

# Mineralogy, Petrology and Geothermobarometry of Aluminous Archean Rocks in the Spuhler Peak Metamorphic Suite of the Tobacco Root Mountains, Southwestern Montana

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## INTRODUCTION

Archean rocks exposed in the Tobacco Root Mountains of Montana are made up of three different rock groups: the Spuhler Peak Metamorphic Suite (SPMS), the Pony Middle Mountain Metamorphic Suite (PMMMS), and the Indian Creek Metamorphic Suite (ICMS) (Vitaliano et al., 1979). The exact relationship of the SPMS to the PMMMS and the ICMS remains elusive. The purpose of this study was to expand the pool of data available concerning the SPMS, helping to shed light upon the nature of the SPMS-PMMMS-ICMS relationship. Previous SPMS work has been focused on the southeastern section of the unit; my study focuses on the northwestern end. There were two stages to my research: first, I compiled the petrology and mineralogy of a series of samples collected from the Sunrise Lake and Noble Lake areas, then I used my data to obtain P-T constraints on the metamorphic episodes experienced by the SPMS rocks.

## METHODS

Sixty-four samples of SPMS rocks were collected, 28 from Sunrise and 34 from Noble. From these, 25 thin sections were made, 10 from Sunrise, 14 from Noble, and one from another area. Four of these sections: JLH-2a, JLH-2e, JLH-38b, and JLH-38h, all from Sunrise, were examined using a scanning electron microscope (SEM). Chemical analyses of minerals were determined using the energy dispersive spectrometer on the SEM. Petrogenetic grids from Spear (1993) were used to obtain approximate pressures and temperatures.

