Structural and Metamorphic History of an Intensely Deformed Zone, Lower Branham Lake, Southern Tobacco Root Mountains, Montana

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Introduction: The purpose of this study was to describe the structural and metamorphic history of an intensely deformed zone within the Spuhler Peak Formation near Lower Branham Lake in the Southern Tobacco Root Mountains, Montana (Figure 1). These Archean rocks have undergone upper amphibolite to granulite prograde metamorphism and a late minor greenschist retrograde metamorphism (Burger, 1967; Wooden and others, 1988).

Field Observations: The area contains an intensely deformed metasedimentary package enveloped by a massive amphibolite package, with metaultramafic pods present throughout. An offshoot granodiorite plug of the Late Cretaceous Tobacco Root Batholith cuts across these rock units (Figure 1). In both metasedimentary and amphibolite packages, foliations are oriented approximately N50^{o}W; 60^{o}NE. Contacts between the packages are parallel to the foliations and are folded in some places. Within the intensely folded metasedimentary package three generations of folds were recognized. The metasedimentary package also includes an intensely recrystallized metamylonite (?) zone.

Analytical Techniques: Sixty-two oriented samples were collected in the field; from these twenty-nine thin sections were cut and analyzed. Sixteen samples were selected for whole rock chemical analysis. X-ray fluorescence, inductively coupled plasma, and loss on ignition techniques were used to determine major and trace element compositions. Whole rock chemical compositions and lithologic descriptions are listed in Table 1. A detailed geochemical analysis of these rocks is forthcoming.

Lithologies:

Massive Amphibolite Package: These rocks are medium- to coarse-grained, dark gray to black amphibolites with white plagioclase and quartz foliation bands. Mineralogy includes mainly hornblende and plagioclase with quartz, biotite, garnet, magnetite and chromite as accessories. Hornblende and biotite crystals are oriented parallel to the foliation bands. According to field observations and whole rock chemistry, possible protoliths for the massive amphibolites are basalt flows or tuffs (Table 1).

Metasedimentary Package: Interlayered quartzofeldspathic gneiss, amphibolite, and quartzite comprise this intensely deformed zone.
Quartzofeldspathic Gneiss: This lithology consists of coarse-grained, lensing and laminated biotite-garnet-sillimanite quartzofeldspathic gneiss. Mineralogy includes quartz, plagioclase, alkali feldspar, sillimanite, garnet, biotite, muscovite, chlorite, and zircon. Accessories include cordierite and magnetite. Cordierite, muscovite, and chlorite may represent a late greenschist retrograde event. The foliations consist of alternating bands of biotite-sillimanite layers and quartz-plagioclase layers. Biotite and sillimanite crystals are oriented parallel to foliations and are observed to both wrap around folds and be axial planar in tightly appressed hinge zones. The quartzofeldspathic gneisses are interpreted to represent a metamylonite that was recrystallized during a heating event after the deformation that caused the mylonitic texture. Their geochemistry and the presence of rounded zircon grains suggest a sedimentary protolith.
Amphibolite: These rocks are medium-grained dark gray to black amphibolite layers with white plagioclase foliation bands, interstratified with quartzofeldspathic gneiss and quartzite. Mineralogy is identical to that of the massive amphibolites. Geochemical data and field observation suggests basalt as a possible protolith.
Quartzite: Commonly green with chrome-rich fuchsite, this lithology consists of fine grained quartzite interlayered with amphibolite and gneiss. Minerals include quartz and accessories. A pure quartz sandstone or chemically deposited chert are two possible protoliths based upon geochemistry.

Metaultramafics: These rocks are found in pods of coarse-grained dark gray-green metaultramafic. Minerals include olivine, orthopyroxene, clinopyroxene, and hornblende with traces of biotite, phlogopite and opaques. Most minerals have been altered by a greenschist retrogression causing serpentinization and

Figures 5, 6, 7, and 8. Differentiation diagrams illustrate that the meta-ultramafics consistently fall in the komatiite field and not the peridotite field. Amphibolites are plotted to show distinct chemical differences between meta-ultramafics and amphibolites (Crosses are meta-ultramafics, filled boxes are amphibolites and hornblende-plagioclase-quartz gneisses.)

