Petrographic Analysis of Amphibolites from the Spuhler Peak Formation, Indian Creek Metamorphic Suite, and Pony-Middle Mountain Metamorphic Complex Tobacco Root Mountains, Montana

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Introduction:

In this project, I am looking for any petrographic and petrochemical distinctions that exist between the amphibolites from the Spuhler Peak Formation and those in the surrounding rocks of the Indian Creek Metamorphic Suite and the Pony-Middle Mountain Metamorphic Complex. The similarities and differences will further an understanding of the protoliths and metamorphic histories of the rocks in this study.

Many authors (Cummings and McCulloch, 1992; Mogk and Henry, 1988; and Wilson, 1981), who have worked in this area previously, support the theory that the Spuhler Peak Formation is a slice of oceanic crust which is now sandwiched between two formations of metamorphosed sedimentary and intruded rocks. The Spuhler Peak amphibolites are thought to have originated as submarine thoeliitic basalt flows. Amphibolites in the Indian Creek Metamorphic Suite and the Pony-Middle Mountain Metamorphic Complex are mostly from flows and sills on the margins rimming this small, rift-bounded basin (Mogk and Henry, 1988).

I am also comparing my conclusions with these models. If they do not agree, I hope to delineate reasons, such as metasomatism, that explain the discrepancies.

Field Methodology:

Samples were collected from three basic regions in the southern Tobacco Root Mountains. These locations were based mostly on accessibility of the terrain by road and foot. The northernmost area, around Noble Lake, extended from the north side of Spuhler Peak south to Mustard Pass. Samples collected here and discussed below include PC-32, 36, 42, and 77. The central collection region ran along Indian Ridge, east to Thompson Peak. Samples PC-2, 7, 15, 20, 22, 26, and 27 are from this area. Samples were also taken from a zone enclosing Leggat Mountain's west-trending ridge, Gneiss Lake cirque, and the area to the west of Lower Brahnam Lake. Samples collected in the third locality are PC-62, 63, 67, 68, and 70. Additionally, four samples were collected north of these three main regions, in an isolated pocket of the Spuhler Peak Formation. One of these samples, PC-54, is discussed below. PC-75, was collected from south of Leggat Mountain, near the road leading to Brahnam Lakes.

Two basic types of amphibolites were identified, based on appearances in the field, within the Spuhler Peak Formation (SPF). These included the more common "salt and pepper amphibolite" and the "wispy amphibolite". The first type has a salt and pepper-like appearance from the distribution of small white plagioclase and quartz crystals and of darker hornblende crystals and other mafic minerals. The second type of amphibolite has "wispy" leucosomes of felsic material. The majority of samples collected were salt and pepper amphibolites. The wispy amphibolites were less widespread, and the possible focus of another student's research.

Amphibolites in the Indian Creek Metamorphic Suite (ICMS) and the Pony-Middle Mountain Metamorphic Complex (PMMMC) did not show wisps. The amphiboltes of these two formations may be of similar composition, though the PMMMC, overall, lacks the marbles and iron formations found in the ICMS. Wilson (1981), tested the whole rock chemistry of eight amphibolite samples. Five of these amphibolites were from the Tobacco Root Mountains, in the ICMS, and three from the Ruby Range. He found that they all had identical bulk chemistries. He also stated that they compared well with other amphibolites from nearby, such as the Beartooth, Spanish Peaks, and Madison Ranges.

Discussion:

Eighteen samples from the Spuhler Peak Formation, Indian Creek Metamorphic Suite, and the Pony-Middle Mountain Metamorphic Complex were selected based on the degree to which they represented their formation's amphibolites, the amount of weathering, and a size large enough for whole rock chemical analysis. Observation through the petrographic microscope of these samples has yielded the accompanying data.

The Spuhler Peak amphibolites are the largest grained and are mainly subhedral to euhedral. The ICMS rock grains are fine to medium sized and subhedral to anhedral. PMMMC amphibolites show medium to coarse

