The petrology and geothermobarometry of the Indian Creek Metamorphic Suite and the Spuhler Peak Metamorphic Suite, Tobacco Root Mountains, southwestern Montana

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INTRODUCTION

The Tobacco Root Mountains, located in the southwestern Montana, make up the northwest corner of the Wyoming Province. Major rock types include three distinct Archean metamorphic rock suites, consisting predominantly of Archean gneisses (older than 2500 Ma) in the northwest, west, and south, and a body of Late Cretaceous (77-72 Ma) granitic and dioritic intrusives known as the Tobacco Root Batholith in the eastern and central regions (Vitaliano et al., 1976). The three Archean units, the Indian Creek Metamorphic Suite (ICMS), the Spuhler Peak Metamorphic Suite (SPMS), and the Pony-Middle Mountain Metamorphic Suite (PMMMS), preserve a complex and interesting metamorphic history that is not completely understood.

Archean rocks record major high-grade, granulite facies metamorphic events at 2.8-2.6 Ga (Vitaliano et al., 1979) and 2.4-2.2 Ga (Mueller et al., 1996), overprinted by a lower-grade, upper amphibolite facies event at 1.8-1.6 Ga (James and Hedge, 1980). Aluminous schists from the ICMS and SPMS provide clues to unraveling the metamorphic history of the units. Textures and mineralogy of samples from both units indicate that upper amphibolite to lower granulite pressures and temperatures created melting throughout most of the pelites. Later isothermal decompression retrograde conditions are preserved in a few pelite samples from the SPMS. The lack of retrograde reaction textures in most of the pelites may be attributable to bulk composition or melt leaving the system. Thus, the pelites within the ICMS and SPMS are most likely restites from a high temperature, high pressure event occurring at 1.8-1.6 Ga.

METHODS

All chips were stained for the presence of K-feldspar. The flat surfaces of the billets were polished on a diamond lap wheel to create a smooth surface. This smooth surface was etched for ten to twenty seconds with hydrofluoric acid. The etched surfaces were then dipped in sodium cobaltinitrite for one minute. The samples were finally rinsed and allowed to dry. A canary yellow stain remained on Alkali-feldspar grains.

The Zeiss Digital Scanning Electron Microscope (SEM) with a LINK Energy Dispersive Spectrometer (EDS) was used in conjunction with the program "Program Thermobarometry 2.0" (Kohn and Spear, 1996) to calculate equilibrium pressures and temperatures of metamorphism. Temperatures and pressures were calculated using the Patino Douce et al. (1993) calibration for the garnet-biotite exchange reaction thermometer and the Koziol (1989) calibration for the garnet-aluminosilicate-quartz-plagioclase (GASP) net transfer reaction barometer.

RESULTS

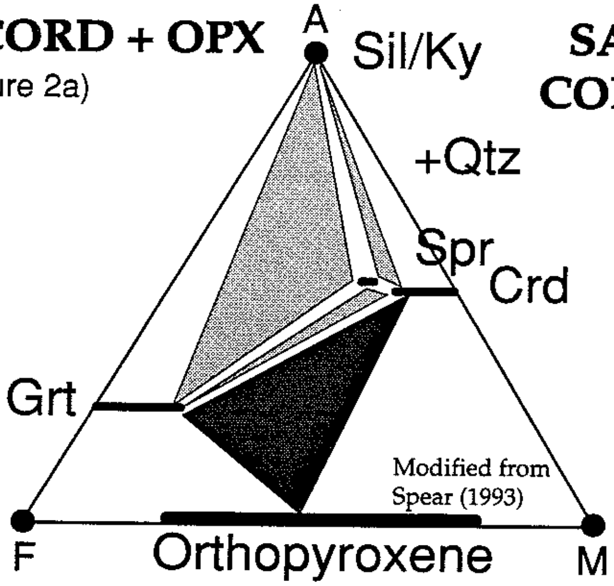
Petrography. Pelites from the ICMS contain a total mineral assemblage of quartz ± biotite ± sillimanite ± garnet ± plagioclase ± potassium feldspar ± muscovite ± rutile ± chlorite. Pelites of the SPMS contain a total mineral assemblage of quartz ± biotite ± sillimanite± kyanite ± garnet ± plagioclase ± potassium feldspar ± muscovite ± rutile ± ilmenite ± cordierite ± spinel ± chlorite. Modes of samples are dependent upon sample location, but significant differences in modes are not necessarily attributable to differences between units. Both assemblages indicate upper-amphibolite facies metamorphism with melt textures existing in thin-section. Evidence of previous metamorphism and metamorphic grade is not present in either unit. The key differences between the sections are the presence of kyanite, cordierite, and spinel in the SPMS but not the ICMS. Sillimanite pseudomorphs of kyanite also exist in the SPMS and were observed in many samples collected by Tierney (1996).

