Sapphirine symplectites in orthoamphibolites of the Archean Indian Creek Metamorphic Suite (ICMS), Tobacco Root Mountains, Montana

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INTRODUCTION

The ICMS is one of three metamorphic suites that comprise the Archean rocks in the Tobacco Root Mountains. As described by Burger et al. (1994), the ICMS represents metasupracrustal rocks whose protoliths are a sequence of marine sedimentary rocks with possible interlayered volcanics or felsic intrusives. ICMS lithologies include quartzo-feldspathic and hornblende gneisses, marble, schists, quartzite, iron formation and minor orthoamphibole gneiss.

Due to their structural and petrographical similarities, the ICMS and the Pony Middle Mountain Metamorphic Suite (PMMMS) have been interpreted to be the same unit which was later juxtaposed with the Spuhler Peak Metamorphic Suite (SPMS) during distributed simple shear (Harms et al., 1996). Previous petrologic studies on SPMS rocks summarized by Cheney et al. (1994, 1996) have shown that the SPMS is polymetamorphic and involves an earlier high pressure (>10kb.) event followed by a later lower pressure (<6kb.) event. This last event was amphibolite to granulite facies in grade and had T's and P's of 650 ± 25 °C and 5.5 ± 1kb., and corresponds to $^{40}Ar/^{39}Ar$ hornblende ages of 1800 Ma, and a clockwise P-T-t path.

PURPOSE AND METHODS

Samples were taken from various sites within the ICMS, with particular interest paid to amphibolite gneisses containing orthopyroxene. Detailed analysis has been focused primarily on two main areas: "Quartz Creek", the ridgeline running from Leggat Mountain south toward Quartz Creek, and "Granite Creek", an area just inside the Beaverhead National Forest boundary near the east fork of Granite Creek on the southeastern flank of the range. These areas contain the most interesting and varied lithologies that provide the most information with which to constrain the tectonometamorphic evolution of the ICMS.

PETROGRAPHY

This study focuses on an orthoamphibolite lithology found in both the Quartz Creek and Granite Creek areas. This assemblage consists of garnet + orthoamphibole + orthopyroxene ± biotite ± rutile + quartz, with some variations, including kyanite and staurolite inclusions in the garnets, ± kyanite or sillimanite, and ± cordierite. Two reaction textures are present in Granite Creek rocks: a cordierite + orthopyroxene symplectite, and a sapphirine + spinel + cordierite symplectite.

DISCUSSION

Documentation of the previous history of the ICMS has been somewhat ambiguous and self-contradictory. Brady et al. (1994) reported a counter-clockwise P-T path in the ICMS based on aluminous schist minerology. Tuit (1996) agreed based on the occurence of garnet rims (with Cpx and Plag) on Opx porphyblasts in amphibolites, and garnet zoning in pelitic schists. However, Cheney et al. (1996) claimed that geothermobarometry from ICMS amphibolites is consistant with the (clockwise P-T-t path) evolution of the SPMS.

The cordierite + orthopyroxene symplectite observed in the ICMS Granite Creek rocks (see **figure 2a-c**) represents the rapid mineral growth as garnet is consumed in the following reaction:

garnet + quartz --------> cordierite + orthopyroxene (1)

This type of symplectite has been interpreted as indicative of decompression (or a clockwise P-T-t path) by Raith (1997). This observation agrees with Cheney (1996), and is consistant with the texture in hornblende amphibolites near Quartz Creek also cited by Tuit (1996), consisting of garnet rims on orthopyroxene. According to Spear (1997) for rocks with similar textures and grade in the Adirondack mountains of New York, garnet rims of this type can grow during cooling as part of a clockwise P-T-t path.