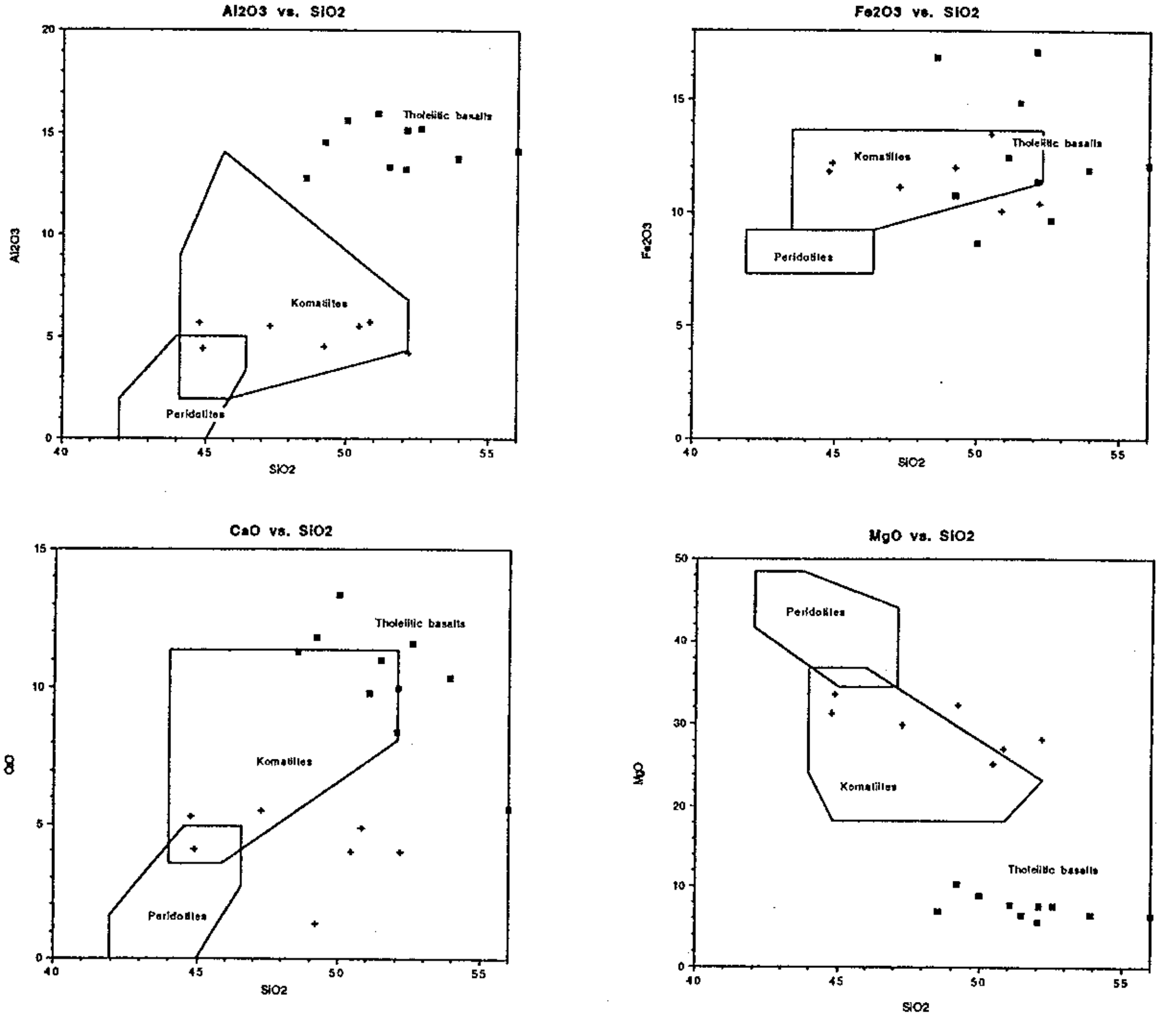
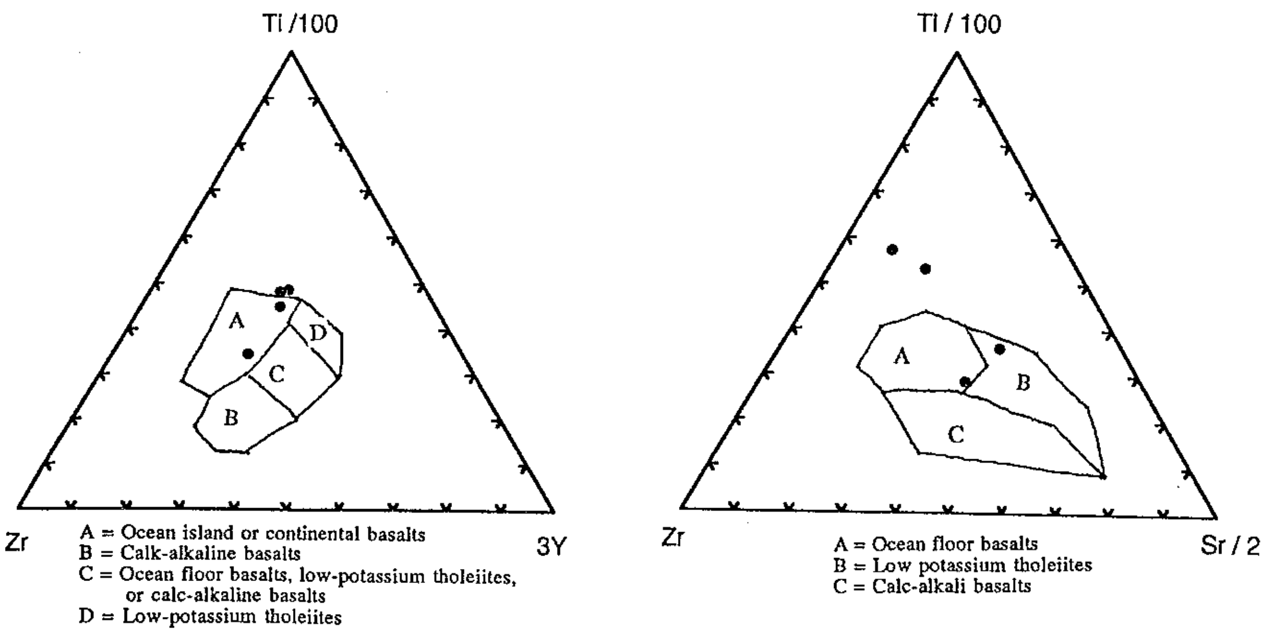