Garnet Zoning. SEM traverses from rim to rim show that garnets representing the majority of the samples in both assemblages are homogeneous with respect to Fe^{2+}, Mg^{2+}, Ca^{2+}, and Mn^{2+} (figures 1 and 2). The traverse of TBR-133 shows that trends in Mn^{2+} and Mg^{2+} concentration are inversely

SYMPLECTITES IN THE GRANITE CREEK AREA

CORD + OPX

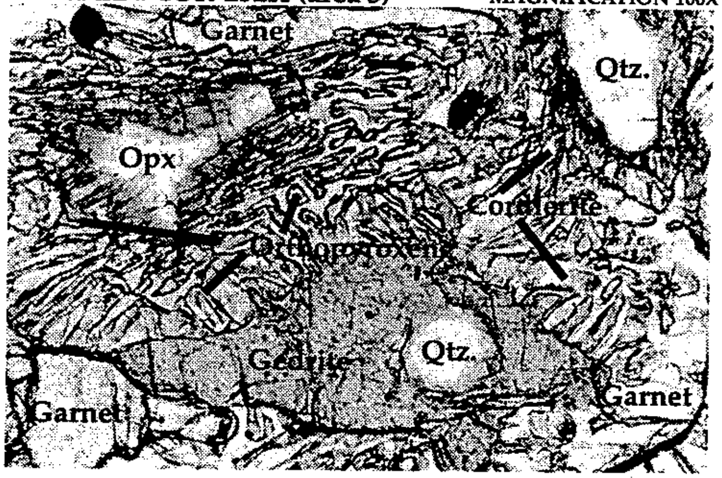
Figure 2a)



Modified from Spear (1993)

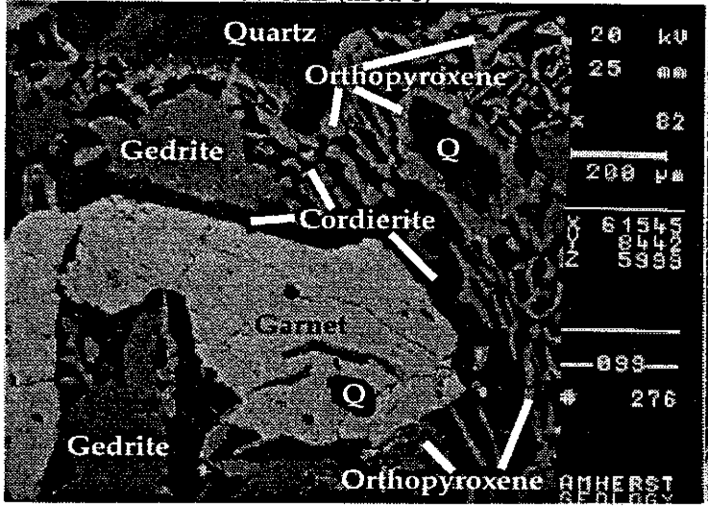
2b) PHOTOMICROGRAPH:

