and kinematic indicators. Powders of 6 samples representing mafic gneiss lithologies were analyzed by x-ray fluorescence for major and trace element concentrations. To determine rare earth (REE) and high field strength element concentrations, instrumental neutron activation analysis was conducted on 3 of the 6 powders. Empirical data were cataloged on Microsoft Excel spreadsheets and analyzed using the MinPet computer application.

LITHOLOGY

The Wet Mountains were previously mapped as undifferentiated Precambrian gneiss. Keck field work distinguished 5 separate lithologies including, in order of abundance; pink, medium-grained gneissic granite; hornblende gneiss; biotite gneiss; pink, medium-grained granite and gray, coarse-grained, augen-rich granodiorite. Discussion is focused on the hornblende and biotite gneisses to avoid duplication of work done on amphibolitic and granitic units (Folley, Stiles, this volume). Hornblende and biotite gneisses are intimately associated in the field area with amount of gneisses increasing westward along the northern margin. Outcrops are minimally weathered, well foliated and display mafic mineral lineations.

PETROGRAPHY

Hornblende and biotite gneisses are distinguished according to mineral percentages and average crystal diameter. Relative to biotite gneiss (>2% hornblende, ~50% quartz), hornblende gneiss is typified by a greater percentage of hornblende (~40%) and a lesser amount of quartz (~30%). Biotite gneiss average grain size is slightly larger (1.625 mm) compared to predominately fine-grained hornblende gneisses (1.350-1.375 mm). Where present, average lengths of biotite and amphibole overprints are ~3.75 and ~1.75 mm respectively. Hornblende gneisses can be further separated into two sub-units based on the presence or absence of minor clinopyroxene. Mineral constituents of the clinopyroxene-bearing hornblende gneiss, hornblende gneiss and biotite gneiss include, in decreasing order of approximate abundance; quartz, plagioclase, hornblende, microcline, biotite, iron oxide and clinopyroxene with trace amounts of apatite, zircon, epidote, chlorite, sphene and allanite. For all thin sections, mafic mineral orientations define foliation, plagioclase albite twins and biotite laths are frequently warped or kinked and quartz crystals exhibit varying degrees of anealment including undulatory extinction, polygonization and ribboning. Clinopyroxene-bearing hornblende gneiss shows occasional hornblende twinning and biotite and iron oxide incursions along clinopyroxene basal section cleavage. Hornblende gneiss displays zircon radiation halos and poikilitic sphene around iron oxides. Biotite gneiss is typified by elongate to anhedral magnetite filling interstitial crystal space, myrmekitic intergrowth in addition to zircon radiation halos and poikilitic sphene around iron oxides. No kinematic indicators were discernible due to extensive recrystallization in thin section. Recrystalization relates to a minimum of one dynamic metamorphism followed by a static heating event.

DEFORMATIONAL AND METAMORPHIC HISTORY

In the study area, a polydeformed association of amphibolite-grade, migmatitic gneisses was intruded by three generations of granitoids. Intrusive events are inferred at ~1.7, ~1,4 and ~1.36 Ga. Amphibolite-grade metamorphism of presumably sedimentary protoliths resulted in widespread, plagioclase-rich, *in situ* migmatization. No relict sedimentary features are visible today. Axial fold plane orientations evidence isoclinal folding following metamorphism. Isoclinal folds are defined by dark and light gneissic layering (S_1). Axial surfaces of folds and aligned mafic minerals define the S_2 foliation evident in hand sample and thin section. A weak foliation arc is evident in the northwest quadrant of the field area. This arc is evidenced by a change in foliation orientation from east/west striking, moderately north dipping to northwest-striking planes with shallow, northeasterly dips (Fig 1). Corresponding downdip lineations support post-foliation folding (Fig 2) possibly related to shearing in the neighboring Newlin Creek shear

