Petrology and geochemistry of granite in the northern Wet Mountains, south-central Colorado

Layla Stiles
Department of Geology, Trinity University, 715 Stadium Dr., San Antonio, TX 78212
Faculty Sponsor: Diane R. Smith, Trinity University

INTRODUCTION

Proterozoic rocks in the northern Wet Mountains of south-central Colorado are largely amphibolite-grade gneisses and schists intruded by deformed and undeformed granite bodies, ranging from dikes several meters thick to sills several hundred meters thick. The members of this project developed a working stratigraphy for the rocks in the northern Wet Mountains during the summer field studies. Four granite types were defined based on degree of deformation, cross-cutting relations with host-rocks, and petrographic character. Quackenbush (this volume) presents a composite map of the study area, illustrating the intrusive relations described below.

The purpose of this project is to: 1) characterize each of the granite units based on field relationships, petrography, and geochemistry, 2) identify petrographic and geochemical parameters that serve to distinguish among the four identified units, 3) compare the petrologic and geochemical features of these granites with Proterozoic granites elsewhere in the Wet Mountains and Colorado, and 4) evaluate the petrogenesis of the granitic magmas.

FIELD RELATIONSHIPS

The host rocks in the northern Wet Mountains consist of isoclinally folded black gneisses, called the Black Gneiss Association (BGA). The oldest granitic unit, G0, is the only one in the field area that predates deformation because it is isoclinally folded along with BGA. A zircon U-Pb age date has been obtained for this unit and an early report on its age is 1720 Ga (Noblett, pers. comm.).

The next unit, G1, is an augen gneiss with relatively homogeneous grain size and mineral distribution. Foliation in G1 is concordant with foliation in BGA, and G1 intrudes BGA as medium sized dikes (up to several meters thick). Based on outcrop appearance, G1 is tentatively associated with the Boulder Creek Granodiorite; if so, emplacement between 1705 Ma and 1665 Ma is implied (Bickford et al., 1989).

The next unit was originally separated into two different units, G2 and G3. Further field examination showed that G3 is merely a high strain equivalent of G2, thus G2 and G3 are here considered together as G2/3. G2/3 comprises the largest volume of granites in the field area, with large sills (up to several km^2 in areal extent) outcropping throughout the study area. Foliation in G2/3 is semi-concordant with foliation in BGA, and contacts are not sharp. Rather, there appear to be blocks of BGA "floating" in a matrix of G2/3, and the contacts between G2/3 and BGA are diffuse and indistinct. Inclusions of G1-looking material occur within G2/3.

Finally, G4 is the youngest unit in the field area. It is discordant, outcropping as cross-cutting bodies (up to tens of meters thick) with sharp contacts. It has no fabric, and is associated with aplite and pegmatite dikes.

PETROGRAPHY

A total of 23 thin sections of representative samples from the four granitic units were examined. Textures were documented and point counts (at least 1000 per section) were conducted. The petrographic analyses reveal that mineralogy and textures are fairly uniform throughout all the units. All samples are leucocratic, with color index ranging from 1 to 11. Dominant feldspar phases are orthoclase and perthitic microcline, with only minor amounts of plagioclase feldspar. Biotite is the primary ferromagnesian mineral, but occurs in abundances < 5 vol % in these rocks. Figure 1 illustrates modal analyses on the IUGS classification scheme. According to this classification, rock types include alkali feldspar granite and granite. However, the alkali feldspars may be fairly albite-rich, as suggested by major element chemistry (see Figure 2 and discussion below). Accessory minerals found in all units include zircon, apatite, and opaque minerals. Accessory muscovite, garnet, allanite, and sphene are found only in some sections of G2/3 and G4 samples, and amphibole occurs only in G1 samples.

Most samples are fairly equigranular, with grain sizes mostly in the range of 1 to 3 mm. Feldspar augen in G1 samples prove to be microcline granoblasts (up to 8 mm) wrapped by fine mica flakes. Microtextures found in all units include antiperthite, myrmekite, and feldspar poikiloblasts with inclusions of quartz. G1 is the only unit that has microtextures indicating cataclasis of quartz and feldspar.