SAMPLE # TBR-252H (area 3) **MAGNIFICATION 100X**



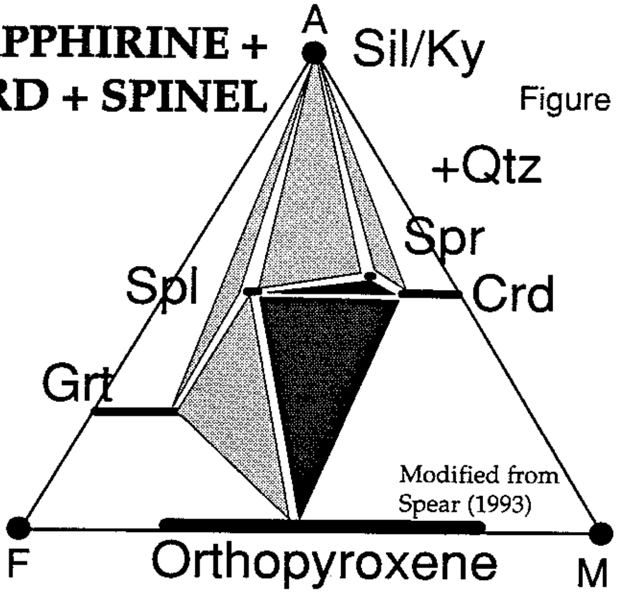
2c) BACKSCATTERED SEM:

SAMPLE # CEH-97-51E (area 6)



SAPPHIRINE + CORD + SPINEL

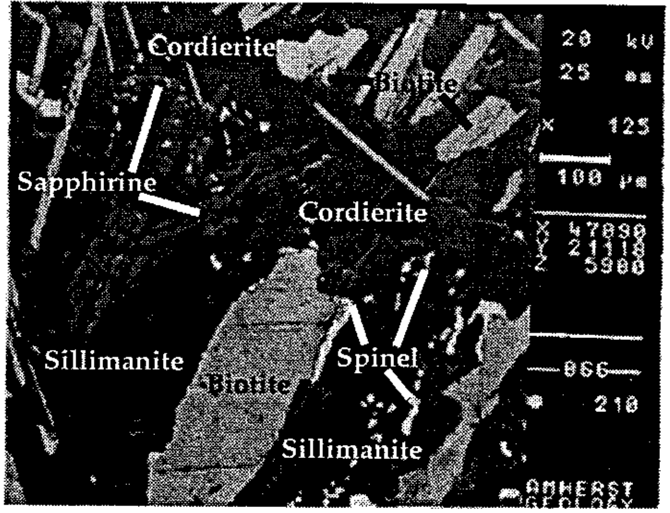
Figure 3a)



Modified from Spear (1993)

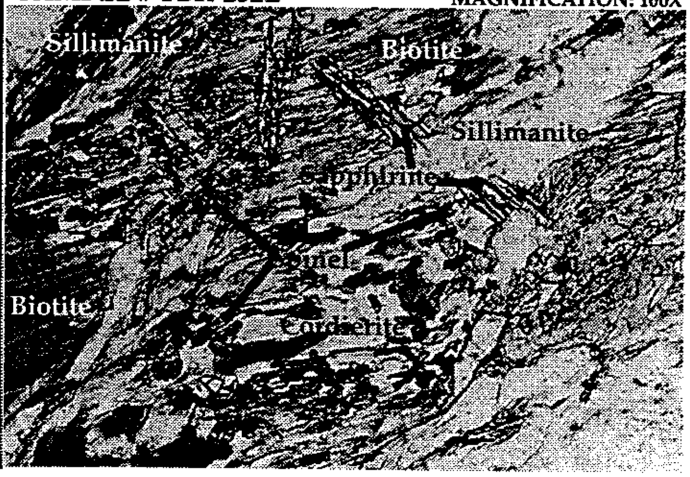
3b) BACKSCATTERED SEM:

SAMPLE # TBR-252E



3c) PHOTOMICROGRAPH:

SAMPLE # TBR-252E **MAGNIFICATION: 100X**



proportional (figure 3). Manganese ion concentration increases and magnesium ion concentration decreases as analysis points approach fractures filled with cordierite (figure 3). Flat lines between these enrichment and depletion trends indicate that the garnet core is homogeneous (figure 3).

