Metamorphic evolution of the Archean Pony Middle Mountain Metamorphic Suite, Tobacco Root Mountains, southwestern Montana

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INTRODUCTION

The Pony Middle Mountain Metamorphic Suite (PMMMS) is the northernmost of three recognized Archean terranes in the uplifted core of the Tobacco Root Mountains (figure 1). The other terranes are the Spuhler Peak Metamorphic Suite (SPMS) and Indian Creek Metamorphic Suite (ICMS) (Burger *et al., 1994*). Previous Keck research has concentrated upon the SPMS and ICMS with small amounts on the PMMMS. The goal of this project is to characterize and determine the metamorphic history of the PMMMS, and to draw correlations between the PMMMS and the other suites present in the Tobacco Root Mountains.

The PMMMS is characterized by thick sequences of quartzofeldspatihic gneisses (approximately 55% of outcrop) along with lesser amounts of thick concordant units of mafic gneiss (approximately 35% of outcrop). The latter is interpreted by Vitaliano *et al.*, (1979) as originally lava flows and/or thin pyroclastic layers. Many of these mafic units can be traced along strike for several kilometers. The remaining 10% consists of thin layers and pods of pyroxene-rich gneiss, aluminous schists, possible iron formation rocks and banded garnet gneiss, ultramafic pods, marble, and quarzite. Later metamorphosed mafic dikes/sills (MMDS) are locally abundant as thin, fine-grained sheets with distinct contacts that cross-cut the gneissic foliation of the host rocks. The mafic gneisses can be distinguished from the MMDS based on their coarser grain size, greater continuity, and concordant nature with regards to the foliation of the surrounding rock types, especially with that of the quartzofeldspathic gneisses.

PETROGRAPHY

Quartzofeldspathic Gneisses: The common mineral assemblage in the quartzofeldspathic gneisses is plagioclase + quartz ± biotite ± hornblende ± garnet. Potassium Feldspar was not found in any of the quartzofeldspathic gneisses, although it has been reported by others (Vitaliano *et al.*, 1979). The mafic mineral content varies from 0 to approximately 30%. Most of the samples collected contain garnets (0.25 to 5 mm in diameter), several of which have slight sigmoidal tails or pressure shadows of felsic material. Foliation is often bent around the garnet porphyroblasts, indicating pre-to-syn tectonic growth. All of the quartzofeldspathic gneisses are strongly foliated in one direction, with several showing evidence for cataclastic shear deformation. The quartzofeldspathic gneisses contain mineral assemblages consistent with metamorphism in the upper amphibolite facies (Immega and Klein, 1976). Sericite alteration of plagioclase grains occurs in most samples and is locally abundant, with two sections showing further alteration to phengite. Such alteration of plagioclase is consistent with a minor late stage (Mesozoic) thermal event, possibly related to Laramide tectonic effects and emplacement of Cretaceous intrusions (Burger *et al.*, 1994), and/or to minor shear deformation of the rocks.

Mafic Gneisses: These are the second most abundant units in the PMMMS. These units are found as both thick layers that are extensive along strike, and as centimeter- and meter-sized boudinaged layers and mafic pods within the quartzofeldspathic gneisses. They contain medium to coarse grains of hornblende and plagioclase ± quartz ± biotite ± garnet ± clinopyroxene ± orthopyroxene ± potassium feldspar. The amphibole is predominantly hornblende. Most samples (~80%) contain a green hornblende in thin section while the other ~15% contains brown hornblende. Only one sample showed both green and brown varieties together. Actinolite occurs as a later, fine-grained replacement.

Cady (1994) described the amphibolites of the PMMMS similarly, but described only those of "salt & pepper" texture, which has a salt and pepper-like appearance from the distribution of small plagioclase and quartz grains and darker hornblende and other mafic minerals. Lowell (1994) described "wispy" amphibolites from the SPMS which are characterized as being migmatized hornblende-amphibolite with abundant felsic melt pockets, or "wisps" of plagioclase and quartz. The PMMMS contains mostly salt & pepper amphibolites, but subordinate wispy types also exist. Quartz and plagioclase inclusions in hornblende exist locally. With a few exceptions, foliation is moderately developed in both the amphibolites and hornblende gneisses. The amphibolites and hornblende gneisses contain mineral assemblages consistent with the upper amphibolite facies. Several samples show mineral assemblages suggesting possible granulite facies metamorphism.

