Petrological and Structural Constraints on the History of the Spuhler Peak Formation Near Noble Lake, Tobacco Root Mountains, Montana

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Introduction

The Spuhler Peak Formation (SPF) is particularly well exposed along the narrow ridge that snakes from Noble Lake up and over Spuhler Peak. This study involved a traverse of Spuhler Ridge, from the SPF's southern contact with the Indian Creek Metamorphic Suite (ICMS) through its northern contact with the Pony-Middle Mountain Metamorphic Complex (PMMMC). Field observations, structural analyses, petrological and geochemical samples were all collected in the hopes of elucidating the murky history of this unusual package of Archean rocks.

Little previous work has focused specifically on the SPF. Gillmeister (1971) concluded that the contact between the SPF and the ICMS and PMMMC is an unconformity, with the SPF structurally on top. Friberg (1976) constructed a detailed stratigraphic column across the SPF, and described the metamorphic history of the SPF in terms of two events; an inital upper amphibolite grade event, and a later, possibly Cretaceous biotite-chlorite grade event, related to the emplacement of the nearby Tobacco Root Batholith.

Significant evidence exists, however, to support the following conclusions of this study:

1) The contact between the SPF and the ICMS and PMMMC is interpreted as a fault rather than an unconformity, as originally suggested by Burger (1969).

2) There appears to have been an additional, lower pressure metamorphic event that overprinted the original upper amphibolite assemblages, before the emplacement of the Tobacco Root Batholith. This event was associated with melting and folding of the SPF.

Stratigraphy: Major Units of the SPF

The Spuhler Peak Formation is comprised of hornblende-plagioclase amphibolites, ortho-amphibolites (containing gedrite and anthophyllite), aluminous quartzites, and occasional meta-ultramafic pods. Along Spuhler Ridge, the seven lithologic units described by Friberg were found to be difficult to distinguish. Due to the great variety of textures and appearances, his five different amphibolite units have been regrouped into two major units for the purposes of this study. There are five units within the SPF in the study area (Fig. 1).

1) Quarzite Package: This unit has previously been referred to as the Basal Member, due to its frequent occurrence at or near the contact. However, it is not in fact present at all contact locations. It ranges in thickness from 0 to 30m, and is predominantly quartzite, with quartz, garnet, plagioclase, and biotite, and sometimes kyanite, sillimanite, and microcline. Amphibolites containing hornblende, plagioclase, garnet, quartz, and biotite are interlayered with the quartzites on a cm to 2m scale. Ortho-amphibolites with gedrite, plagioclase, quartz and garnet form layers and lenses under 1m thick.

2) Wispy Amphibolite: Immediately above the QP is the WA, an 80 to 150m thick, migmatized hornblende- amphibolite with abundant felsic melt pockets, or "wisps" of plag (55%) and quartz (40%). The mafic restite is accordingly depleted in quartz and plag, with up to 90% hornblende, and minor garnet. Hornblende crystals are large and often euhedral, and all minerals appear to have crystallized at the same time. Foliation is weak.

3) Massive Amphibolite: The WA grades into the MA, which ranges from 50 to 200m in thickness. Overall hornblende, plagioclase and quartz percentages are similar to the WA, but it has not been migmatized, so the mafic and felsic minerals are evenly distributed. Crystals are smaller and more poorly formed than those of the WA, and foliation is more strongly developed. Biotite (up to 15%) and pyroxene (up to 8%) are present in the MA but not in the WA. The crystallization sequence is well preserved, with pyx early and garnet late.

4) Aluminous Quartzite: The most visually distinctive unit of the SPF is the AQ, a 10 to 40m thick, orange quartzite containing up to 30% sillimanite and 15% biotite. Quartz grains have been coarsely recrystallized.

5) Ultramafics: Clinopyroxene-rich meta-ultramafic pods are scattered throughout the SPF, with one pod present just southeast of the summit of Spuhler Peak. Samples of the UM were too altered for much detailed study.

Although they are a significant component of the SPF, and mineralogically distinct, ortho-amphibolites have not been included as one of the major units due to their lateral discontinuity and irregular distribution within the various other units. These rocks include both gedrite and anthophyllite, and may be nearly mono-mineralic, or contain large amounts of garnet, plagioclase, quartz, and sometimes cordierite. Garnets as large as 10 cm, and orthoamphiboles as long as 15 cm were observed.

References

Burger, H.R., 1967, Bedrock geology of the Sheridan District, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 41, 22p

Gillmeister, N.M., 1971, Petrology of Precambrian rocks in the central Tobacco Root Mountains, Madison County,

Montana [Ph.D. thesis]: Bloomington, Indiana, Indiana University, 210 p.