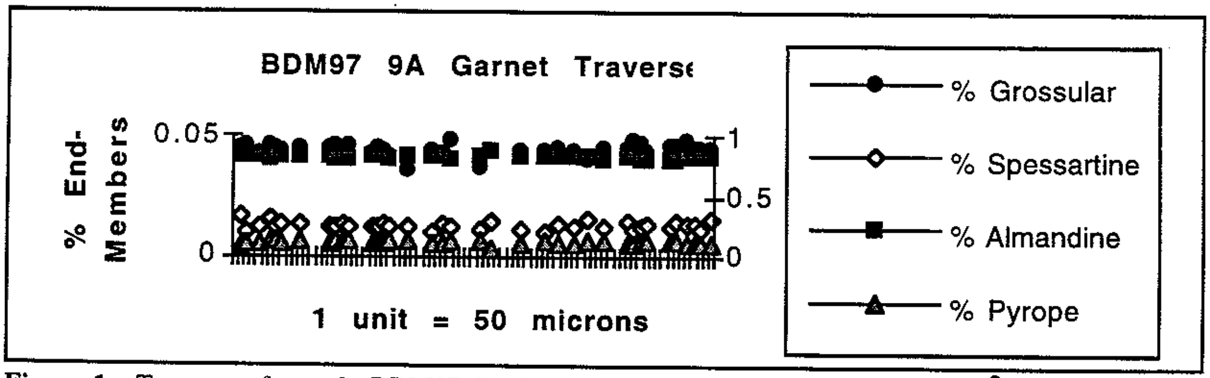


Figure 1: Traverse of sample BDM97 9A from the SPMS. Percent almandine (Fe^{2+}) and pyrope (Mg^{2+}) correspond to the right vertical axis. Percent grossular (Ca^{2+}) and spessartine (Mn^{2+}) correspond to the left vertical axis. Flat trends in lines indicate chemical homogeneity of garnet across traverse.

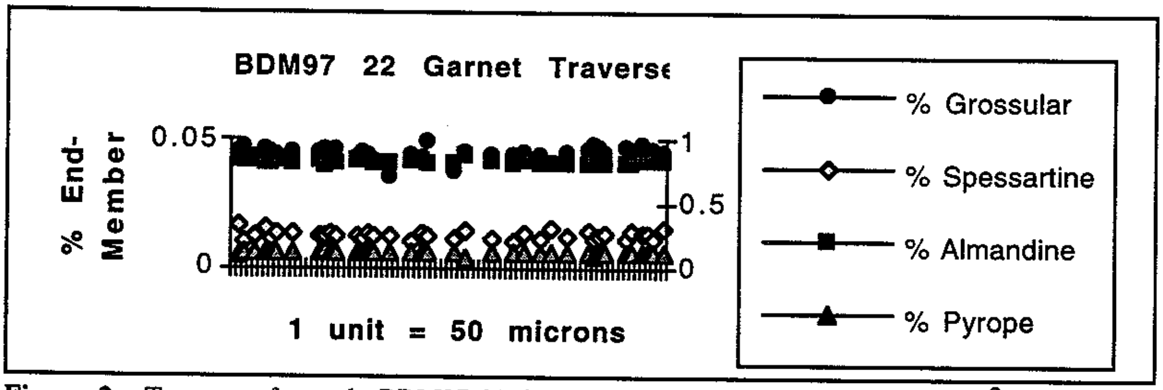


Figure 2: Traverse of sample BDM97 22 from the SPMS. Percent almandine (Fe^{2+}) and pyrope (Mg^{2+}) correspond to the right vertical axis. Percent grossular (Ca^{2+}) and spessartine (Mn^{2+}) correspond to the left vertical axis. Flat trends in lines indicate chemical homogeneity of garnet across traverse.