Another symplectic assemblage found in the Granite Creek area also represents rapid mineral growth. The sapphirine + spinel + cordierite symplectite (see **figure 3a-c**) represents a local quartz-absent

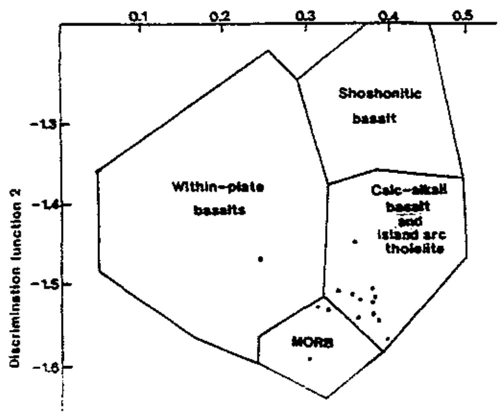

Figure 3. Major element discrimination diagram for basalts (after Pearce, 1976). Function 1: $+0.0088SiO_2 - 0.0774TiO_2 + 0.0102Al_2O_3 + 0.0066FeO - 0.0017MgO - 0.0143CaO - 0.0155Na_2O - 0.0007K_2O$. Function 2: $-0.0130SiO_2 - 0.0185TiO_2 - 0.0129Al_2O_3 - 0.0134FeO - 0.0300MgO - 0.0204CaO - 0.0481Na_2O - 0.0715K_2O$.

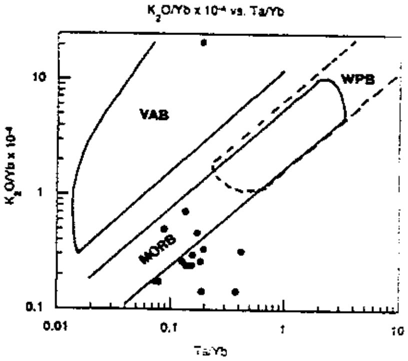

Figure 4. Basalt discrimination diagram (simplified), using Yb as a normalizing factor (after Pearce, 1982). VAB: volcanic-arc basalts; WPB: within-plate basalts.

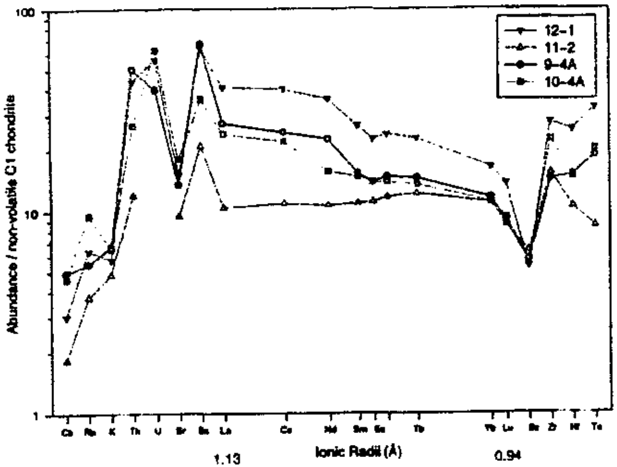

Figure 5. Spider diagram for four MMD samples. Courtesy of Oregon State University Radiation Center.

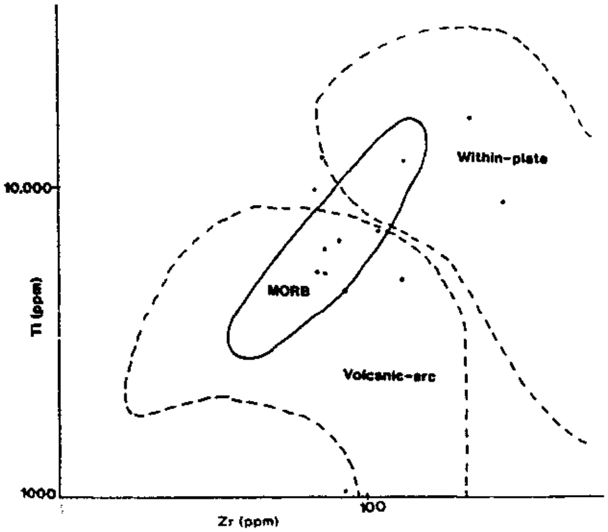

Figure 6. Ti-Zr basalt discrimination diagram (after Pearce and Cann, 1973).