GEOCHEMISTRY

Twenty-one granite samples, representing the four units from many different localities throughout the study area, were analyzed for major elements and trace elements via ICP methods at the University of Houston. Additional trace element analyses were obtained for fifteen samples by INAA methods at Oregon State University.

Most of the granites are peraluminous to weakly metaluminous. Chemically, they are granitic in composition, plotting within the granite field of the Q-Or-(Ab+An) normative ternary diagram (Figure 2). They are rather siliceous (up to 78% SiO_2), alkali-rich (up to 7% K_2O and 4% Na_2O), and have high FeO/(FeO + MgO) ratios (0.7 to 0.9) (Figure 3).

These granites exhibit relatively high concentrations of trace elements that fall within the ranges for Proterozoic anorogenic granites compiled by Anderson (1983). In addition, wide variations are observed for Sr (75 to 375 ppm), Ba (400 to 2600 ppm), Rb (50 to 225 ppm), and Th (5 to 32 ppm). When the granite suite is examined as a whole, several types of REE-chondrite normalized patterns can be distinguished on the basis of LREE abundance and La/Yb ratios (Figure 4). However, these patterns do not serve to distinguish among the four granite units. For example, G2/3 exhibits all four REE pattern types (Figure 4). Pearce et al. (1984) discrimination diagrams show that most of these granites plot in the volcanic arc granite field. With increasing silica, Al_2O_3, MgO, Fe_2O_3, CaO, Sr, Ba, La, show broadly decreasing abundances, but other elements do not exhibit any clear differentiation trends.

Neither major nor trace elements allow distinctions among the four granite units. Wide variation is shown both within individual units, as well as among units (Figure 3). As an example, for samples of G1 with ~73% SiO_2 variations include K_2O from 3.5% to 5.5%, Na_2O from 2.1% to 3.9%, Rb from 100 to 225 ppm, and Sr from 125 to 325 ppm.

PETROGENESIS

The lack of coeval mafic to intermediate intrusions in the study area indicates that anatexis of lower crust is a reasonable petrogenetic model for the granite bodies in the northern Wet Mountains. Cullers et al. (1993) used partial melting models of tonalitic to granodioritic crust to produce petrologically and geochemically similar granite elsewhere in the Wet Mountains. Similarly, Roberts and Clemens (1993) point out that the origin of high-K_2O granites via anatexis requires intermediate crustal compositions.

Crustal melting models were tested to evaluate the origin of the granites in this study. Partial melting trends were calculated with the batch partial melting equation [$C_l = C_o/(D+F(1-D))$]. The focus is on Ba and Sr because in granitic systems, the distribution of these elements is believed to be controlled by major phases and not accessory minerals (e.g. in contrast to REE which can be strongly controlled by apatite and/or allanite). Estimates of crustal source compositions (C_o) were obtained from Rudnick and Presper (1990) who give the mean and median of hundreds of analyses of intermediate lower crust. A wide range of bulk distribution coefficients (D) for Sr and Ba were selected based upon inferred crustal mineralogy. Figure 5 illustrates calculated Sr and Ba contents in partial melts (C_l), with results for F=0.1 to 0.3 highlighted (i.e., 10% to 30% melting). The results show that the heterogeneity in these granites can be produced using a reasonable range of bulk D's, source compositions, and degrees of partial melting. The high Ba contents in some samples require low D_{Ba} (0.05), and some granites (i.e., those with the highest Sr contents) may be melts from sources not represented by the Rudnick and Presper (1990) estimates.

However, fractional crystallization may account for some of the variations observed in the granites. Fractional crystallization trends were calculated from the Rayleigh fractional crystallization equation [$C_l = C_o*F^{\wedge}(D-1)$]. D_{Ba} and D_{Sr} values were chosen based on crystallization assemblages that are inferred to be feldspar rich. The fractional crystallization vector in Figure 5 indicates that variation within the granite suite can in part be attributed to feldspar fractionation.

CONCLUSION

These granites show similar petrographic and geochemical affinities to Proterozoic anorogenic granites in the Wet Mountains and elsewhere. Granite units in the study area can be distinguished from one another based upon convincing field evidence. Because wide petrographic and geochemical variation is found both within as well as among units, petrography and geochemistry do not distinguish the units. Compositional heterogeneity in granite units can be attributed to anatexis involving a variety of crustal source compositions, mineralogy, and degrees of melting. It is also possible that some magmas were affected by feldspar fractionation.