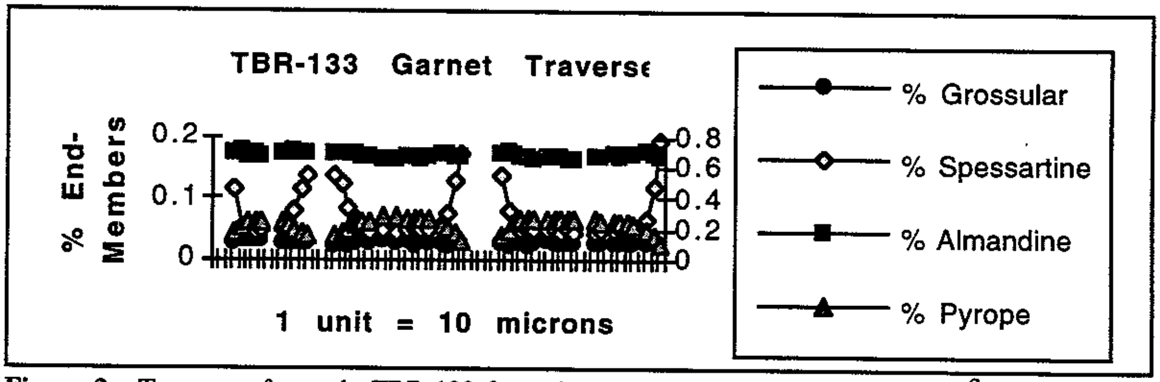


Figure 3: Traverse of sample TBR-133 from the SPMS. Percent spessartine (Mn^{2+}) increases and percent pyrope (Mg^{2+}) decreases near fractures filled with cordierite. Flat trends between these fractures indicate a chemically homogeneous core.

Geothermobarometry. Geothermobarometry shows similar high pressure and temperature conditions for garnets in samples of the most common modal mineralogy. Pressures and temperatures within the ICMS range from 7-11 Kbars and 660-850 °C (figures 4 and 5). Similarly, pressures and temperatures of non-retrograde samples within the SPMS range from 8-10 Kbars and 650-750°C (figure 6). Calculated pressure and temperature from TBR-133, a sample containing spinel and cordierite rims around garnet grains, is lower than those from samples not containing spinel and cordierite. Pressures and temperatures range from 5-7 Kbars, 550-650°C (figure 7).

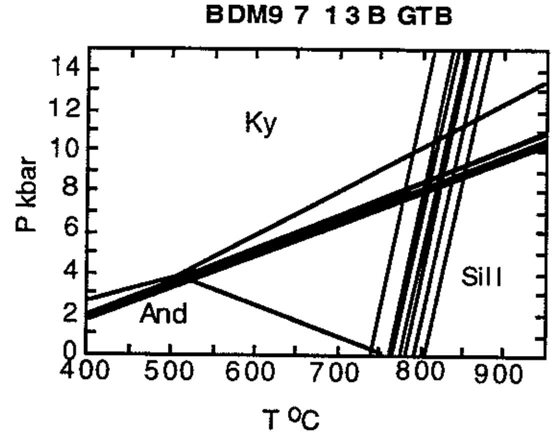


Figure 4: GTB of sample BDM97 13B from the ICMS yields a P-T range of 7-9 Kbar, 750-850°C.

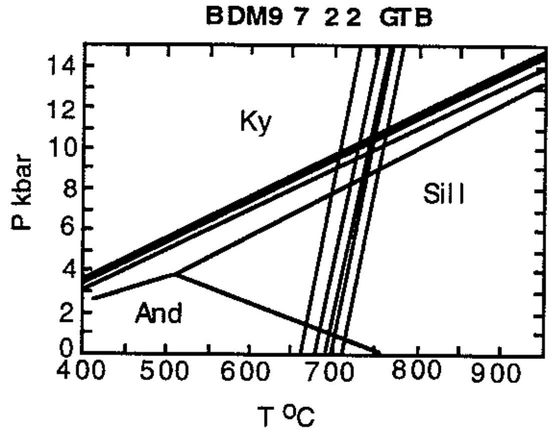


Figure 5: GTB of sample BDM97 22 from the ICMS yields a P-T range of 9-11 Kbars, 670-770 °C.

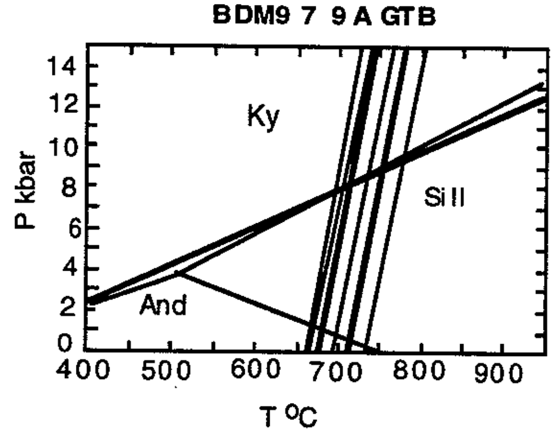


Figure 6: GTB of sample BDM97 9A from the SPMS yields a P-T range of 7-9 Kbars, 670-770 °C.

