Ductile deformation in the Tobacco Root Mountains of Southwest Montana

Daniel Blednick
Department of Geology, Amherst College, Amherst, MA 01002-5000
Faculty Sponser: Tekla Harms, Amherst College

INTRODUCTION

The Spuhler Peak Metamorphic Suite (SPMS) lies between the Indian Creek Metamorphic Suite (ICMS) and the Pony-Middle Mountain Metamorphic Suite (PMMMS) in the Tobacco Root Mountains of southwest Montana. The SPMS is a distinct lothologic assemblage consisting of amphibolite, horneblende-plagioclase gneiss, gedrite-garnet-plagioclase gneiss, sillimanite schist, and quartzite (Burger et. al., this volume). The rocks of the PMMMS and ICMS vary greatly from the SPMS rocks as they are dominated by quartzofeldspathic gneiss and marbles, with much lesser amounts of amphibolite. The contact between the SPMS and the gneisses of the ICMS and PMMMS is currently folded in a km-scale, possibly non-cylindrical fold (Burger et. al., this volume). Burger (1969) hypothesized that the contact may have originally been a regional scale fault. The fault model for the contact explains the juxtaposition of the contrasting lithologic assemblages of the SPMS and the ICMS and PMMMS. In contrast, Gillmeister (1971) hypothesized that the contact was originated as a depositional contact. This distinction is critical to the tectonic and metamorphic history of the Tobacco Root Mountains. Accordingly, it is necessary to test these interpretations of the SPMS/ICMS-PMMMS contact by determining if shear occurred along this contact; and, if so, identifying the direction and sense of that shear.

METHODS

In this study, 40 oriented samples were taken from 30 outcrops of quartz rich rocks at the SPMS contact and up to 0.5 km from the contact on either side. The samples consisted primarily of fuchsitic quartzite from the SPMS and quartzofeldspathic gneiss from the ICMS and PMMMS. Microscopic analysis of quartz deformation fabrics requires a large number of grains to be analyzed in thin section, thus requiring the selection of fine grained samples. In order to sample a broad range of fine grained, quartz-rich rock, samples were taken from many points along the SPMS contact. Locations were chosen not only from the nose of the fold, as in the Kranenberg (1996) study, but also down both limbs of the fold. This enabled comparison between the deformed rocks of the nose and the deformed rocks along each limb. Each sample was cut to produce two mutually perpendicular thin sections: both perpendicular to foliation, one parallel to lineation.

In order to provide sufficient evidence for the strain history of these rocks, both textural analysis of samples in thin section as well as quartz C-axis analysis were completed. Initial petrographic analysis of these samples was followed by C-axis analysis in which the orientations of quartz C-axes were measured using a universal stage to determine if lattice preferred orientation (LPO) exists. The data were then plotted on a lower hemisphere projection and interpreted.