Pyroxene-rich Gneisses: Pyroxene gneisses were found predominantly as centimeter- and meter-sized boudins and layers in the hornblende gneiss sequences, as well as minor boudins in quartzofeldspathic gneisses of intermediate mafic content. Clinopyroxene is the dominant pyroxene. A few samples, however, showed both clinopyroxene and orthopyroxene. Several of the pyroxene gneisses are heavily altered with replacement of many of the pyroxene grains by very fine-grained lower temperature/pressure minerals (talc and serpentine?). Several samples have large relict clinopyroxene crystals (up to 1.2 cm in length) in a finer matrix of clinopyroxene + plagioclase + quartz + hornblende + garnet ± orthopyroxene. The large diallage clinopyroxene porphyroclasts appear to be in disequalibrium with the rest of the minerals in the section, and are rimmed by smaller (0. 25 to 0.75 mm) equilibrium clinopyroxene grains. These porphyroclasts may be relict igneous pyroxenes or relicts from a earlier metamorphism that has been partially overprinted. Minor amounts of "starburst" amphibole, very fine-grained randomly oriented needle-like cummingtonite, exists in a few samples. These starburst amphiboles may be an indication of a late (?) low pressure thermal event.

Aluminous Schist: Minor amounts of aluminous schist exist in the PMMMS. One thin section contained quartz + biotite + garnet + plagioclase + kyanite + sillimanite. The garnet porphyroblasts appear to be pre-to syn-kinematic and range from 0.50 to 6.0 mm in diameter. Sillimanite appears to be replacing kyanite, suggesting that this sample barely crossed the sillimanite isograd during Proterozoic metamorphism.

Magnetite Gneiss and Banded Garnet Gneiss: Several samples contain abundant amounts of magnetite (up to 25%). Mineralogy consists of magnetite + clinopyroxene + orthopyroxene + garnet + quartz + plagioclase + hornblende. The mineralogy is similar to that of iron formation rocks described by Immega and Klein (1976) from similar locations and elsewhere in the southern Tobacco Roots. Immega and Klein (1976) concluded that on the basis of electron microprobe studies of pyroxene-rich assemblages the iron formation rocks of the Tobacco Roots are of granulite-facies rank.

Banded garnet gneiss outcrops in the northern portion of the PMMMS. These samples contain garnet + plagioclase + quartz + muscovite + biotite + clinozoisite (?). The gneiss consists of alternating bands of garnet and quartz + plagioclase. According to McClain and others (1979), compositional modeling suggests that the banded garnet gneiss is a metamorphosed impure iron formation with up to 30% added Al_2O_3 and SiO_2.