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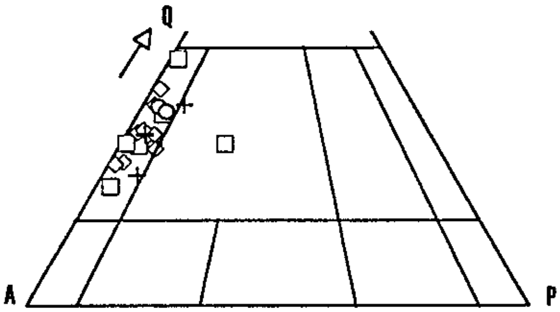

Figure 1. Modal compositions of granites plotted on IUGS classification system.

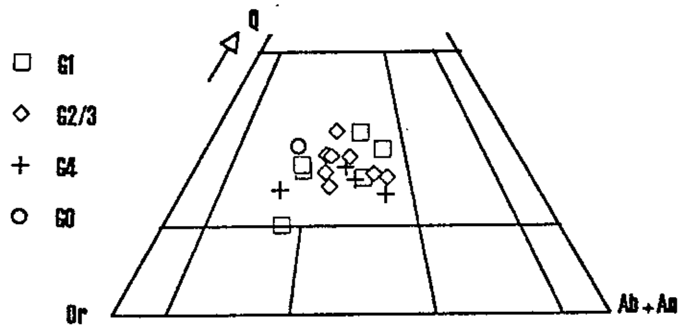

Figure 2. Normative compositions of granites plotted on IUGS classification system.

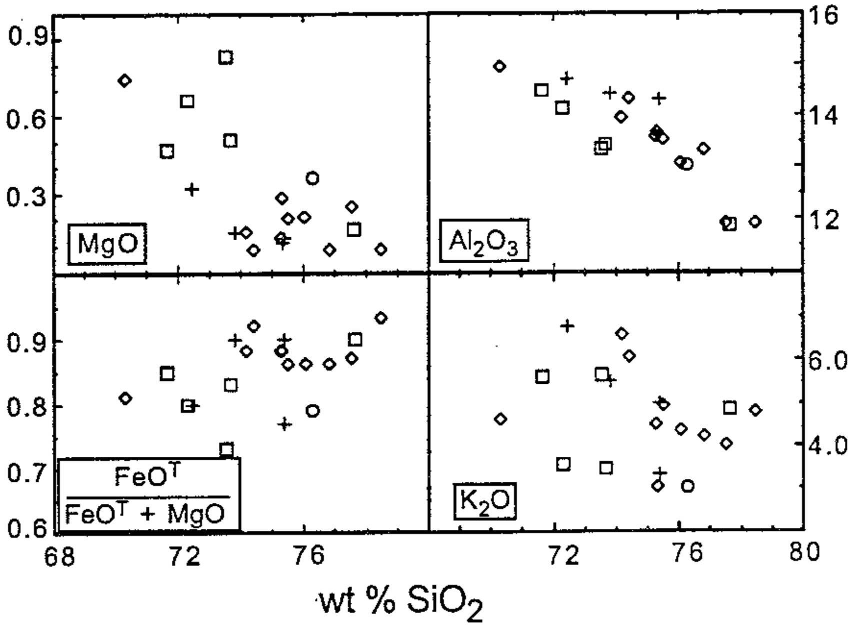

Figure 3. Harker diagrams of selected major elements (symbols as in Figures 1 and 2).