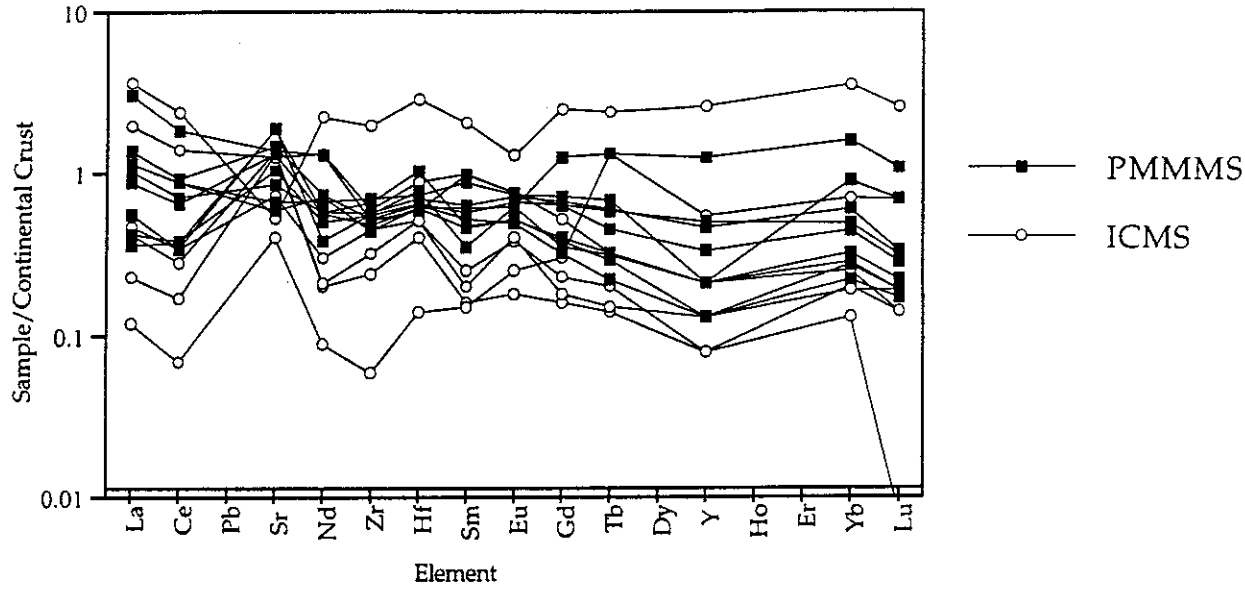


Figure 1. Rare earth element spider plot for samples of the PMMMS and ICMS metamorphic assemblages.

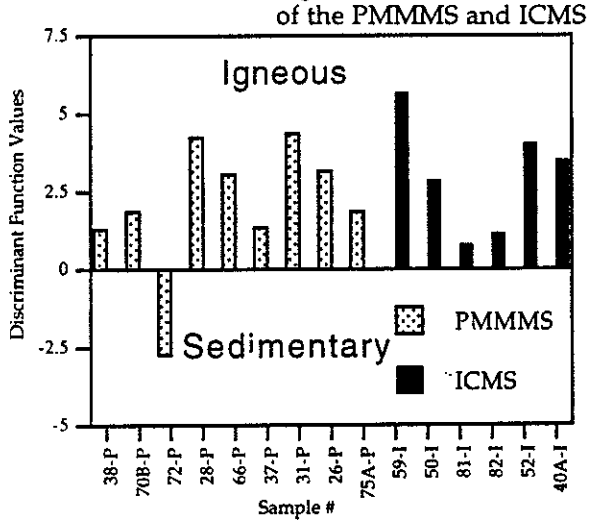


Figure 2. Discrimination diagram based on Shaw (1971), indicating that most of the samples of the PMMMS and ICMS assemblages plot as igneous.

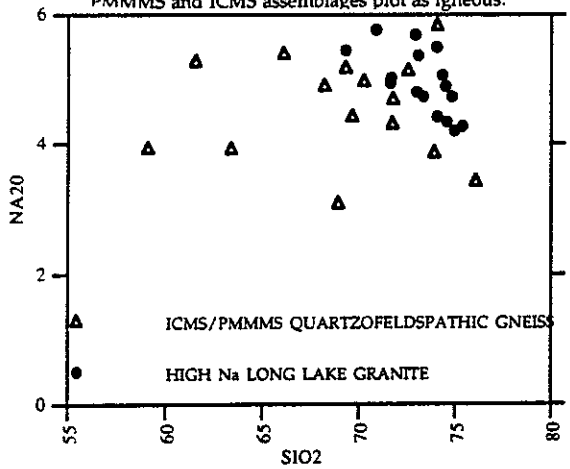


Figure 4. Comparison of PMMMS and ICMS assemblages to high Na Long Lake Granite from the nearby Beartooth Mountains (Mogk,1988)