DISCUSSION

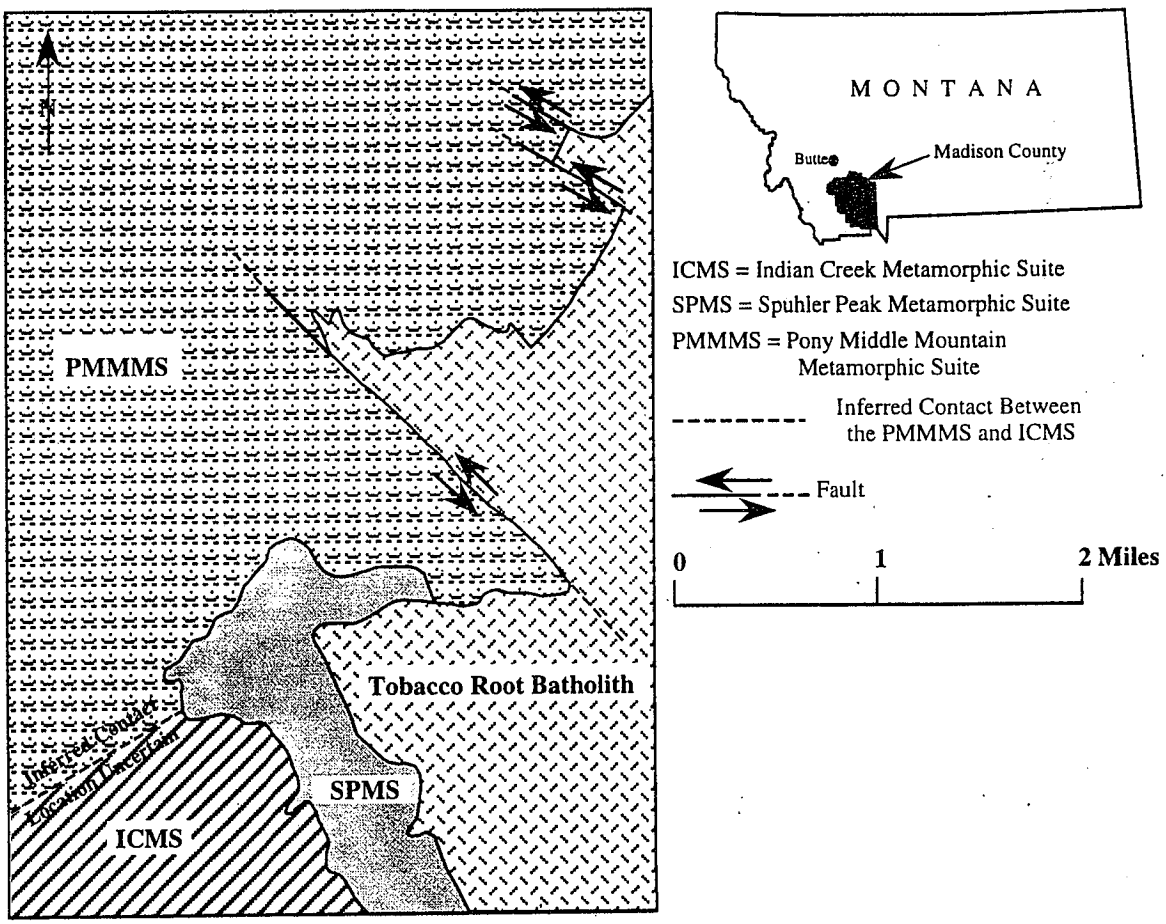
There is evidence for at least two Precambrian metamorphic events in the SPMS and possibly the ICMS, the first being high pressure and the second being a lower pressure (4-6 kb) event (J. Brady, personal communication). The oldest age for rocks in the Tobacco Roots is 2.7 Ga which is correlated with upper amphibolite facies metamorphism (Burger *et al.*, 1994). There is also clear evidence from $^{40}Ar/^{39}Ar$ dates on amphiboles from MMDS from the ICMS and amphibolites from both the ICMS and SPMS for a regional thermal event at 1.8 Ga (Brady *et al.*, 1994). There is slight evidence for a third event that postdates the lower pressure (4-6 kb) event. Evidence for this event comes from randomly oriented starburst amphiboles (probably cummingtonite), which must postdate the last ductile deformation event (J. Brady, personal communication). It is unknown whether they represent a Proterozoic event, or are associated with intrusion of the Cretaceous Tobacco Root Batholith. These starburst amphiboles have been recognized in all three metamorphic suites (J. Cheney, personal communication). A minor period of retrograde greenschist facies metamorphism of approximately 100 Ma is attributed to Laramide tectonic activity and to the intrusion of the Tobacco Root Batholith. The effects of this event are thought to be minimal, except along major faults, shear zones, and along the immediate contacts of intrusions (Vitaliano *et al.*, 1979).

From previous studies it is known that the majority of mineral assemblages from the PMMMS are consistent with upper amphibolite conditions of 650-750 °C and 4-6 kb (Immega and Klein 1976). MMDS which intruded after 2.7 Ga but before 1.8 Ga are good evidence for an 1.8-1.6 Ga thermal event of amphibolite facies in the PMMMS, which correlates with the age determined for metamorphism of MMDS from the ICMS (Vitaliano *et al.*, 1979; Brady *et al.*, 1994; and Burger *et al.*, 1994). The development of low grade alteration minerals in the PMMMS, such as sericite, phengite, chlorite, talc, serpentine and minor amounts of muscovite and biotite is most likely the result of Cretaceous thermal metamorphism, but may be from an earlier retrograde event.

Small amounts of rock in the PMMMS and other suites contain mineral assemblages indicative of a higher granulite facies event. The PMMMS rocks containing these higher grade assemblages are most commonly pyroxene-rich boudins or pods and iron formation rocks containing orthopyroxene. Granulite facies assemblages have been reported from quartzofeldspathic gneisses of the PMMMS (Hanley, 1975 and Vitaliano *et al.*, 1979). There are several probable explanations for the existence of sporadic granulites in the PMMMS. First, they could be relicts of a regional granulite facies developed during the 2.7 Ga event and subsequently overprinted by the younger 1.8 Ga amphibolite event. The rheology of these rocks might be such that they have resisted, in part,

overprinting by subsequent metamorphism. Or, perhaps the granulites were developed locally during prograde metamorphism in H_2O-deficient pockets during the 1.8 Ga event, due to local differences in pH_2O/pCO_2 from the surroundings. Evidence for this may come from Cheney *et al.*, (1994) who reported pressures and temperatures in the range of 8 kb and ~750 °C from kyanites of the SPMS thought to be 1.8 Ga, however, they could be Archean in age. According to Burger *et al.*, (1994) there is textural evidence from elsewhere in the Tobacco Roots to suggest both scenarios. Further research into the P-T histories of the granulites is needed in order to provide constraints on their formation, which in turn might prove useful in determining tectonic setting for the PMMMS and related suites in the Tobacco Roots.