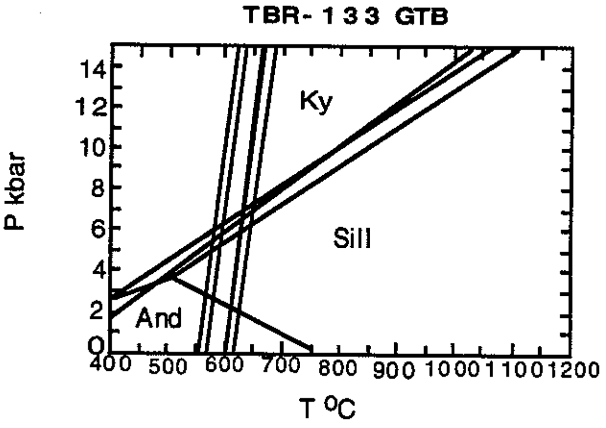


Figure 7: GTB of sample TBR-133 from the SPMS yields a P-T range of 5-7 Kbar, 550-650 °C.

DISCUSSION

Similar textures and mineralogy of pelites from the ICMS and SPMS indicate similar conditions of metamorphism. The presence of melt seams containing aligned biotite, larger, prismatic grains stretched parallel to the direction of biotite alignment, and smaller grains of quartz and K-feldspar suggests that melted material may have left the pelite. Melting of pelites can occur in the absence of a vapor phase (Spear, 1993). In such cases, meltintg is facilitated by the dehydration of muscovite and biotite which can be represented by the following reactions:

muscovite + quartz = K-feldspar + sillimanite (Spear, Kohn, and Cheney, 1998, in review)

biotite + sillimanite + plagioclase + quartz = garnet + K-feldspar + melt (Spear, Kohn, and Cheney, 1998, in review)

The latter melting equation accounts for the production of garnets within the pelites.

The chemical homogeneity of garnets is a result of volume diffusion which starts to occur at temperatures greater than 650°C, at or above the sillimanite isograd (Tracy et al., 1976). Since growth zoning has been completely obliterated in large garnets, temperatures at or above 650°C must have persisted for an extended period of time. The slight increase in almandine percent in garnet and increase in phlogopite (Mg end-member) percent in biotite at grain boundaries is indicative of a disequilibrium response to rapid retrograde cooling from granulite grade temperatures (Lasaga et al., 1977). Thus, rapid cooling occurred at some point in the P-T evolution of the rocks.

Evidence for decompression exists in a few samples from the SPMS. Sample TBR-133 of the SPMS shows a rim of cordierite and spinel around garnet which indicates isothermal decompression (Spear, Kohn, and Cheney, in review). This rim was created by the reaction:

garnet + sillimanite = cordierite + spinel (Spear, Kohn, and Cheney, 1998, in review)

Cordierite and spinel are intergrown outside of the garnet grains. Sample KAT-41, also from the SPMS, shows sillimanite pseudomorphs of kyanite which has been interpreted as evidence for isothermal decompression (Cheney et al., 1994). The absence of these retrograde textures in the ICMS may be due to the loss of melt products from the rock. The loss of melt not only changes the bulk composition, it also takes away the water component necessary for retrograde metamorphism to be recorded (Spear, Kohn, and Cheney, 1998, in review).

CONCLUSIONS

Pelites from the ICMS and SPMS record a high pressure, high temperature metamorphic event that caused partial melting and the development of restites. A few samples record a later-stage decrease in pressure which implies a clockwise P-T-t path for the SPMS. If earlier, high pressure and temperature assemblages in both units are recording the same event, it is likely that the ICMS also underwent isothermal decompression but did not record the conditions (much like many of the SPMS rocks) due to change of bulk composition and absence of water caused by the removal of melted pelites from the system. If P-T-t evolution is the same for both units, it is likely that the units were juxtoposed prior to the recorded metamorphic event. The presence of metamorphosed dikes and sills (MMDS) in the ICMS and not the SPMS makes juxtaposition prior to the earlier metamorphic events unlikely. Thus, the metamorphic event recorded by the pelites is likely to have occurred at 1.8 Ga.