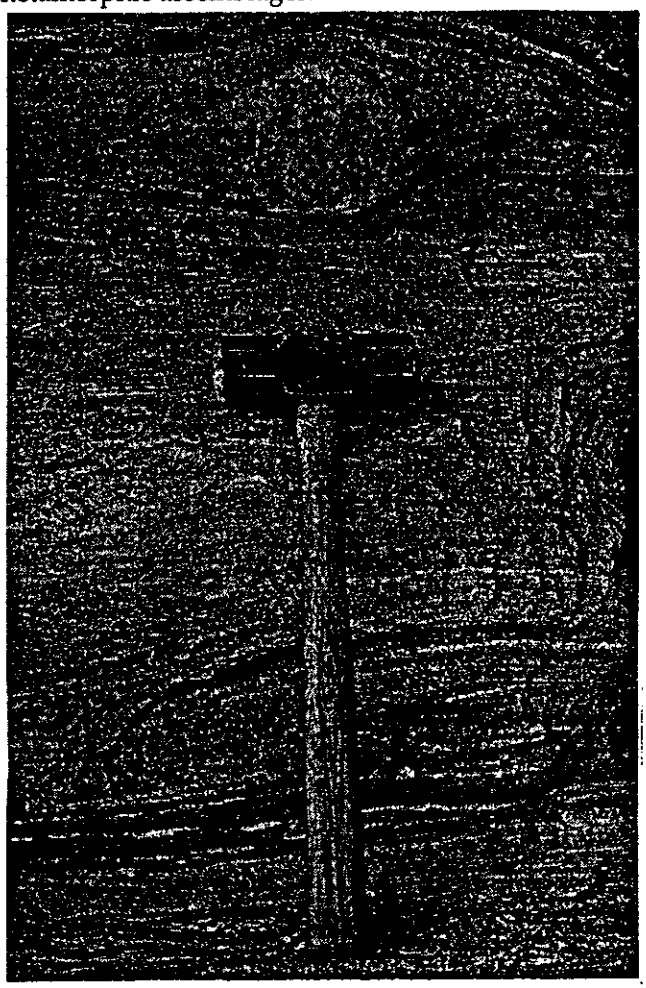


Figure 3. Large potassium feldspar porpyroblast found in the ICMS assemblage representative of those found throughout thePMMMS and ICMS assemblages.

QUARTZ MICROFABRICS

Quartz grains of varying size and shape occur within a single sample. Grain sizes range from <1mm to 5mm. The larger grains are elongate and have some undalose extinction and deformation lamellae. These elongate grains have complex, polygonal 120° grain boundaries with a high surface area to volume ratio, and are decorated along their boundaries with small, optically distinct, polygonal quartz grains. We interpret these elongate irregular shapes, which are present in rocks from all three units, to be inherited from originally strongly serrate ribbon grains (and subgrains). They record a history of dynamic recrystallization during simple shear followed by static thermal annealing. There is also a smaller percentage of samples that are dominated by more typical, equigranular metamorphic quartz grains.

QUARTZ LATTICE PREFERRED ORIENTATION

C-axis measurements were plotted on a lower hemisphere projection and rotated with respect to regional lineations. Contour density plots support the hypothesis that penetrative simple shear occurred along the contact. Determining the orientation of the c-axis of quartz grains extends the work of Kranenberg (1996) who recovered asymmetric cross girdle patterns from C-axis analyses of rocks from the Sunrise Lake region of the ICMS. His patterns are consistent with a hypothesis of penetrative simple shear along the contact. Of the six samples plotted by Kranenberg, two produced interpretable results. This study has yielded plots with a similar variability, and some plots can be initially interpreted as having a cross girdle pattern. However, this study uses samples from a broader range of sample locations than those considered in the Kranenberg study. However, other plots from this study did not produce recognizable cross girdle patterns, but rather small circle patterns opening the possibility of pure shear flattening along some parts of the contact.

CONCLUSIONS

Both the quartz microfabric and C-axis data, taken together, indicate that shear has indeed occurred along the contact. Analysis of these C-axis patterns and microfabrics supports the conclusions of Kranenberg (1996) and Burger (1969) that the contact represents a fault rather than a depositional contact.