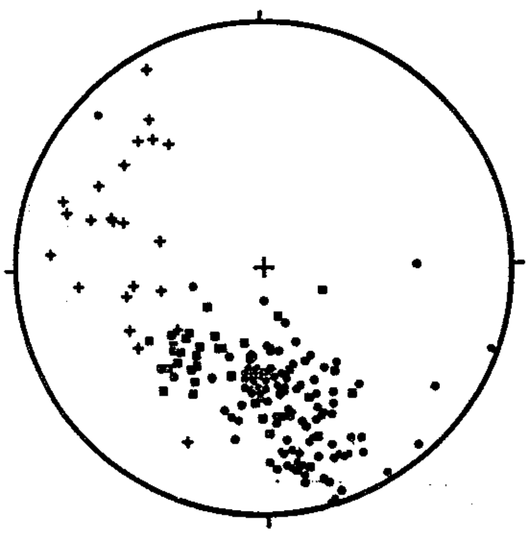

Figure 1: Equal area projection of poles to planes of hornblende gneiss, biotite gneiss, granodiorite and gneissic granite in the (•, n=112) southeastern, (□, n=23) westcentral and (+, n=39) northwestern field area quadrants.

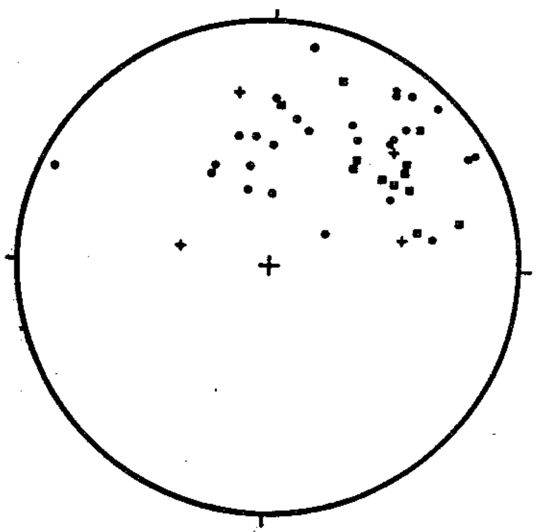

Figure 2: Equal area projection of hornblende gneiss and biotite gneiss mineral lineations in the (•, n=26) southeastern, (□, n=11) westcentral and (+, n=4) northwestern field area quadrants.

zone. Asymmetric augen in a felsic gneiss west of the field area show ductile, top to the southwest shear sense overprinted by brittle, top to the northeast shear sense. Concordant, foliated bodies of granodiorite tentatively correlated with the 1.7 Ga Boulder Creek granodiorite were intruded parallel to S_2 foliation. The granodiorite is foliated. Syn-kinematic injections of medium-grained granite are found discordant and concordant to preexisting foliation. Final tectonism foliated this granite creating high strain zones and boudinaged pegmatites. The minimum age of 1.44 Ga for the foliated granite is provided by an unfoliated granite sill date (Bickford *et al.*, 1989). Final intrusions are largely discordant dikes and sills of medium-grained granite and associated crosscutting pegmatite. Unaligned biotite forms a textural overprint which may have developed during a 1.4 Ga heating event identified in the northern Colorado Front Range (Selverstone, 1995).

GEOCHEMISTRY

Major and trace element concentrations in clinopyroxene-bearing hornblende gneiss, hornblende gneiss and biotite gneiss were analyzed for protolith and depositional environment. Si and Al weight percents ranged from 56-65% and 14-18% respectively. Hornblende gneisses are distinguished from biotite gneisses by lower SiO_2 and Al_2O_3 contents. North-American-Shale-Composite-normalized REE plots (Fig 3). Biotite and hornblende gneiss plot in subgraywacke and arkosic fields respectively on Al_2O_3/ Fe_2O_{3T} / SiO_2 ternary diagrams (Fig 4). Fe_2O_{3T} /MgO/ (Na_2O+K_2O) and (Na_2O+K_2O)/ SiO_2 plots imply that