Diagram 9 and 10. Amphibolites plot in three different fields on the Ti-Zr-Y and Ti-Zr-Si ternary diagrams, offering ocean island basalts, continental basalts, ocean floor basalts, and low-potassium basalts as possible parent rock types.



chloritization. There are no foliations or chill margin apparent within the metaultramafics but there is a blackwall of biotite surrounding the pods. The pods are oriented subparallel to the regional foliation.

Metaultramafics are present throughout this area but their protolith and mechanism of emplacement were not resolved. The lack of chilled margins favors cold tectonic emplacement as slivers of ultramafic, but when this occurred is hard to tell. Since there is no foliation within the metaultramafics, it could be postulated that tectonic slicing occurred after the foliations formed. However, the metaultramafics may have been rigid enough to resist the deformation that caused the foliations.

Structure: The structure of this area includes a metamylonite (?), foliations, and three generations of folds. Foliations have a regionally consistent strike and dip of approximately N50°W; 60°NE (See Figure 1). In both amphibolites and gneisses, the poles to foliations are clustered in the southwestern quadrant though the poles to gneissic foliations are slightly more dispersed (See Figures 2 and 3).

There are three generations of folds present within the metasedimentary package. F1 and F2 folds are tight to isoclinal reclined folds seen in amphibolites and gneisses. In the field, folds were measured as F1 folds if they were refolded by another fold. Those folds that were seen to refold F1 or that belong to a set of folds whose members refolded F1 were designated as F2 folds. F3 folds, found on the limbs of earlier folds, were differentiated by axial surfaces oriented almost perpendicular to those of F1 and F2 folds. F1 and F2 hingelines mainly plunge into the northeastern quadrant at approximately 50°. F1 axial surfaces are N40°W; 50°NE and are subparallel to regional foliation (See Figure 4). F2 axial surfaces are more scattered but tend to strike NW and dip NE (See Figure 5). The uncommon F3 folds are open, upright folds. F3 hinge lines are oriented approximately N40°E; 50° which is subparallel to F1 and F2 fold hinges, but their axial surfaces strike to the NE and dip vertically (Figure 6).