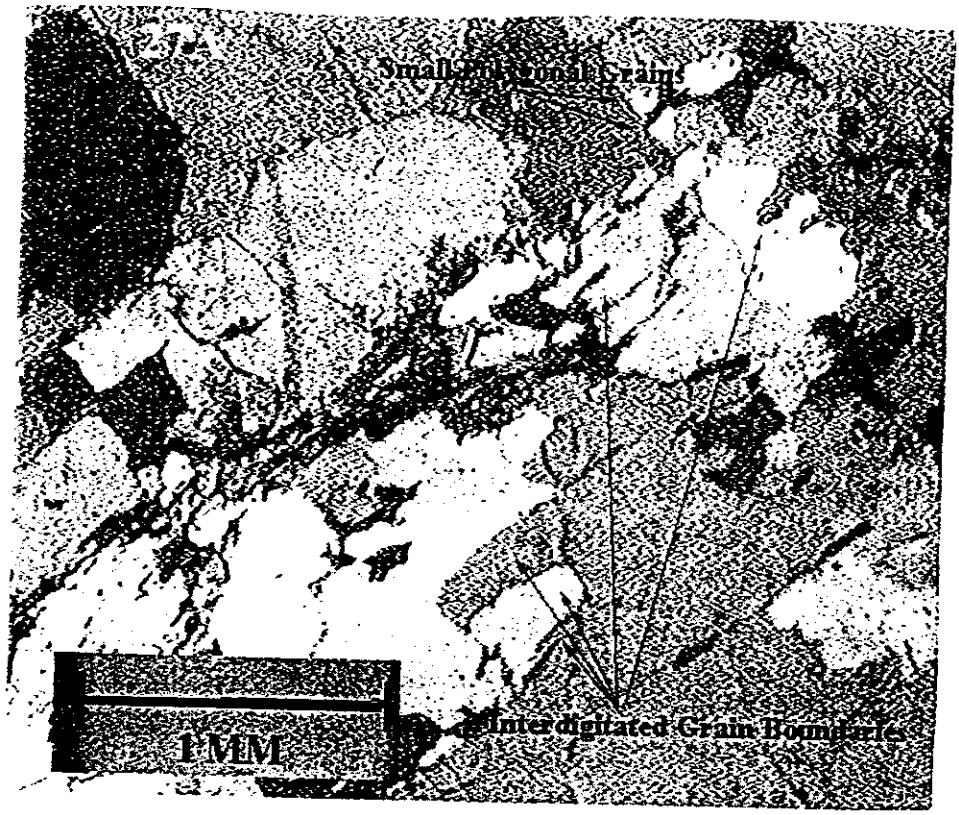
REFERENCES CITED

Burger, H.R., 1969, Structural evolution of the southwestern Tobacco Root Mountains, Montana: Geological Society of America Bulletin, v.80, p.1329-1342.