Lowell, J., 1994, this volume

Syncock, M.J.,1994, this volume

Vitaliano, C.J., Burger, H.R., Cordua, W.S., Hanley, T.B., Hess, D.F., and Root, F.K., 1979, Explainatory text to accompany the geologic map of the southern Tobacco Root Mountains, Madison County Montana, Geological Society of America Map and Chart Series, MC-31, 8 p.

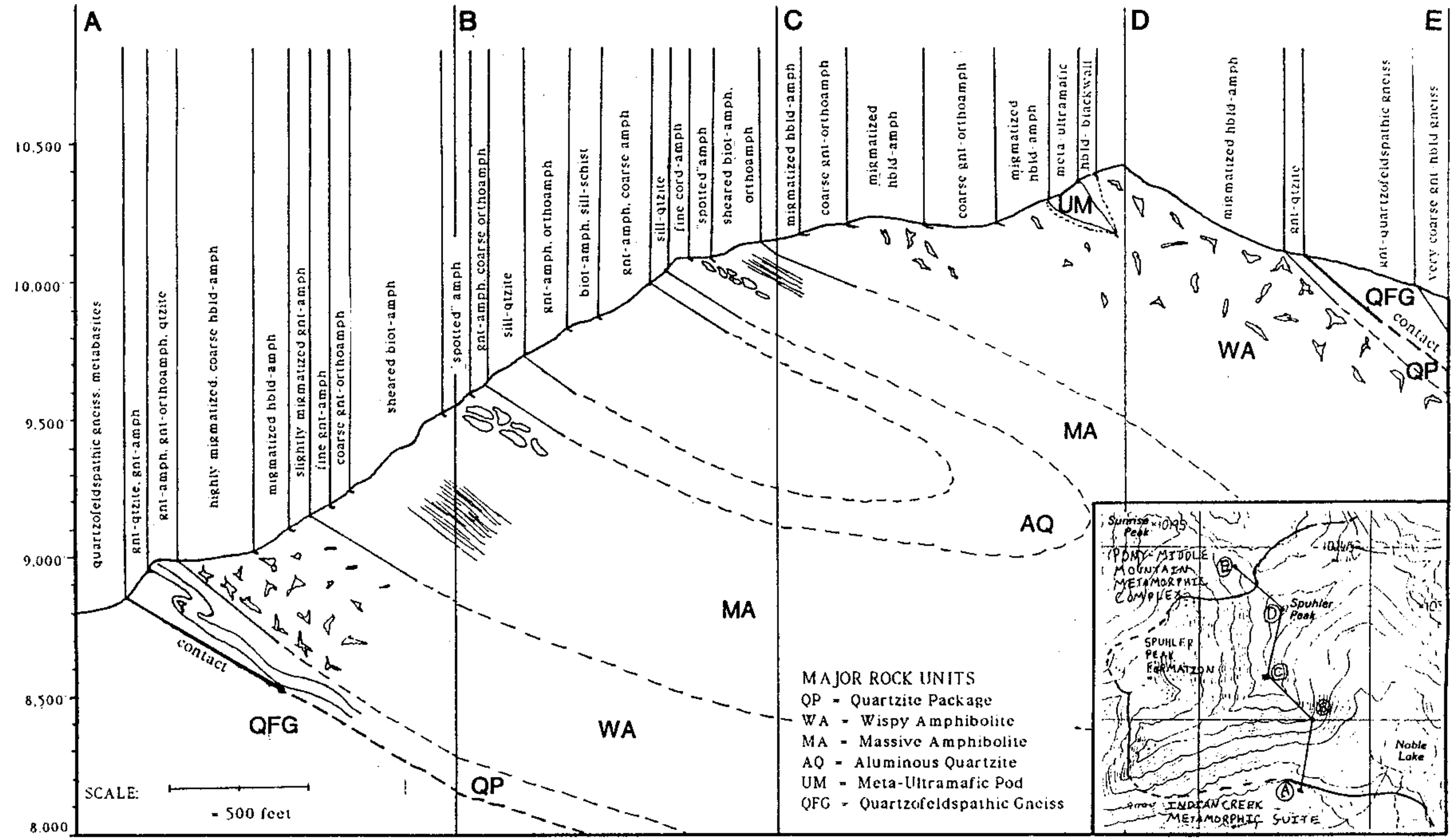

Fig. 1: Strip map / cross-section of traverse through the Spuhler Peak Formation near Noble Lake. Vertical columns describe individual lithologies, which have been grouped into major rock units. Inset map shows location of traverse from A to E, through turns-in-section at points B, C, and D.