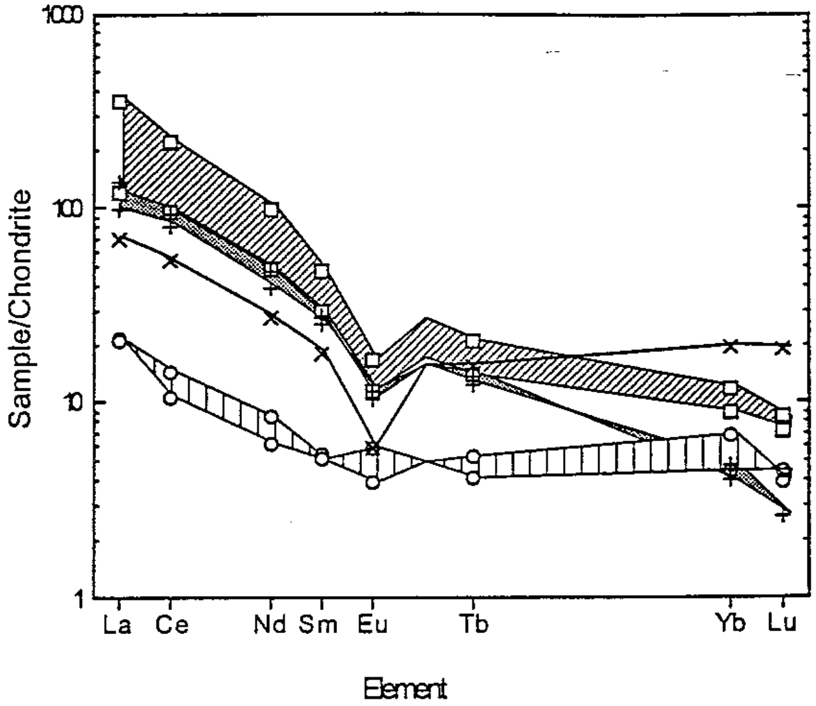

Figure 4. REE patterns for G2/3 samples only.

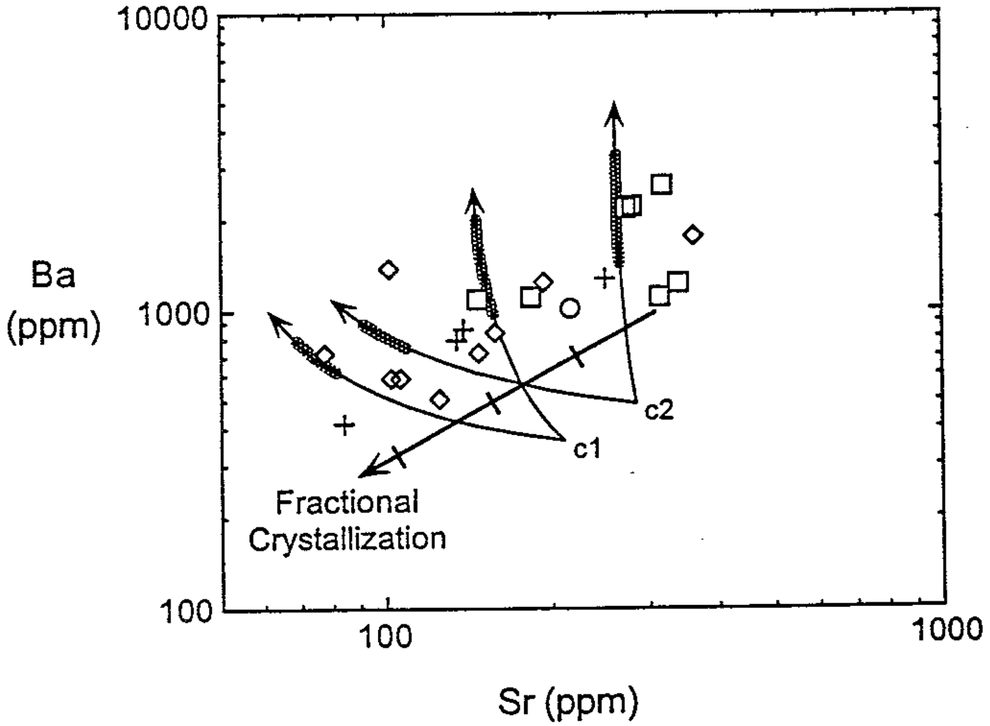

Figure 5. Log Ba vs. Log Sr contents in G0 through G4 (symbols as in Figure 1). Curves show calculated trends for partial melting of intermediate crust (c1=mean and c2=median of analyses from Rudnick and Presper, 1990). Highlighted portions along curves represent 10% to 30% partial melting. D_{Ba} and D_{Sr} varied from 0.1 to 0.4 and from 1.5 to 3.3 respectively. Fractional crystallization vector shown for D_{Ba} and D_{Sr} each equaling 4. Tick marks indicate increments of 10% crystallization.