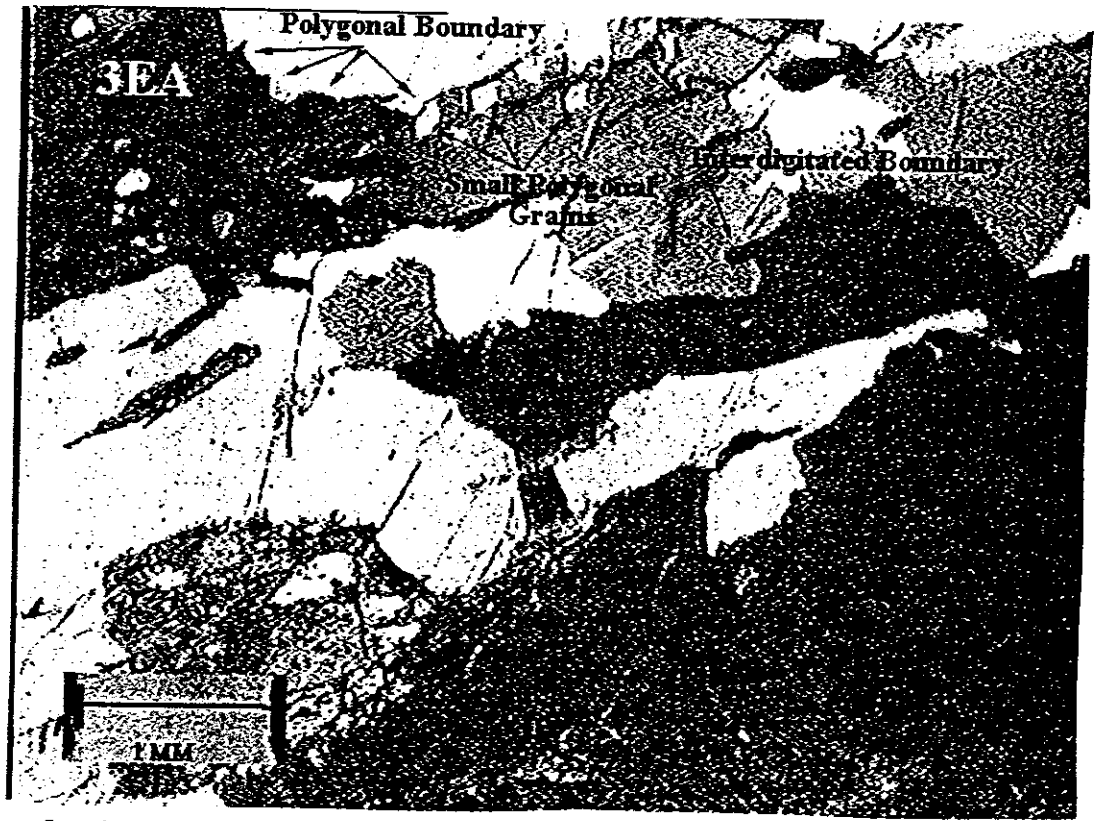
Gillmeister, N.M., 1971, Petrology of Precambrian rocks in the central Tobacco Root Mountains, Madison County, Montana [Ph.D. thesis]:Bloomington, Indiana, Indiana University, p.289.

Burger et. al., 1998, (This volume).

Kranenberg, S, 1996, Structural Relationships among metamorphic suites in the Tobacco Root Mountains of Southwestern Montana: Ninth Keck Research Symposium in Geology, p.102-106.

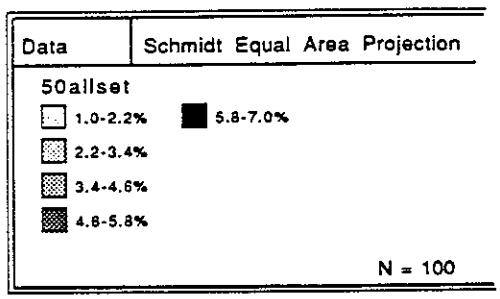


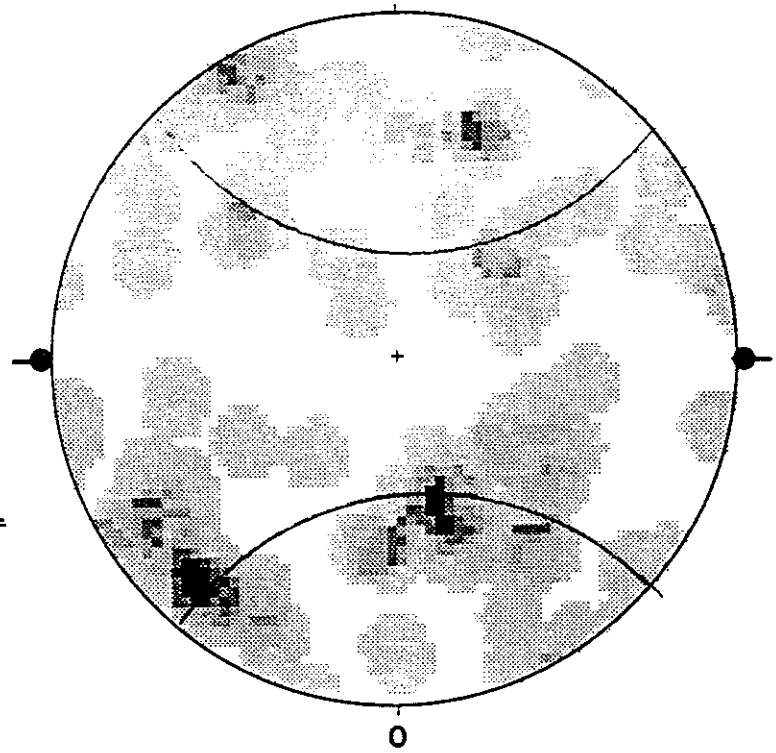
Sample **27A** is a quartzofeldspathic gneiss from the PMMMS/SPMS contact. The photomicrograph was taken under crossed nichols.