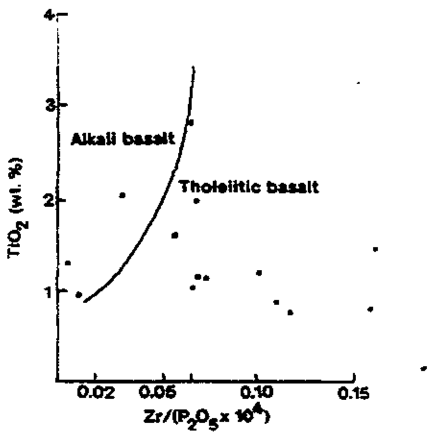

Figure 7. TiO_2-Zr/ (P_2O_5 x 10^4) basalt discrimination diagram (after Winchester and Floyd, 1976).

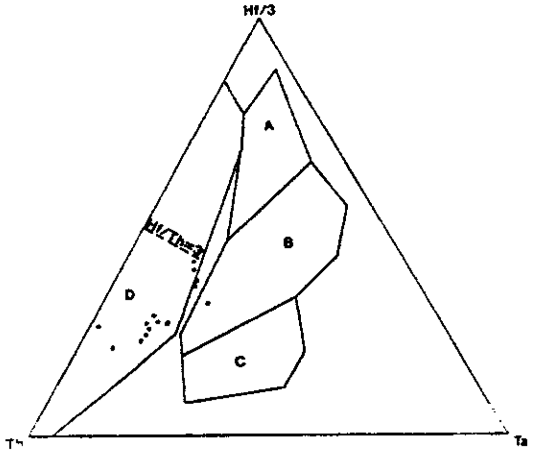

Figure 8. Th-Hf-Ta discrimination diagram for basalts (after Wood, 1980). A: N-type MORB; B: E-type MORB and within-plate tholeiites; C: alkaline within-plate basalts; D: volcanic-arc basalts, with island-arc tholeiites plotting in the field where Hf/Th > 3.0.

equilibration as aluminosilicate is consumed.

Based on the evolution of assemblages in these orthoamphibolites, peak conditions must have been ≥11 kbars to allow kyanite and orthopyroxene to be in equilibrium. Staurolite inclusions in garnet (in both Granite and Quartz Creek samples) constrain peak pressures to ≤16 kbars, and represent a lower temperature in a clockwise P-T-t path. The Fe/Fe+Mg content of garnet requires that these rocks equilibrated between 10 and 12 kbars. This pressure corresponds to the M1 assemblage (Gar + AS + Oam), and represents a point along the P-T-t evolution curve of the ICMS (**see figure 1**). The most recent assemblage, M2 (Gar + Cord + Oam), may be represented by preliminary geothermobarometry on garnets in contact with the orthopyroxene symplectite that yields pressures of 6-8 kbars and temperatures of 650-750°C.

CONCLUSIONS

Within the ICMS several different assemblages and reaction textures are evidence for decompression from a maximum of 14 kbars and 800°C down to ~6 kbars and 650-750°C:

1) cordierite + orthopyroxene symplectite replacing garnet,
2) garnet rims grown on orthopyroxene on cooling,
3) presence of sapphirine + spinel + cordierite symplectite,
4) staurolite and aluminosilicate enclosure in garnets as evidence for a clockwise path,
5) Fe/Fe+Mg constraints on garnet equilibration, and
6) results from preliminary geothermobarometry on the reaction assemblage.

This evolution is both similar to and consistant with the clockwise path of the adjacent Spuhler Peak Metamorphic Suite (SPMS). It is therefore likely that the ICMS and SPMS evolved together. However, the fact that the fragile symplectite structures are still intact implies that this metamorphism must not have involved significant strain. This particular orthoamphibolite assemblage is similar to rocks found in the SPMS. However, it in fact reflects a different bulk composition and is intercalated with very different calc-silicate rocks that occur exclusively in the ICMS.

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Figure 2) Cordierite + Orthopyroxene symplectite: **a)** Schematic AFM diagram from Spear (1993), **b)** Photomicrograph, **c)** Backscattered SEM image.