Petrology: Evidence of Three Metamorphic Events

Metamorphic ages of 2.7 Ga have been obtained through isotopic dating of the ICMS (Mueller and Cordua, 1976), but no dates have yet been published from the SPF. It is unclear whether the 2.7 Ga event affected the SPF, but it had to be metamorphosed at upper amphibolite conditions at some point early in its history. The MA preserves much of this first metamorphic assemblage, with clinopyroxene, hornblende, plagioclase, garnet, quartz, and biotite. Kyanite is a significant component of the QP. It is clearly an early mineral, and the high pressures required for its formation may be consistent with genesis during the first event. However, kyanite crystals also define a strong lineation both inside the SPF and north of the contact, in the PMMMC, suggesting crystallization contemporaneous with high shear stress.

A second, lower pressure metamorphic event may have been associated with a regional thermal event that reset K-Ar clocks outside of the SPF at 1.6 Ga (Gilletti, 1966). Low pressure replacement reactions are the primary evidence of this event. Sillimanite replaces kyanite, and cordierite is formed by the reaction; kyanite + garnet + quartz => cordierite (Fig. 2). Clinopyroxene in the MA is partially replaced by hornblende, suggesting the involvement of water in the metamorphism and associated melting. Hydrous melting created the WA from the MA. It segregated the mafic and felsic components of the originally homogeneous amphibolite, hydrating pyroxene to amphibole and recrystallizing all minerals simultaneously.

The final metamorphic event was of the greenschist facies, and may have been associated with the intrusion of the Cretaceous Tobacco Root Batholith. Biotite and chlorite represent the most recent assemblage, filling fractures in garnets and other minerals.

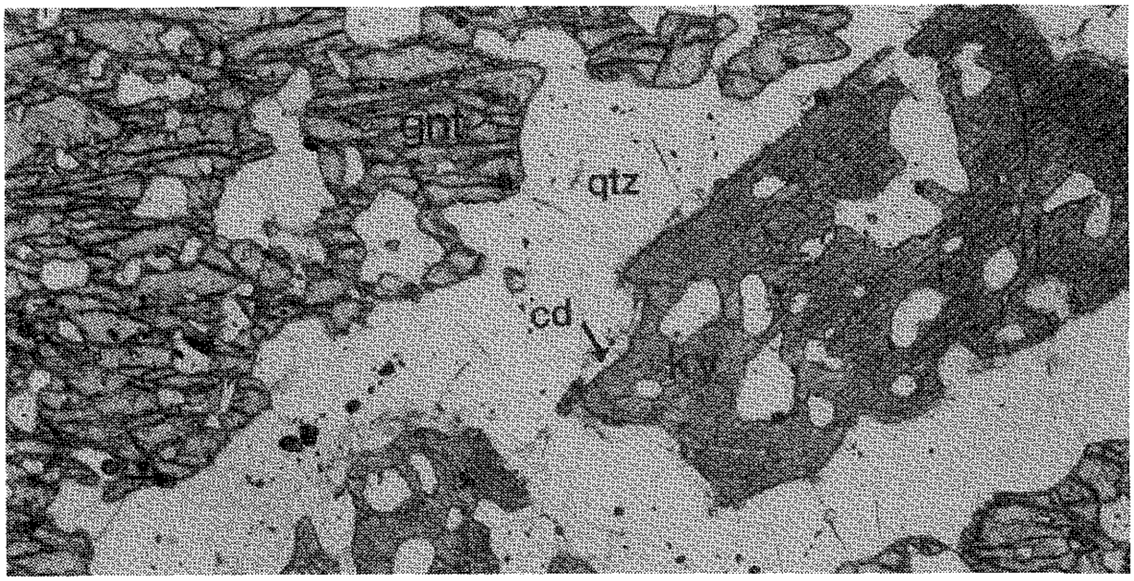

Fig. 2: Photomicrograph under plane polarized light of sample from the QP, near the SPF's southern contact with the ICMS. Photo illustrates the reaction; kyanite + garnet + quartz => cordierite, which is evidence of the second, low pressure metamorphic event.

Structure: Emplacement and Folding of the SPF

The nature of the contact between the SPF and the ICMS and PMMMC is critical to an understanding of the tectonic and metamorphic history of the region. A wide range of evidence suggests that the contact is most likely a fault: Shear zones have been mapped at or near the contact in several places; Quartzites at the contact have been tectonically thickened; Map patterns show a change in large-scale folding styles across the contact; Late Archean metabasite dikes are found throughout the ICMS, but nowhere within the SPF. Melting relationships also point toward the likelihood of a fault. The migmatized WA is located close to the contact throughout the field area. Melting must therefore also be concentrated close to the contact. Even within the WA, there is a clear pattern of increased degree of melting towards the contact, which suggests that the contact may be controlling the melting. If the contact is a fault, it could serve as a conduit for water, permitting the melting to occur.