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Structure of Archean Marbles of the Indian Creek Metamorphic Suite, Tobacco Root Mountains, Southwestern Montana

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INTRODUCTION

The Indian Creek Metamorphic Suite (ICMS) in the Tobacco Root Mountains of Southwestern Montana is characterized by abundant marbles. The abundance of marbles in the ICMS is unlike the other metamorphic suites, Sphuler Peak Metamorphic Suite (SPMS) and Pony - Middle Mountain Metamorphic Suite (PMMMS). The ICMS carbonates are associated with isoclinal, gently inclined to overturned folds. These folded carbonates are exposed in the west-central region of the range, and due to their resistance, the carbonates serve as good markers that define the shape and attitude of the folds (Burger, 1966). These folds are inferred to be the earliest recognizable folding in the region produced during the main penetrative deformational event (Brady et al,1996). This deformational event (S1) produced the dominant foliation observed in the Tobacco Root Archean rocks. This deformation may have occurred during the initial Precambrian deformation event that occurred at 2.7 Ga (Mueller and Cordua, 1976; James and Hedge, 1980). Due to their presence and resistance to weathering, the marbles may yield information on the region's deformation history. With that in mind, the purpose of this study is to understand the structural orientation of the marbles of the ICMS and its relationship to the SPMS.

ICMS STRUCTURAL FIELD OBSERVATIONS

The mesoscopic folds common to the ICMS and west-central regions of the Tobacco Root Mountains are sequences of upright, sub-isoclinal folds that plunge gently to the north-northwest, north, or north-northeast at gentle angles, and are dominated by folds with west dipping axial surfaces (Brady et al, 1996). Brady et al. (1996) state that these structures distinctly deform the dominant foliation developed by earlier recumbent folds of the region. Thus, assuming the main fabric is the earliest deformation, these superimposed folds are referred to here as F2. The ICMS outcrop scale folds range in style from open-to-close, concentric folds to tight-to-isoclinal similar folds. A majority of these folds are cylindrical in nature at outcrop scale, yet at large scale linear folds axes are scattered implying curved fold axes and macroscopic non-cylindrical folds (Brady et al, 1996). One possibility for the non-cylindrical fold geometry is sheath folding. Sheath folds are described by strongly curved fold axes that form a scattered great circle distribution (Mies, 1991) . These patterns have been seen in the region and interpreted as characteristic of simple shear deformation (Harms et al, 1996). Brady et al (1996) add that the scattered fold axis pattern is diverted by outcrop-scale third-generation, broad, open folds and if simple shear related sheath folds exist in the ICMS of the Tobacco Roots, it predate the last period of folding.

METHODS AND ANALYSIS

Total Station and 3-point problems. To better understand the structural geometry and orientation of the map scale folds in ICMS marble marker horizons, a total station was used to survey a series of strategic points along lithologic layering of fold limbs in three areas. Those three areas were Horse Creek, Mill Creek and Quartz Creek. The results gathered were used to construct six three-point problems. In addition, several foliation attitude measurements were taken and recorded from Horse, Mill and Quartz Creeks and Leggat Ridge. These measurements were applied to the study.

Station markers were placed along the contact between marble and ICMS quartzofeldspathic gneisses. A minimum of three station markers were measured for each fold limb. The purpose of the total station is to accurately measure the orientation of marble beds in the ICMS. Some three-point problem results were analyzed both graphically and mathematically through Excel spreadsheets. In addition, all fold results were plotted with Stereonet 4.9 (Allmendiger, 1995). Due to lack of recorded total station information, the Horse Creek fold was only analyzed graphically. The Quartz Creek fold was analyzed graphically, but could be recalculated analytically. The Mill Creek fold was initially analyzed graphically, but due to the tight survey area and relatively steep dip of one limb, it was prone to error. As a result, the Mill Creek fold was analyzed mathematically.

Total Station Results. The total station results show that the Horse Creek eastern fold limb dips shallowly to the west, while the western fold limb dips shallowly to the east (Figure 1; Figure 2). The Horse Creek fold has an