Hopefully, further petrologic and geothemobarometry work will shed more insight on the relationship between the PMMMS and ICMS. Previous workers (Levandowski, 1956, Burger, 1966, and Cordua, 1973, in Burger *et al.*, 1994) have separated the PMMMS and ICMS based on lithologic characteristics. The ICMS, located in the west-central and southern portions of the Tobacco Roots, consists of quartzofeldspathic gneiss, hornblende gneiss, dolomitic marble, aluminous schists, quartzite, and iron formation. Although no definitive contact has been located between the PMMMS and ICMS they were separated on the basis of the abundance of marble and iron formation in the ICMS, and relative absence in the PMMMS. Data, presented by Owen (this volume), suggests that both the PMMMS and ICMS are one unit that has been folded around the outside of the SPMS. This along with the fact that there are minor amounts of marble, quartzite and iron formation in the PMMMS is evidence that they may in fact be lateral facies variations on the same unit. The metamorphic evidence seems to be consistent with the structural evidence for a one unit scenario for the PMMMS and ICMS. Both the PMMMS and ICMS appear to have similar metamorphic histories, as evidence suggests that they have both undergone at least two events; a higher pressure event first, followed by a lower pressure thermal event.



Schematic Reference Map for Archean Metamorphic Suites of the Tobacco Root Mountains, Madison County, Montana

Map adapted from: Vitaliano, C. J., and Cordua, W. S., 1979, Geologic Map of Southern Tobacco Root Mountains, Madison County, Montana: Geological Society of America Map and Chart Series MC-31.

REFERENCES CITED

Brady, J. B. et al., 1994, Geochemical and $^{40}Ar/^{39}Ar$ evidence for terrane assembly in the Archean of southwestern Montana: Geological Society of America Abstracts with Programs, v. 26, p. 232.

Burger, H. R., Brady, J. B., and Cheney, J. T., 1994, Archean rocks of the Tobacco Root Mountains, Montana: Seventh Keck Research Symposium in Geology (Trinity University), p. 54-59.

Cady, Pamela, 1994, Petrographic analysis of amphibolites from the Spuhler Peak Formation, Indian Creek Metamorphic Suite, and Pony-Middle Mountain Metamorphic Complex, Tobacco Root Mountains, Montana: Seventh Keck Research Symposium in Geology (Trinity University), p. 64-66.

Cheney, J. T. et al., 1994, Metamorphic evolution of Archean rocks in the Tobacco Root Mountains of s.w. Montana: Geological Society of America Abstract with Programs, v. 26, p. 226.

Hanley, T. B., 1975, Structure and petrology of the northwestern Tobacco Root Mountains, Madison County, Montana (Ph.D. thesis): Bloomington, Indiana, Indiana University, p. 289.

Immega, I. P., and Klein, C., 1976, Mineralogy and petrology of some metamorphic Precambrian iron formations in southwestern Montana: American Mineralogist, v. 61, p. 1117-1144.

Lowell, Josh, 1994, Petrological and structural constraints on the history of the Spuhler Peak Formation near Noble Lake, Tobacco Root Mountains, Montana: Seventh Keck Research Symposium in Geology (Trinity University), p. 78-81.

McClain, L. K., Mathews G. W., and Frank, C. O., 1979, Petrogenesis of a metamorphic garnetite, Tobacco Root Mountains, southwestern Montana: Geological Society of America Abstracts with Programs, v. 11, p. 279.

Owen, David, 1996, Archean Deformation of the Tobacco Root Mountains, southwestern Montana: Ninth Keck Research Symposium in Geology (Williams College).

Vitaliano, J. C., Cordua, W. S., Hess, D. F., Burger, H. R., Hanley, T. B., and Root, F. K., 1979, Explanatory text to accompany geologic map of southern Tobacco Root Mountains, Madison County, Montana: Geological Society of America map and Chart Series, MC-31.