Figure 3) Sapphirine + Cordierite + Spinel symplectite: **a)** Schematic AFM diagram from Spear (1993), **b)** Photomicrograph, **c)** Backscattered SEM image.

PETROGENETIC EVOLUTION OF ICMS AMPHIBOLITES

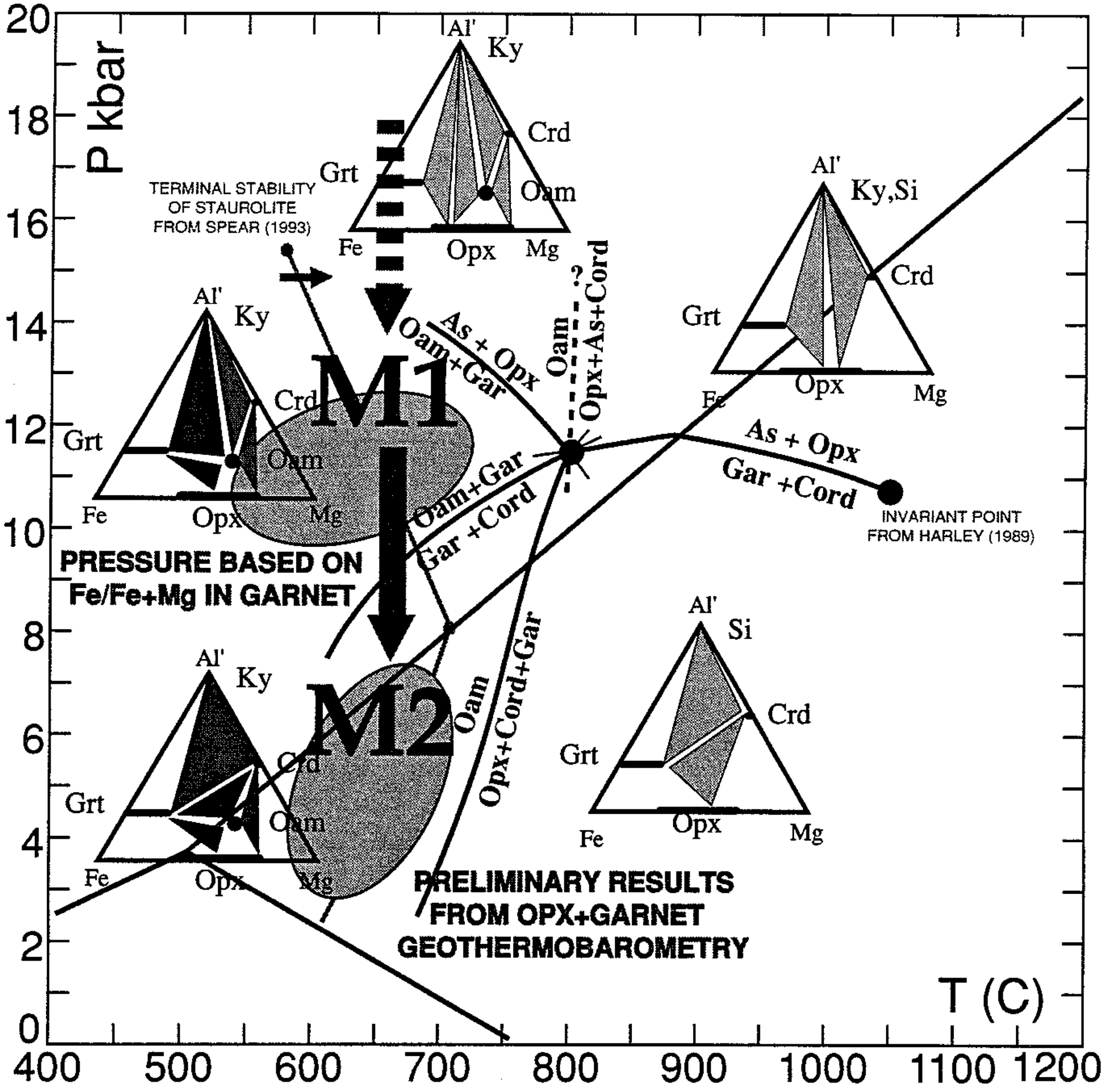
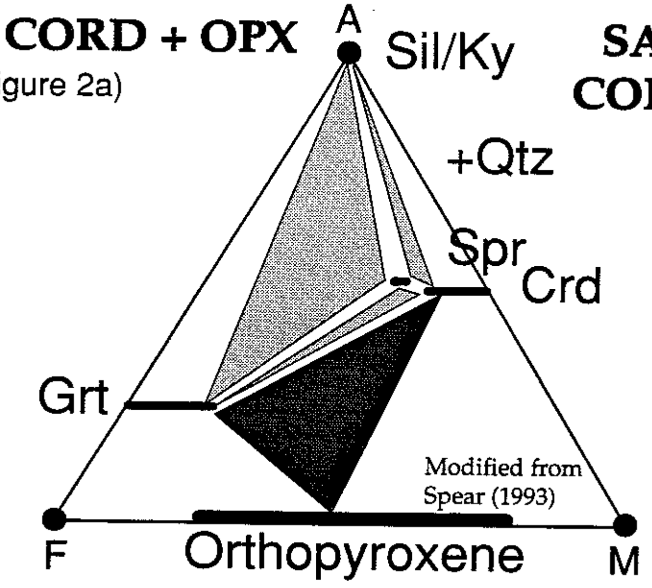