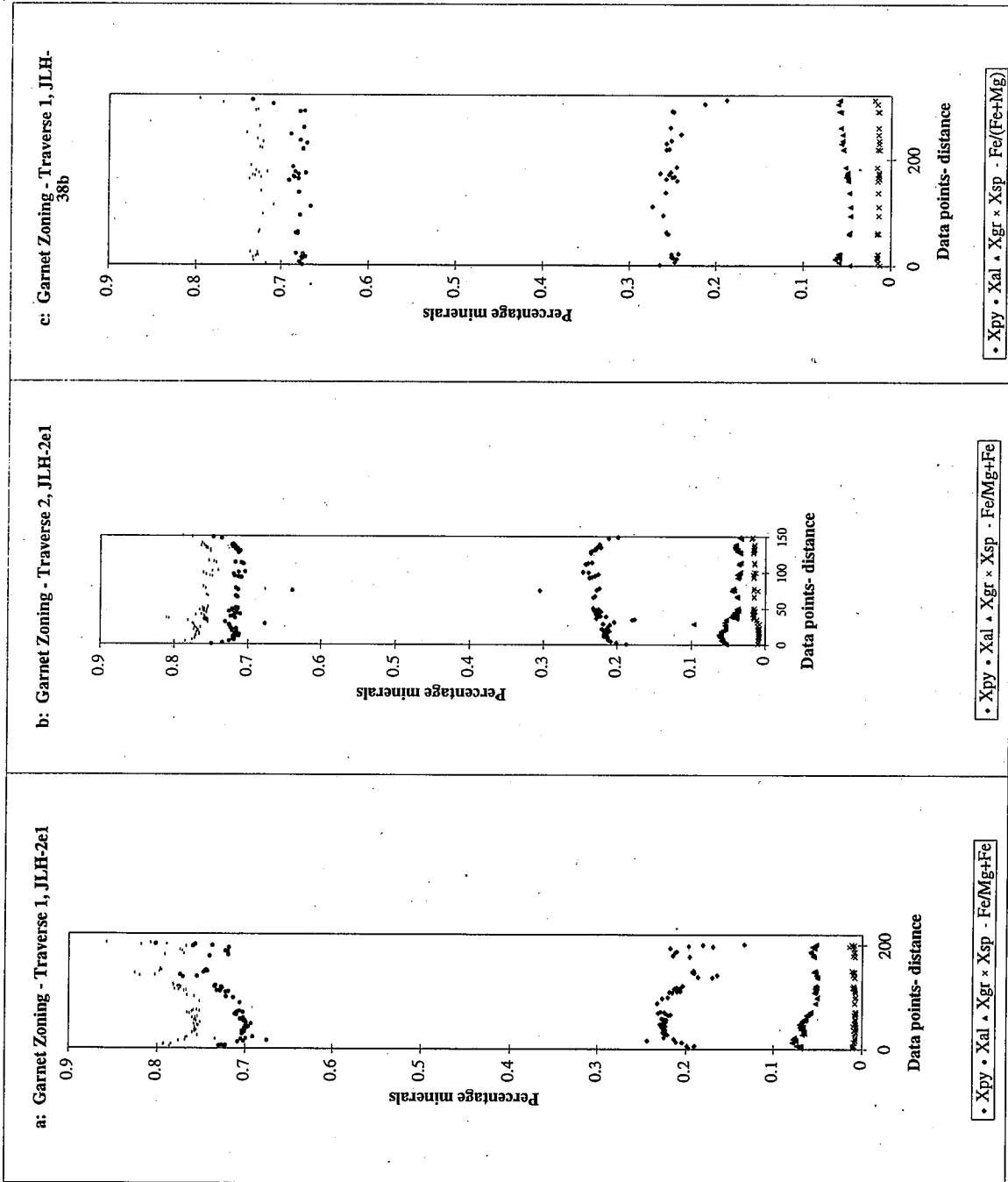
## RESULTS AND DISCUSSION

**Mineralogy and Petrology.** The rocks I collected were selected using two main criteria: that they be representative of the SPMS as a whole in that area, and that they contain as diverse a mineral assemblage as possible, to increase the likelihood of finding useful geothermobarometric assemblages. The rocks can be divided very loosely into two main groups: those that contain amphiboles and those that do not. The rocks with amphiboles I termed "garnet-amphibole" rocks, and those without were called "aluminous quartzite schist." This nomenclature reflects the unusual bulk composition of these rocks. The garnet-amphibole rocks are very coarse in hand sample, with very large and abundant garnets (up to 8 cm in diameter and comprising up to 70% of the rock in places) and bladed amphibole crystals, both of hornblende and gedrite. The aluminous schist rocks are characterized by large sillimanite pseudomorphs of kyanite, micas (mostly biotite) and quartz, and typically also contain garnets, though smaller and fewer than those in the amphibole rocks. They also are notably poor in feldspar.

Both groups of samples are typified in thin section by the assemblage: quartz + plagioclase + garnet ± biotite ± hornblende ± gedrite ± sillimanite ± kyanite ± muscovite ± ksp. Very little of the quartz has undulatory extinction, and the crystal boundaries are mostly very sharp and straight. The plagioclase is generally of composition An<sub>25-29</sub>, although one slide examined under the SEM had plagioclase of An<sub>34-36</sub> composition. The plagioclase shows normal zoning, with a slightly higher sodic content on the edges than in the cores. The garnets occur as idio- to subidioblastic poikiloblastic porphyroblasts, and are typically of ~70% almandine composition, with up to ~23% pyrope, ~6% grossular, and ~1% spessartine content. The numerous inclusions are of quartz, plagioclase, biotite, and amphibole, especially hornblende. One observed garnet contains kyanite, with sillimanite appearing just outside the garnet's rim. Some garnets are so poikilitic that they exhibit an "exploded" texture. No positive identification of cordierite could be made in thin section. A significant amount of cordierite is commonly found in other samples from the SPMS but appears to be, if not actually absent from my samples, then at least only a minor constituent of them. Figure 1 shows some sample mineral analyses from my SEM work.

**Figure 1:** some sample mineral analyses. All number represent stoichiometric formulas calculated according to preset  
 Oxygen values: 12 for garnets, 8 for kspar and plag, and 11 for biotite.

Sample	Mineral	Wt%tot	Si	Al	Ti	Mg	Fe2+	Mn	Ca	Na	K
JLH-2a	garnet	99.022	2.986	1.958	0.005	0.061	1.485	1.471	0.042	0.048	0
JLH-2a	garnet	100.147	2.976	1.95	0.005	0.607	1.573	0.756	0.128	0.101	0.002
JLH-2e	garnet	99.998	2.968	1.971	0	0.697	2.155	0.022	0.203	0.079	0
JLH-2e	garnet	99.964	2.967	1.953	0.002	0.682	2.235	0.042	0.12	0.11	0.003
JLH-38h	garnet	100.332	2.99	1.964	0.003	0.778	2.022	0.041	0.171	0.119	0
JLH-2a	kspar	99.154	2.969	1.027	0	0.016	0.001	0.001	0.001	0.135	0.825
JLH-2a	kspar	100.826	2.958	1.03	0	0.018	0.003	0.002	0.003	0.157	0.827
JLH-2a	plagioclase	101.499	2.695	1.294	0.002	0	0.002	0.001	0.292	0.754	0.002
JLH-2a	plagioclase	99.224	2.701	1.294	0	0	0.002	0	0.296	0.73	0.005
JLH-2e	plagioclase	100.019	2.709	1.296	0	0	0.003	0	0.296	0.712	0.003
JLH-38b	plagioclase	100.097	2.63	1.363	0	0	0.004	0.001	0.368	0.656	0.001
JLH-2a	biotite	96.196	2.709	1.58	0.164	1.571	0.749	0.04	0.003	0.135	0.902
JLH-2e	biotite	96.466	2.702	1.562	0.208	1.136	1.198	0.004	0.001	0.1	0.891