Thrust faulting may explain the formation of kyanite. Faulting would likely be accompanied by significant tectonic thickening - perhaps enough to generate the high pressures necessary to form kyanite. Motion along the fault could produce the strong kyanite lineation, and account for crystals that have been pulled apart in the direction of their long axes.

At some time after its emplacement, the SPF was extensively folded by at least two phases of deformation. The first phase was characterized by isoclinal folds with axes plunging 35 to 45 degrees to the NE. In outcrop, these F1 folds cause local repeats in section, and are refolded by broad, open folds with steeply plunging, north trending axes (Fig. 3). The contact between the SPF and the ICMS and PMMMC appears to have been folded into a large, isoclinal synform during the F1 phase, as its fold axis aligns well with those of the outcrop scale F1s (Fig.4). Folding probably occurred synchronously with the second metamorphism and melting event. Melt pockets near the contact are concentrated in fold noses, while farther back melt is concentrated in small (1 to 2cm) shears parallel to foliation. In fold noses, mineral crystallization times span the range from pre- to post-folding.

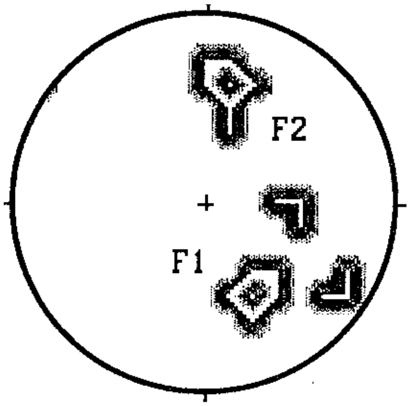

Fig. 3: Contoured equal area projection of poles to axial planes of folds in the SPF, showing two phases of folding.

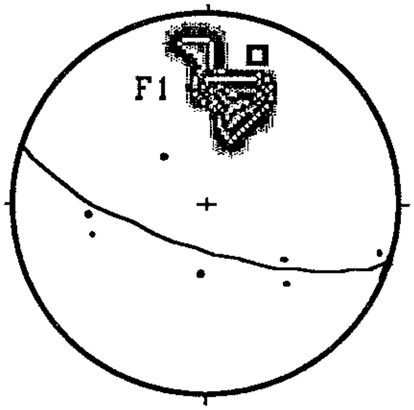

Fig. 4: Equal area projection of attitude of SPF contact (dots), fold axis of contact (box), and axes of F1 folds (contoured).

Conclusions: A Proposed Metamorphic and Deformational History

Given the field relationships, petrological and structural evidence, and conclusions of previous researchers, a sequence of events affecting the Spuhler Peak Formation in the Noble Lake area may be tentatively extrapolated to a partial history of the formation as a whole. Much of the following sequence is still open to interpretation and re-evaluation until geochemical data is available to test several apects of the present theory. Isotopic ages from within the SPF will help clarify some major timing questions. Since protoliths are as of yet unestablished, the history must begin with the first metamorphic event.

1) An upper amphibolite grade metamorphism formed the first amphibolites and quartzites, with the dominant assemblage; cpx-hbld-plag-gnt-qtz-biot. This event may have coincided with the 2.7 Ga event that affected the ICMS.

2) The SPF was emplaced above the ICMS and PMMMC along a thrust fault. Kyanite may have formed during the emplacement, but could also have been a component of the original metamorphic assemblages.

3) A second, lower pressure metamorphic event was accompanied by melting and folding. Sillimanite replaced kyanite, cordierite was formed, and pyroxene was hydrated to hornblende. The whole formation, including the contact, was folded into a large, isoclinal synform, with many parasitic isoclines along the limbs. Synchronous melting was concentrated close to the contact, as the fault chanelled fluids into the system to facilitate melting. This event may have been related to the high temperature event at 1.6 Ga recorded in nearby units. The second period of folding may have been continuous with the first, or may represent a seperate episode.

4) The final, low grade metamorphic event filled old fractures with chlorite and a new generation of biotite, possibly in the Cretaceous.

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.

Friberg, N., 1976, Petrology of a metamorphic sequence of upper-amphibolite facies in the central Tobacco Root Mountains, southwestern Montana [Ph.D thesis]: Bloomington, Indiana, Indiana University, 146 p.

Gilletti, B. J., 1966, Isotopic ages from southwestern Montana: Journal of Geophysical Research, V. 71, p. 4029-4036.