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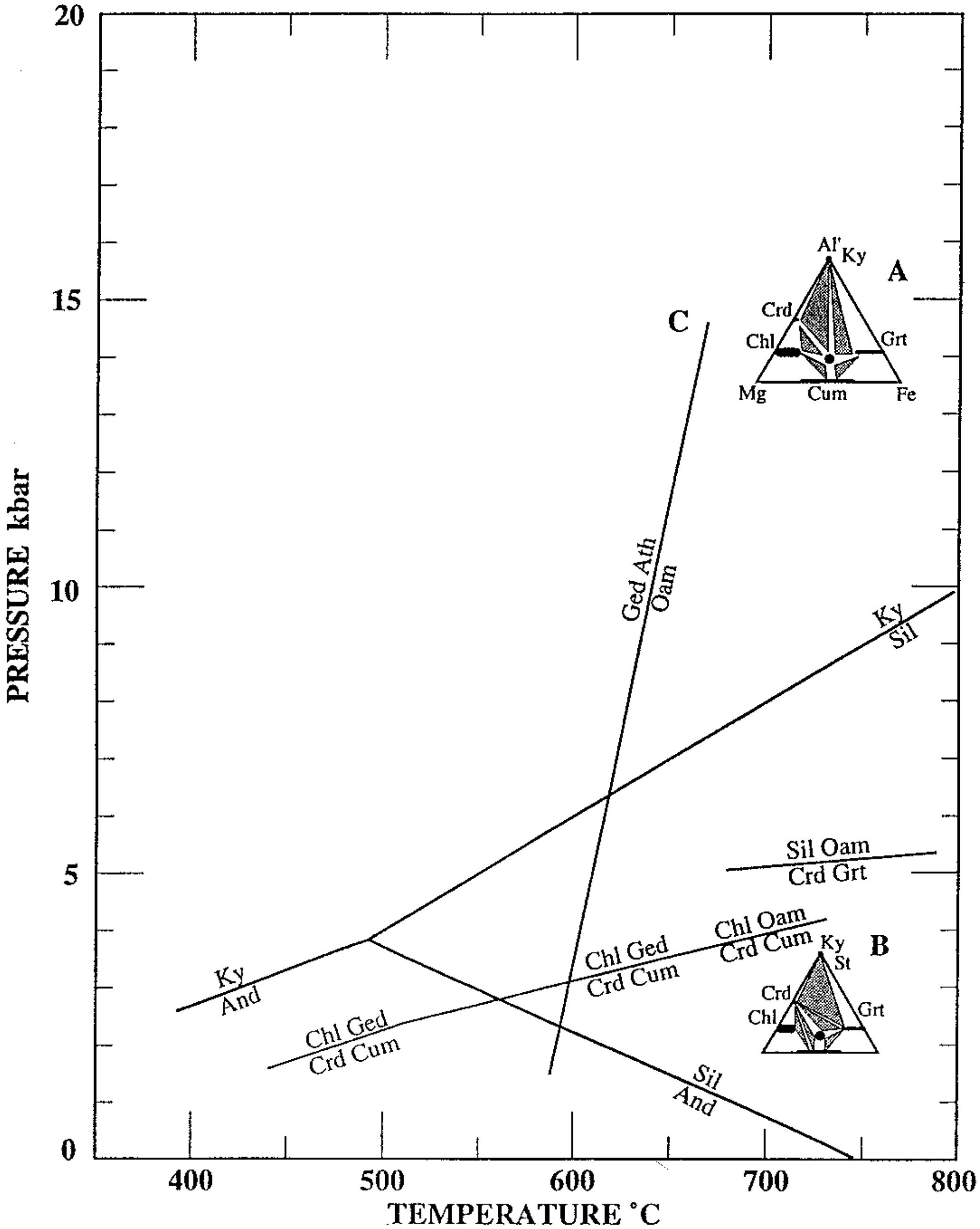

Figure 2. P-T diagram showing an empirical petrogenetic grid for cordierite anthophyllite rocks (After Spear, 1993).

grain sizes and subhedral to anhedral grain shapes. The larger and more well-formed grains of the SPF may be the result of a greater degree of equilibration as a result of slower cooling.

The amphiboles found in all of the samples are mostly hornblende. Cummingtonite also exists in about half of the samples. Most of these cases are in Spuhler Peak rocks. The higher magnesium content of cummingtonite could reflect an ocean origin. Magnesium nodules, for example, are found on the sea floor. Embayments of amphibole by plagioclase is fairly common, especially in SPF thin sections. This indicates plagioclase growth below the crystallization temperature of amphibole (1100^0 C). Additionally, inclusions of small plagioclase grains within a large amphibole crystal (PC-7) point to the solid-state growth of amphibole. Both of these observations illustrate responses to inequilibrium during metamorphic events.