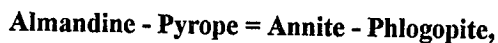
**Figure 2:**

a: Garnet traverse, rim to rim, JLH-2e

b: Garnet traverse, rim to rim, JLH-2e

c: Garnet traverse, core to rim, JLH-38h

**Garnet Zoning.** The garnets in my samples are zoned. This is diffusion zoning, which occurs as a retrograde redistribution of elements during the cooling of rocks. This particular zoning is generally driven by the reaction:



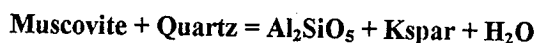
where annite and almandine and phlogopite and pyrope are the Fe- and Mg-rich end members, respectively, of biotite and garnet. The reaction causes the garnet rims to become enriched in Fe during cooling, while the biotite rims are enriched in Mg. The rate of this diffusion for biotite is much faster than the rate for garnet, so while the biotite generally regains homogeneity, the garnets can remain zoned (Spear, 1993).

Three automated garnet traverses were run on the SEM to detect zoning, one from the core to the edge of a garnet, and the other two from edge to edge. In all three cases, the Fe/Fe+Mg ratio was found to drop in the cores and rise at the rims. In addition to Fe/Mg zoning, all three garnets show a definite fluctuation in Ca, or percentage grossular (figure 2).

The zoning of the garnets, along with the relative homogeneity of the biotite in my samples means that while the core of the garnets may still reflect the original P-T conditions at which they crystallized, the rims and adjacent biotite crystals have changed in composition during cooling and subsequent aging of the rocks. As a result of this activity, analyses taken from the rims of garnets and biotites and used for geothermometry may not actually reflect the original temperature. A more ideal reading would be from the core of a garnet and from a biotite crystal not bordering a garnet, though there would then be no guarantee in this case that the biotite crystallized in equilibrium with the garnet (Spear, 1993).

**Kyanite-Kspar Coexistence.** In one thin section, JLH-2a, kyanite and kspar were found to be in contact. This sample's assemblage is biotite + garnet + quartz + plagioclase + kspar + kyanite. The kyanite is found as a single, very large metacryst with inclusions of quartz, plagioclase, and a small amount of kspar. Some additional crystals of kspar are found outside of and not in contact with the kyanite crystal. The existence of kspar in conjunction with the absence of muscovite from this sample (as well as from most of my samples) indicates a very high pressure and temperature of origin, including partial melt of the original components.

Spear (1993) presents two different equations involving the loss of muscovite to create kspar. The first,



crosses the kyanite-sillimanite reaction at approximately 800°C and 10 kb (figure 3), while the second,



intersects the boundary at nearly 720°C and 8kb (figure 4). Also in this figure is another curve, representing the solidus of H<sub>2</sub>O-saturated pelites. The former is a positive curve, while the latter has a negative slope, and they intersect at approximately 650°C and 3.6 kb. At this point, according to Spear, muscovite in dry rocks begins to dehydrate. In rocks already containing H<sub>2</sub>O, melt will begin to occur under less intense metamorphic conditions.

A study by Gardien *et al.* (1995) of H<sub>2</sub>O-undersaturated melting shows that in pelitic rocks containing only biotite, melting starts to occur at temperatures and pressures of 800°C and 10 kb and kspar starts to appear. However, no aluminosilicates will appear, even up to temperatures at and above 825°C, when orthopyroxene grows. No orthopyroxene was found in my samples. On the other hand, pelitic rocks containing biotite and muscovite yielded both sillimanite and kspar by 825°C and 10 kb. All of their experiments including muscovite conclude that muscovite dehydrates and melts at about 750°C, 10 kb, providing water to the system and causing further melt. It also provides for the formation of Al<sub>2</sub>SiO<sub>5</sub>, while biotite does not.