Gillmeister, N. M., 1971, Petrology of Precambrian rocks in the central Tobacco Root Mountains, Madison County, Montana [Ph.D thesis]: Cambridge, Massachusetts, Harvard University, 210 p.

Mueller , P.A., and Cordua, W. S., 1976, Rb-Sr whole-rock ages of gneisses from the Horse Creek area, Tobacco Root Mountains, Montana: Isochron/West, v. 16, p. 33-36

Geochemistry of orthoamphibole-bearing Archean rocks, central Tobacco Root Mountains, southwestern Montana

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INTRODUCTION

The Spuhler Peak Formation (SPF) of Guillmeister (1971) is located in the central Tobacco Root Mountains and extends from the Branham Lakes area northwest to Spuhler Peak, Guillmeister's type location. The SPF is made up of interbedded amphibolites and ortho-amphibolites, with minor amounts of sillimanite schist, quartzite, and meta-ultramafics. The nature of the contact of the SPF with the metamorphic packages structurally above and below it is not well understood. Additionally, the protolith of this package has not been well constrained, and is the focus of this study.

PREVIOUS WORK

Burger (1966), Guillmeister (1971) and O'Neil (1983) have conducted mapping studies of areas of the Spuhler Peak Formation. Vitaliano and Cordua's (1979) compilation map provides a detailed look at the regional geology of the area. Cummings and McCulloch (1992) performed a geochemical study of amphibolites and ultramafic rocks of the SPF in the area Branham Lakes. They suggest that the amphibolites are tectonically emplaced metamorphosed oceanic crust. This suggestion is consistent with the small amounts of ocean-floor metasediments in the area (sillimanite schist and quartzite), but does not address the protolith the orthoamphibole-bearing rocks.

ORIGIN OF CORDIERITE-ORTHOAMPHIBOLE ROCKS

The cordierite-orthoamphibole metamorphic assemblage has received a great deal of attention because the chemistry of these rocks is not easily comparable to modern igneous or sedimentary rocks. These rocks are calcium deficient, so orthoamphibole $((Mg,Fe)_7Si_8O_{22}(OH)_2)$ is a major component as opposed to hornblende $((Ca,Na)_{2\text{-}3}(Mg,Si,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2)$. Proposed processes to produce these rocks include: metasomatic addition of Fe and Mg and depletion of Ca (or re-distribution of Fe, Mg, and Ca) during metamorphism, partial melting of pelitic rock (leaving a Mg-rich, Ca-poor residuum), or chemical alteration prior to metamorphism. This last category includes rocks that were influenced by Mg-rich evaporitic waters, sub-aerial weathering, deuteric alteration, and hydrothermal alteration. A good summary of the history of this debate is given by Robinson and others (1982).

PETROGRAPHY

Samples containing ortho-amphiboles were collected from the SPF. They contain the assemblage garnet-orthoamphibole-quartz-plagioclase, with varying amounts of cummingtonite, hornblende, and cordierite with minor sillimanite and apatite. The rocks are consistently of high amphibolite grade. Iridescence in the orthoamphiboles caused by anthophyllite exsolution in gedrite is common.

GEOCHEMISTRY

Rocks were selected for eventual geochemistry work, so "fresh" samples were collected. Because of this the sampling bias is towards fine-grained, non-permeable specimens. Geochemical data for 23 samples (Table 1) was obtained using Beloit College's inductively coupled argon plasma spectrometer (ICAP) for both major and trace elements.

The major element geochemistry of the orthoamphibole-bearing rocks is in the range of basalts except for CaO, which averages 3.5 weight percent. When plotted on the Jensen Cation Diagram (Jensen, 1976) the samples fall in the field of high-iron tholeiitic basalts (Figures 1 and 2). However, a plot on the trace element discrimination diagram of Pearce and Cann (1973) falls in the field of calc-alkali basalts (Figure 3). Incompatible element ratios diverge from chondrite ratios. Al_2O_3/TiO_2 is lower than the chondrite value of 20 (Figure 4). Ti/Zr, Ti/Y, Y/Zr, and Sc/Zr are all lower than chondrite values of 110, 209, .39, and 1.4. La and Ce are enriched compared to chondritic values (and Y). There is a complex correlation between Sr and Ca (Figure 5).

DISCUSSION

It has been noted by many workers (e.g. Humphris and Thompson, 1978a) that hydrothermal alteration of basalts causes depletion in CaO and SiO_2 and enrichment of MgO and H_2O. Such hydrothermally altered basalts have the bulk-chemistry to serve as the protolith of cordierite-anthophyllite rocks (Robinson and others, 1982) in