Friberg (1976) notes that the presence of two to twenty percent garnet helps to distinguish rocks of the Spuhler Peak Formation from those of surrounding formations. This assessment does not hold true for the amphibolites that I collected. The presence and absence of garnet appears to be dispersed throughout the samples studied here.

Plagioclase, as was mentioned above, has been able to grow at the expense of nearby amphiboles. Some thin sections (PC-22, 54, 67, 68, and 70) also have sericitized plagioclase, but lack biotite. Water was introduced below the crystalization temperature of amphibole, but above that of plagioclase (550^0 C). This could have occurred before the lower grade metamorphic event (450^0 C, 2 kb) mentioned by both Friberg (1976) and McCulluch (1989) that occurred after the main, amphibolite facies event. Sample PC-54 contains small, interstitial plagioclase grains which go into optical extinction at one angle around larger amphibole grains. This, too, points to a plagioclase matrix that cooled as one unit. This may have happened prior to the retrograde metamorphic event just mentioned, as the region was cooling down from the hotter event.

Biotite of both green and red pleochroism are found in these rocks. Friberg (1976) and Wilson (1981) mention that the red crystals are the result of prograde metamorphism and the green of retrograde.

Future Research Plans:

Thin section analysis did not seem to indicate characteristic trends for the major minerals within each formation. Additional thin section observation of the minor minerals may lead to more obvious divisions.

Distinguishing between amphibolites of sedimentary origin and those of igneous origin is notoriously difficult. Friberg (1976), during his study in this region, used the Niggli carbon-versus-magnesium plot to test six amphibolite samples. He found equal amounts indicating meta-sedimentary and meta-igneous paths. I will also plot a Niggli diagram in hopes of seeing a more definate trend in my samples. Another test of this type, the Leake magnesium-calcium-aluminun plot, may give clearer results. Other major element plots which aid in delineating protoliths involve sodium and potassium-versus-silica, and the Harzberg graphs of magnesium-, calcium-, and aluminum-versus-silica.

Whole rock petrochemical analysis will be conducted by crushing and fusing into glass discs at least twelve of the samples discussed above (samples PC-2, 15, 20, 26, 36, 42, 54, 62, 63, 70, 75, and 77). Additionally, using petrochemical data that other students have gathered on this region's amphibolites will help support my hypothseses. Through the use of discriminant diagrams, my analyses may aid in the differentiation between amphibolites of these three rock groups.

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Modal Percentages

Sample #	Fm	Amphibole	Garnet	Plagioclase	Quartz	Biotite	Glass	Opaques	Epidote	Chlorite	Sphene	Apatite	Monazite
PC - 2	S Pk	20%	25%	30%	20%	1.50%	-	2%	-	1.50%	-	-	-
PC - 7	S Pk	45%	-	33%	20%	0.50%	-	-	-	-	0.50%	0.50%	-
PC - 15	S Pk	35%	35%	3%	20%	5%	-	2%	-	-	-	-	-
PC - 20	S Pk	40%	-	25%	35%	-	-	-	-	-	-	trace	-
PC - 22	S Pk	50%	30%	5%	15%	-	-	trace	-	-	-	-	-
PC - 26	S Pk	50%	9%	20%	15%	0.50%	5%	-	-	0.50%	-	-	-
PC - 27	S Pk	64%	-	10%	25%	-	-	1%	-	-	-	-	-
PC - 32	S Pk	30%	9%	15%	35%	10%	-	1%	-	-	-	-	-
PC - 36	S Pk	49.50%	15%	10%	25%	0.50%	-	-	-	-	-	-	-
PC - 68	S Pk	34.50%	20%	15%	25%	-	5%	0.50%	-	-	-	-	-
PC - 42	ICMS	75%	-	10%	13%	-	-	2%	-	-	-	-	-
PC - 62	ICMS	45%	26%	7%	21%	-	-	1%	-	-	trace	-	trace
PC - 63	ICMS	20%	30%	15%	20%	12%	-	3%	trace	-	-	-	-
PC - 67	ICMS	55%	-	25%	19%	-	-	1%	-	-	-	trace	-
PC - 70	ICMS	44%	10%	9%	33%	-	3%	1%	-	-	trace	-	-
PC - 75	ICMS	85%	-	5%	9.50%	-	-	0.50%	-	-	-	-	-
PC - 54	PMMMC	55%	5%	13%	23%	-	-	1%	3%	-	trace	-	-
PC - 77	PMMMC	60%	20%	5%	10%	-	4%	1%	-	-	1%	-	-