Discussion: The fabric of the quartzofeldspathic gneiss of the metasedimentary package is dominated by lamination, lensing and rodding of sillimanite and quartz. The field appearance of this lithology suggests that it is a mylonite that has been almost totally recrystallized by a thermal event after the deformation that created the mylonite ended. Layering in the metamylonite and the rest of the metasedimentary package may be a secondary stratigraphy, as there is no evidence of sedimentary features. Metamylonite layers are deformed by all three generations of folds, and indeed there may only be one or two horizons of metamylonite present that have been repeated by intense folding. This could explain the differences in thickness of the metasedimentary package from Lower Branham Lake to Gneiss Lake saddle. The metasedimentary package has been interpreted to be a shear zone by Cummins and McCulloch (1992). My field observations agree with this interpretation even though Cummins and McCulloch fail to recognize the metasedimentary package enveloped by amphibolite that marks the shear zone.

The relationship between F1 and F2 folds is important but not fully resolved. They may represent distinct, successive fold generations. However, the parallelism of axial surfaces and hinge lines; the presence of identical mineral phases associated with both F1 and F2 folds; the parallelism of hinge lines with rare stretching lineations; and the presence nearby of at least one sheath fold whose axis is parallel to F1 and F2 hinges (See abstract by J.T. King, this volume) all suggest that these structures formed as the area was subjected to an extended period of progressive deformation incorporating a large component of simple shear.

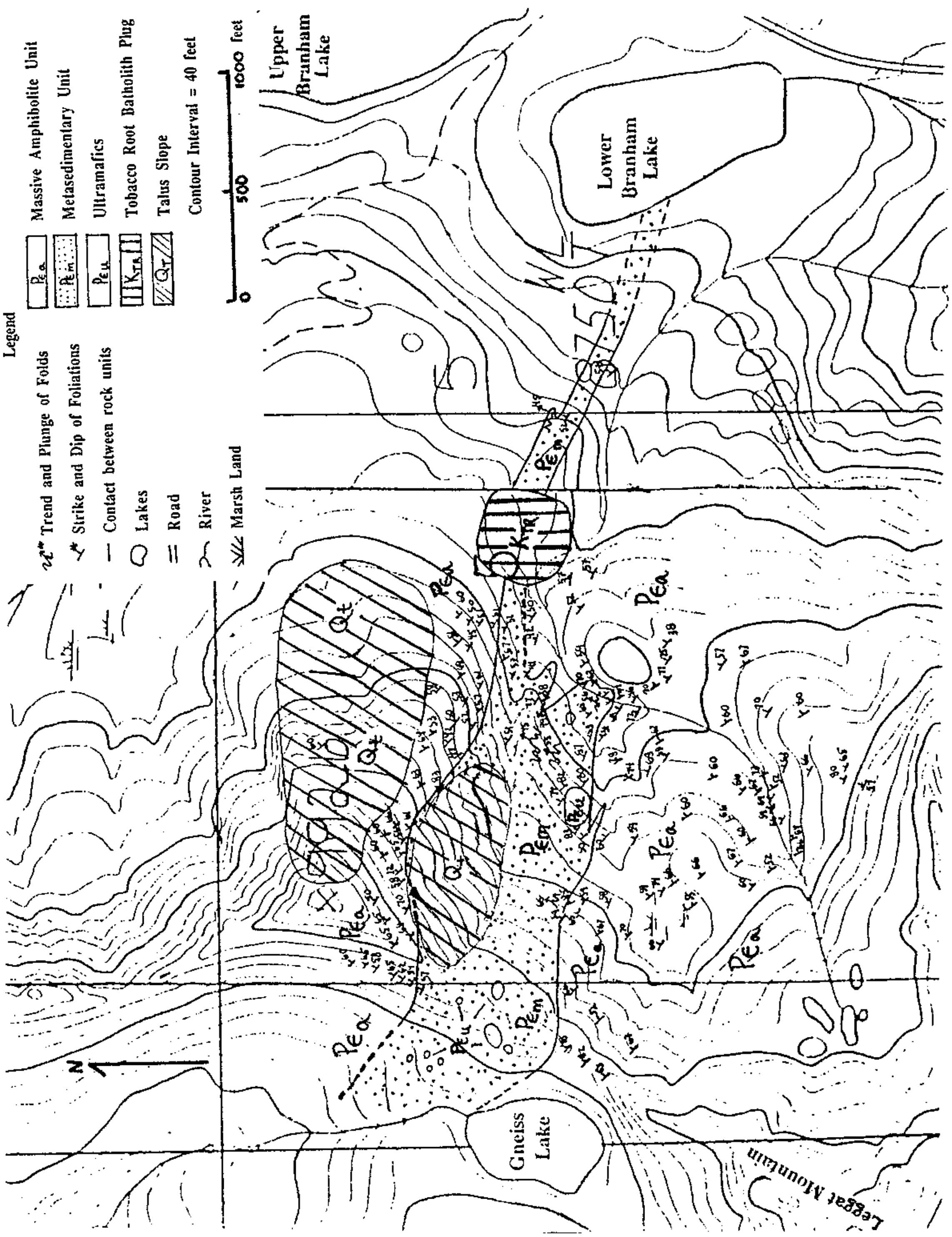
References:

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

Cummings, M.L. and McCulloch, W.R., 1992, Geochemistry and origin of amphibolite and ultramafic rocks, Branham Lakes area, Tobacco Root Mountains, southwestern Montana , *in* Bartholomew, M.J., Hyndman, D.W., Mogk, D.W., and Mason, R., eds., Basement Tectonics 8: Characterization and comparison of ancient and Mesozoic continental margins - Proceedings of the 8th International Conference on Basement Tectonics (Butte, Montana, 1988): Dordrecht, The Netherlands, Klumser Academic Publishers, p. 323-340.

Wooden, J.L., Mueller, P.A., Mogk, D.W., 1988, A review of the geochemistry and geochronology of the Archean rocks of the northern part of the Wyoming province, *in* Ernst, W., Ed,, Metamorphism and crustal evolution in the western U.S.: Rubey Volume, v. VII New York, Prentice-Hall, p. 383-410.

Figure 1. Map of an Intensely Deformed Zone Above Lower Branham Lake, Southern Tobacco Root Mountains, Montana



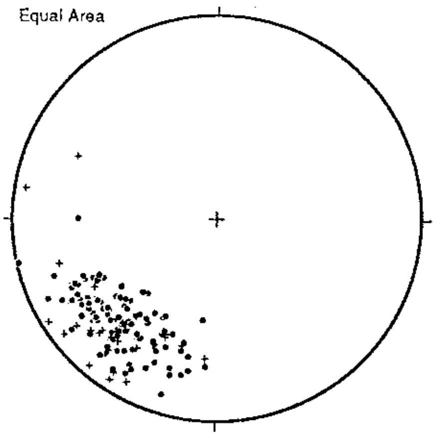


Figure 2. Poles to Foliations for Gneiss (+) and Amphibolites ( ).

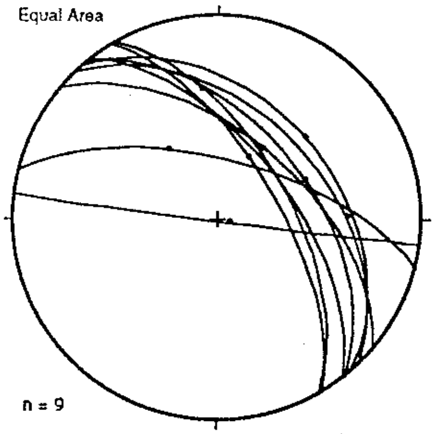


Figure 3. F1 Hinge Lines and Axial Surfaces.