Figure 1) Petrogenetic Grid for Cordierite-Orthoamphibole and Garnet-Orthopyroxene-Orthoamphibole rocks (Schematic Grid calculated by Cheney (1998) with the computer program Gibbs 4.7 written by Spear (1998)). Assumes P H2O = P Total, therefore pressures are maximum values for hydrous Cordierite.

SYMPLECTITES IN THE GRANITE CREEK AREA

CORD + OPX

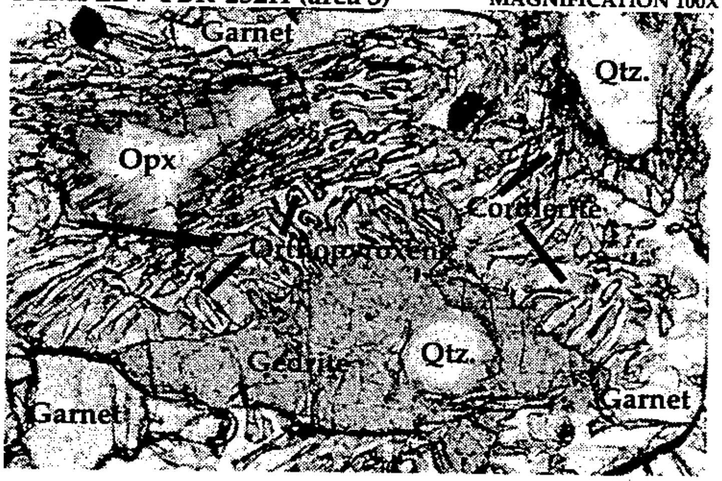
Figure 2a)



Modified from Spear (1993)

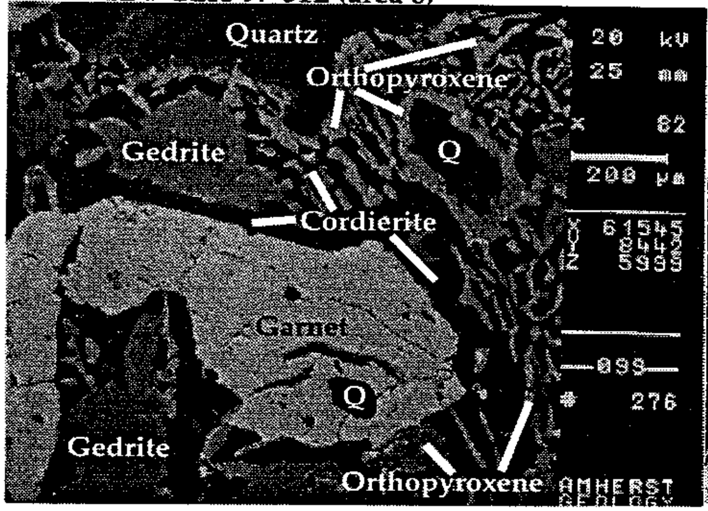
2b) PHOTOMICROGRAPH:

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



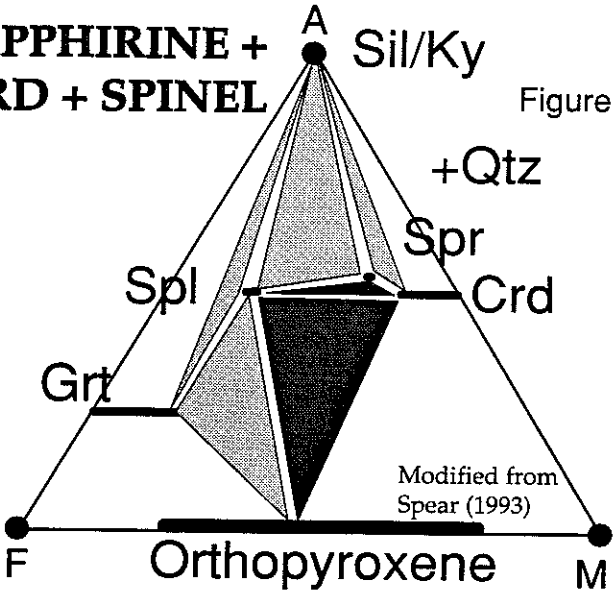
2c) BACKSCATTERED SEM:

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



SAPPHIRINE + CORD + SPINEL

Figure 3a)



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3b) BACKSCATTERED SEM:

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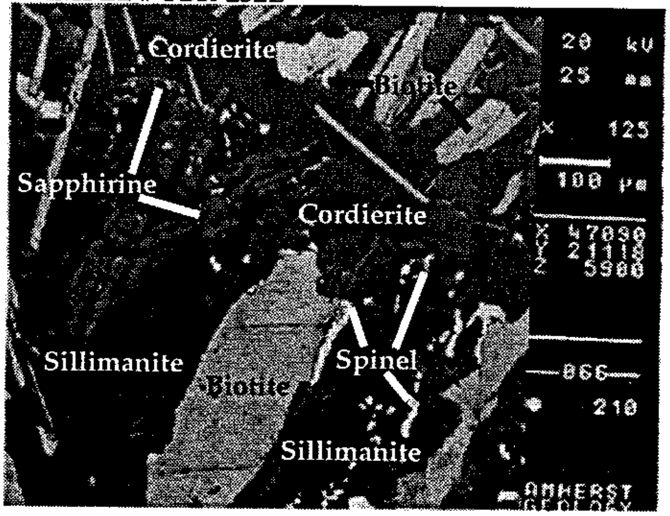
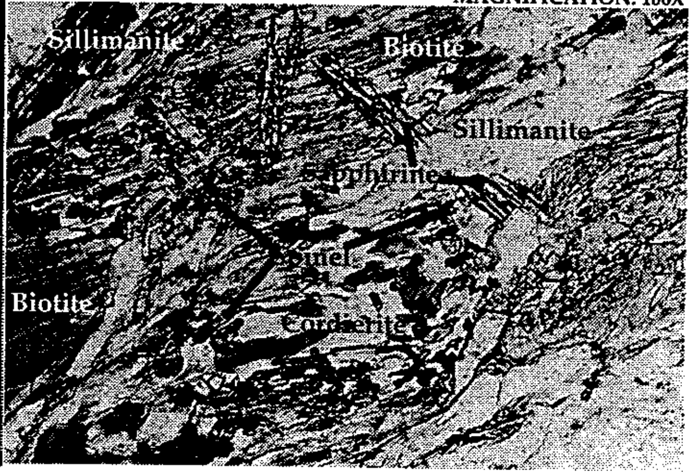


3c) PHOTOMICROGRAPH:

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



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