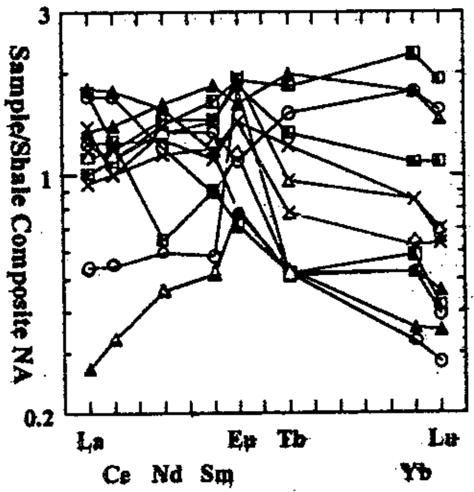

Figure 3: North American Shale Composite normalized REE plot.

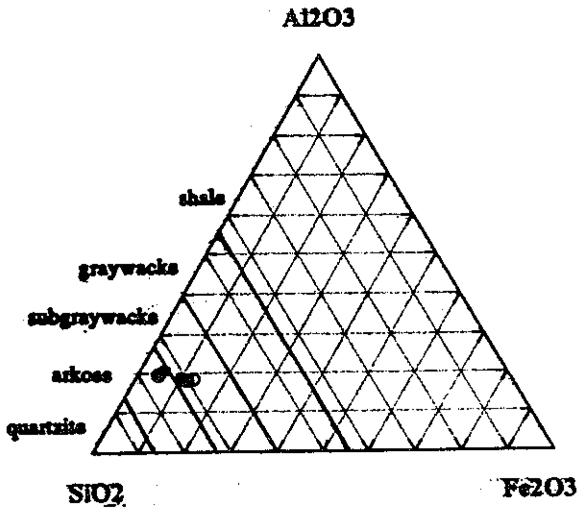

Figure 4: Al_2O_3/Fe_2O_{3T}/SiO_2 ternary diagram. Fields taken from Moore and Dennen, 1970.

possible volcanic contributions to subgraywacke units might originate from mafic, calc- to sub-alkaline sources. Tectonic setting discrimination trends indicate continental settings. TiO_2/($MgO+Fe_2O_{3T}$) variation diagrams suggest a continental arc setting for biotite gneisses and place hornblende gneisses in an active continental margin/island arc setting. Possible volcanic contributions to subgraywacke units show continental arc/continental rift basalt signatures as shown by (TiO_2/10)/ (P_2O_5*10)/(MnO*10) and Th/Hf diagrams.

DISCUSSION

Correlating the Wet Mountains with other recognized southwestern terranes is complicated by a number of factors. Contact between the Wet Mountains and the Idaho Springs formation in the northern Colorado Front Range is obscured by the Pike's Peak batholith. The San Isabel batholith separates the Wet Mountains from the southern Mazatzal superterrane (Karlstrom *et al.*, 1987) and Cenozoic sediments conceal contacts with central Colorado volcanics and volcanosedimentary terranes in Kansas. Thus, it is difficult to classify Proterozoic contacts as depositional or structural. Additionally, amphibolite-facies metamorphism has effectively erased primary structures and textures that might have confirmed geochemical determination of protoliths.

Despite these complications, the age, protoliths, structure and depositional environment of the Wet Mountains are best correlated with the Idaho Springs formation in the northern Front Range, Colorado. The 1.713+/-30 Ga (Peterman *et al.*, 1968) Idaho Springs paragneiss age is similar to an unpublished 1.720 Ga date on isoclinally folded, granitic gneiss in the Wet Mountains. Protoliths in both areas are pelitic. A more ductile deformation style in the Wet Mountains compared to the Idaho Springs formation could be attributed to present day exposure of different crustal depths in the two areas. Both areas have experienced two folding events; primary, widespread ductile folding followed by localized, shear related folding. Tighter, more ductile folding in the Wet Mountains compared to less ductile, open folds and cataclasis in the Idaho Springs formation would be expected if the Wet Mountains represented a deeper equivalent of the Idaho Springs formation proximal to an accretion or subduction zone.

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