## CONCLUSIONS AND FUTURE PLANS

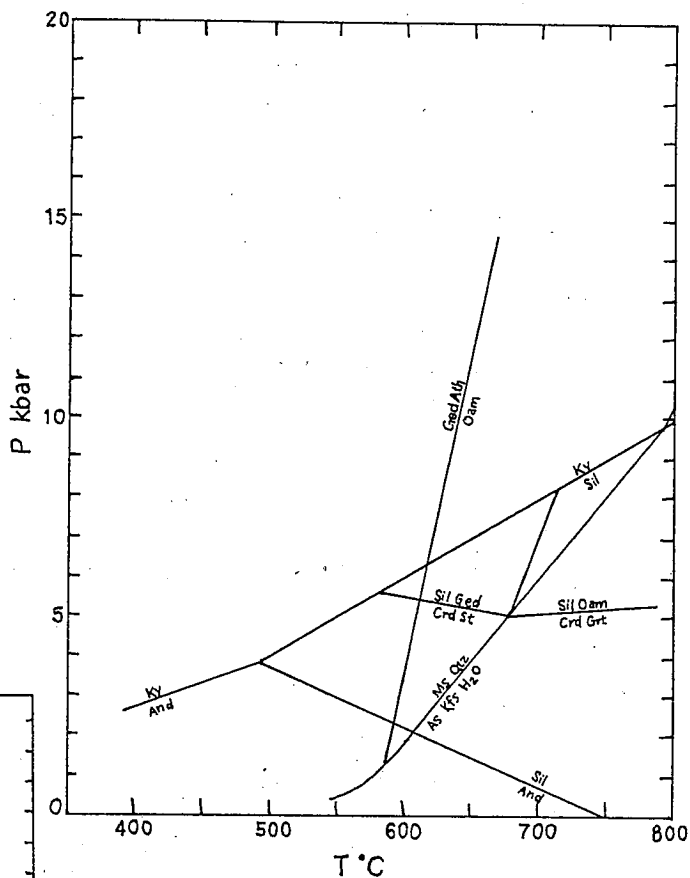
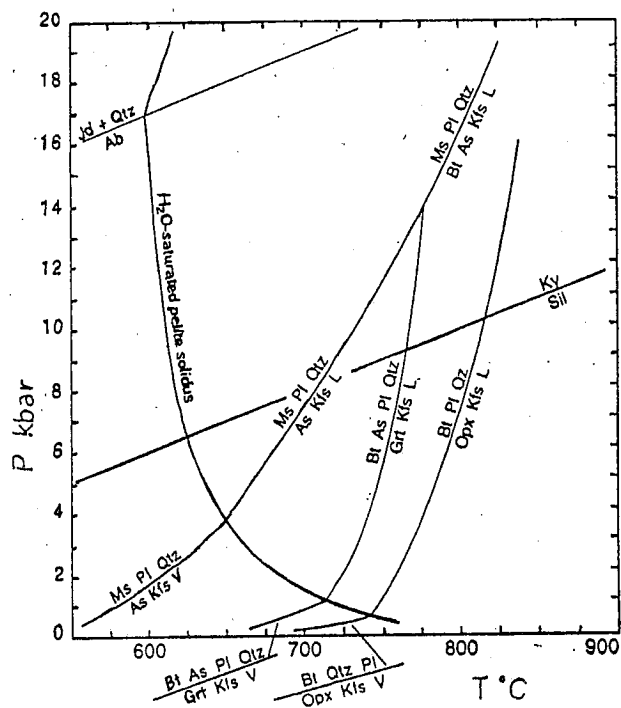
The fact that sample JLH-2a contains not sillimanite and kspar, but kyanite and kspar, constrains it to the pressures and temperatures at and above the kyanite-sillimanite isograd. This fact, coupled with the two intersections of the reaction curves in figures 2 and 3 with this isograd, helps to place my rocks at or above 700-800°C and 8-10 kb.

My research shows that the SPMS rocks may be arrestites- rocks "left over" and recrystallized from a partial melt, with the possible loss of some of the lower melt fraction. This could explain the anomalous quartz-rich, Al<sub>2</sub>SiO<sub>5</sub>-rich bulk compositions of my aluminous quartzite samples and other SPMS rocks.

**REFERENCES CITED**

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**Figure 3:** P-T diagram for cordierite-anthophyllite rocks and reactions in the KNASH system. (after Spear, 1993)



**Figure 4:** "Vapor-absent melting reactions for pelites." (from Spear, 1993)