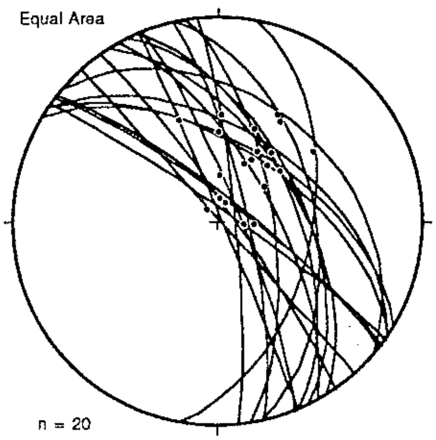


Figure 4. F2 Hinge Lines and Axial Surfaces

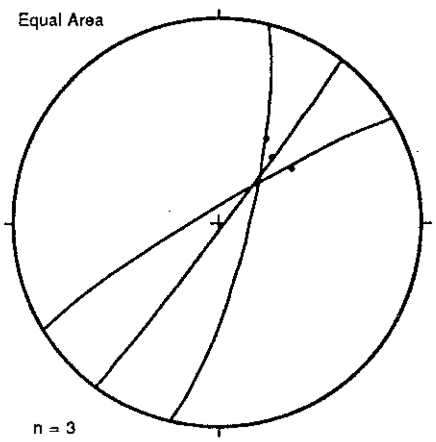


Figure 5. F3 Hinge Lines and Axial Surfaces

Table 1.Whole Rock Chemistry for Twelve Lithologic Samples (N/A means composition not available)

Sample #	6	11	15	17	30	1	14	19	22	24	27	28
Lithology	q.f. gneiss	garnet q.f. gneiss	q.f. gneiss	q.f. gneiss	quartzite	amphibolite	amphibolite	ultramafic	ultramafic	ultramafic	ultramafic	ultramafic
Major Elements												
SiO_2	67.03	53.09	68.28	67.02	94.91	50.26	52.22	44.08	47.51	43.16	43.1	48.32
TiO_2	0.64	0.82	0.54	0.9	0.14	0.9	2.07	0.22	0.19	0.26	0.21	0.3
Al_2O_3	15.38	16.35	13.8	14.68	2.57	13.76	12.28	4.81	5.26	4.34	5.16	4.16
Fe_2O_3	7.6	18.43	7.99	7.99	1.01	13.81	13.82	12.81	11.93	12.32	13.84	9.01
MgO	3.89	5.54	4.3	4.01	0.57	7.64	6.19	30.48	30.42	31.69	30.29	27.34
CaO	0.39	2.34	0.86	0.15	0.09	10.97	9.82	3.53	1.66	3.14	3.57	6.31
Na_2O	0.29	0.15	1.74	0.25	0.18	0.98	1.91	0.18	0.12	0.21	0.24	0.29
K_2O	2.83	0.55	2.84	3.67	0.47	0.55	0.48	0.05	0.03	0.57	0.07	0.27
P_2O_5	0.02	0.05	0.04	0.02	0.02	0.09	0.24	0.03	0.03	0.03	0.02	0.03
MnO	0.9	4.43	0.25	0.38	0.01	0.2	0.24	0.27	0.36	0.43	0.35	0.29
LOI	2.31	0.23	1.13	1.47	N/A	0.97	0.56	3.25	2.21	2.67	3.03	2.72
TOTAL	101.28	101.98	101.77	100.54	99.97	100.13	99.83	99.71	99.72	98.82	99.88	99.04
Trace Elements												
Ba	669	146	744	1194	N/A	41	77	4	9	112	4	38
Be	0.6	0.3	1.2	0.6	N/A	1.4	0	0.5	0.5	0.5	0.5	0.7
Ce	45	58	36	44	N/A	11	18	3	9	1	6	6
Co	23	37	23	23	N/A	59	41	101	103	96	114	73
Cr	317	394	331	367	N/A	162	45	2896	3582	4890	2666	3755
La	24	34	19	22	N/A	30	29	10	4	7	8	20
Sc	13	21	12	17	N/A	40	41	13	13	14	16	22
Sr	9	8	39	10	N/A	89	100	3	8	7	2	13
Ti	0.56	0.85	0.47	0.67	N/A	0.87	1.89	0.19	0.16	0.23	0.19	0.28
V	118	122	92	122	N/A	280	410	89	78	96	94	98
Y	13	25	11	19	N/A	20	48	6	3	5	6	10
Yb	1.3	2.7	0.9	1.9	N/A	2.1	5.9	0.53	0	0.1	0.5	0.8
Zr	156	168	144	225	N/A	63	135	19	12	9	33	36