Sample **3EA** is a highly deformed quartzite from the Sunrise Lake region of the PMMMS. The photomicrograph was taken under crossed nichols.

DGB 50

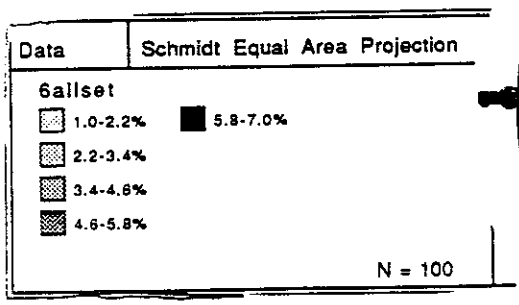


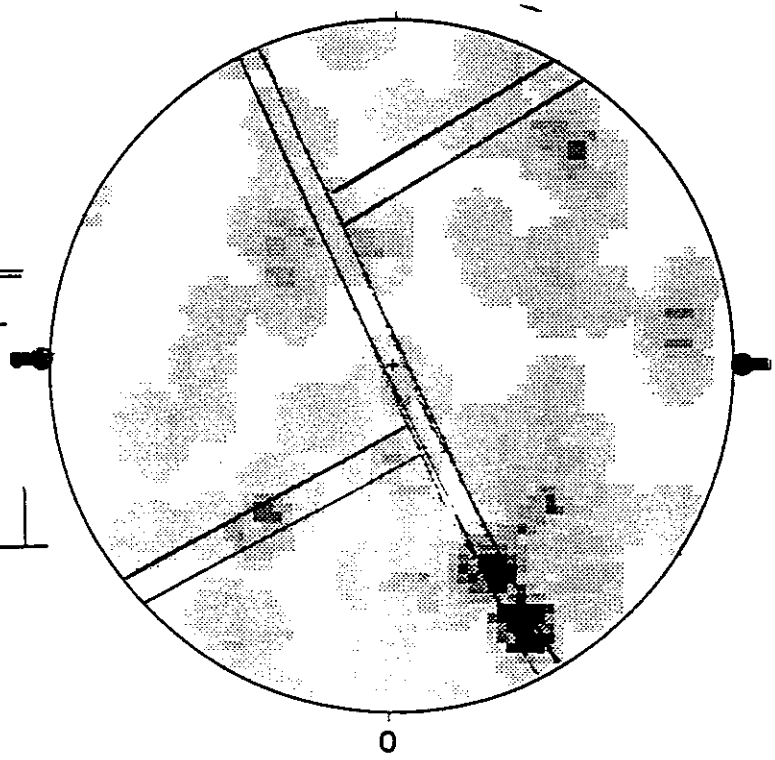


Sample **DGB50** is a quartzofeldspathic gneiss from the ICMS at Thompson Ridge. The plot of quartz C-axis data is difficult to interpret in terms of penetrative simple shear. It may indicate pure shear flattening; a preliminary interpretation is shown. Lineation is parallel to the E/W axis.

Sample **SRK6** is a quartzofeldspathic gneiss from the ICMS at Mustard Pass. It is possible to make a preliminary interpretation of simple shear based on the presence of a weak crossed girdle pattern in the quartz C-axis data plot. Lineation is parallel to the E/W axis.

SRK 6





Geothermobarometry of metamorphosed mafic dikes and sills, Tobacco Root Mountains, southwestern Montana

Sarah Carmichael
Department of Geology, Clark Science Center, Smith College, Northampton, MA 01063-0100
Faculty sponsor: John Brady, Smith College

INTRODUCTION

The Archean metamorphic rocks of the Tobacco Roots Mountains can be divided into three main lithologic units: the Indian Creek Metamorphic Suite (ICMS), the Pony-Middle Mountain Metamorphic Suite (PMMMS), and the Spuhler Peak Metamorphic Suite (SPMS). The SPMS primarily consists of metamorphosed mafic volcanic rocks of an oceanic crustal origin with minor metasediments, while the PMMMS and ICMS contain rhyolitic (Abeyta, this volume) to basaltic metaigneous rocks and metasediments. At least two generations of metamorphosed mafic dikes and sills (MMDS) cross-cut foliation in the ICMS and PMMMS but are not present in the SPMS, although they are present within one meter of it. This uneven distribution of MMDS suggests that the SPMS was juxtaposed with the ICMS and PMMMS after the intrusion of the MMDS.

All units exhibit upper amphibolite to lower granulite grade metamorphism, but several metamorphic events have affected the area. Although the MMDS cross-cut foliation and folds in the ICMS and PMMMS, many of these MMDS are folded themselves. Therefore, at least one metamorphic event must have occured after their intrusion. Owen (1996) has determined that the contact between the SPMS and the ICMS/PMMMS is folded as well, and that the orientation of this contact fold is concordant with the orientations of folds in the MMDS and folds in the ICMS and PMMMS. The similarities of these fold orientations indicates that they were folded together during a period of metamorphism, possibly at around 1.8 Ga (Brady et al., 1994). This study was undertaken in the hope that the pressures and temperatures recorded in the MMDS in the Tobacco Root Mountains would clarify the metamorphic history of the area, and the tectonic processes that affected it.

FIELD OBSERVATIONS

Sixty-six samples of MMDS were collected from a variety of locations across the ICMS and the PMMMS. The MMDS were identified by their gray to black color on fresh surfaces, blocky and brown weathering pattern, fine grain size (0.5 to 2 mm), and cross-cutting relationships with surrounding rock units. Since the hornblende gneiss present in the ICMS and PMMMS generally looked similar to MMDS, cross-cutting relationships with the country rock were the primary criteria used to distinguish between these two rock types.

Samples displayed a variety of visible textures, most noteably a decrease in grain size from the centers of the dikes to the margins of the dikes. In many MMDS there was also a change in mineralogy as well, with biotite and/or amphibole abundant on the margins of the dikes and with garnet and clinopyroxene more prominent in the centers. The abundance of amphibole on the margins of the dikes can be explained by the limited availability of water during metamorphism. Vitaliano et al. (1979) describe MMDS as having sharp contacts against the country rock, with chill margins that indicate emplacement into cool rocks during or after an earlier metamorphic event. Since MMDS do not have igneous mineral assemblages, finer grain sizes on the margins of the MMDS cannot accurately be called chill margins, although they might have been influenced by relict igneous textures.

Foliation in MMDS is parallel to the dike walls rather than to the foliation of the country rock, although many MMDS have a foliation that is nearly concordant to the foliation of the country rock. In some areas, such as Sunrise Basin and the Nicholson Mine region, younger MMDS cross-cut older MMDS. Generally, the younger MMDS have finer grain sizes, while the older MMDS have a somewhat coarser texture with more compositional banding. In many cases, both sets of MMDS have garnets; therefore, they both underwent some sort of metamorphism after the younger dike was emplaced.

PETROGRAPHY

MMDS commonly contain garnet, hornblende, clinopyroxene, plagioclase, quartz, ilmenite, and biotite. The relative amounts of these minerals vary between separate dikes and also across the margins and interiors of individual dikes. Generally, the margins of each dike or sill are richer in hornblende and biotite and depleted in garnet