THE ORIGIN AND EVOLUTION OF THE SPUHLER PEAK FORMATION ALONG THE WESTERN RIDGE OF THOMPSON PEAK, TOBACCO ROOT MOUNTAINS, MONTANA.

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Introduction

The Spuhler Peak Formation (SPF) has been interpreted as a distinct package of rocks within the Archean terrain of the Tobacco Root Mountains (Burger, 1966; Gillmeister, 1971). The Tobacco Root Mountains are contained within the northernmost part of the Wyoming Province as defined by Condie (1976). One of the fundamental characteristics of the SPF is the presence of orthoamphibole bearing rocks. Orthoamphiboles indicate that the rocks in which they are housed have been depleted in Ca and the alkalis and enriched in Mg. Spear (1993) has proposed that the most likely mechanism to explain the anomalous bulk composition of the orthoamphibole rocks is that of premetamorphic alteration by weathering, deuteric alteration, or hydrothermal alteration by sea water. This explanation is especially attractive when applied to the SPF, as it is consistent with the possibility that the SPF is a slice of Archean oceanic crust (since hydrothermal processes on the ocean floor are common in areas of volcanic and tectonic activity). Furthermore, because the extent of alteration depends upon the local access of sea water, which is most likely regulated by the local fracture density, this model can explain the interbedding of orthoamphibole- and calcic amphibole- bearing rocks. An alternative hypothesis to account for the intercalation of Mg-rich and normal basaltic rocks is that the SPF is a fragment of an Archean greenstone terrain and the Mg-rich rocks represent metamorphosed komatiite sequences. In either case, the SPF now resides on a supracrustal sequence, the ICMS, which consists of a sequence of quartzites, marbles, felsic gneisses, aluminous gneisses, and amphibolites.

Purpose and Methods

The objective of this study is to characterize the lithologies exposed along the western ridge of Thompson Peak in order to better constrain the origin and subsequent evolution of the Spuhler Peak Formation. This is being executed both on a macroscopic level, via a strip map illustration which shows the lithologic variation of the SPF exposed along a nearly continuous section (see Figure 1), and on a microscopic level, via analysis of the rocks in thin section. Specially attention has been focussed upon the occurance of cordierite, which has been previously overlooked in the rocks of the SPF. Over 60 hand samples were collected in the field, of which approximately 50 have been made into thin sections. Using the Zeiss Digital Scanning Electron Microscope (SEM) with a LINK Energy Dispersive Spectrometer (EDS), mineral composition data have been obtained from six SPF samples. This data will subsequently be employed in geothermometery and geobarometery in order to constrain the pressure and temperature of the package's metamorphic history.

Results

The western ridge of Thompson Peak contains a repetitive sequence of quartzites, amphibolites, and gneisses, as shown by Figure 1. Because the lithologies along the ridge have been extensively folded, unambiguous interpretation of field relationships is at best limited. The intercalated lithologies may reflect original emplacement or, more likely, indicate that the ridge is part of a large scale fold. Some rocks (especially the amphibolites) are well foliated but did not appear to be folded, whereas others (such as the pelites) commonly have small scale folds.

Most of the quartzites are aluminous and consistently contain silliminite, which is commonly strikingly coarse grained. One notable exception is the quartzite (which Gillmeister defines as the "basal quartzite") that marks the contact between the SPF and the ICMS. It is not aluminous, but does contain feldspar.