Contact Metamorphic Effects of the Wallowa Batholith on the Hurwal Formation, Wallowa Mountains, Oregon.

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Introduction

The Upper Triassic to Lower Jurassic Hurwal Formation is part ot the Eagle Creek area of the southern Wallowa Mountains found in the Seven Devils terrane in Northeast Oregon. This region was deformed by Mesozoic tectonism that faulted and folded the terrane. Jurassic and Cretaceous intrusions of the Wallowa Batholith further metamorphosed the surrounding formations, recrystallizing the rocks and changing their mineralogy.

The Hurwal Formation consists of laminated carbonaceous beds and siltstones interbedded with shale and thin beds of limestone. Although a greater portion of this formation is badly weathered to a rusty color, graded bedding can still be seen in certain sections of the stratigraphic column. While there is no particular pattern to it, the Hurwal Formation tends to be more argillaceous and less silty higher in the stratigraphy. According to Vallier(1977) this is an indication of a deepening basin. For easier identification and convenience, I divided the formation into three sub-units:

1)Argillaceous Hurwal interbedded with limestone and/or marble
2)Shaley Hurwal, and
3)Limy Hurwal or siltstone

The three sub-units alternate throughout the stratigraphic column but follow no specific alternation pattern. The Hurwal conformably overlies the Martin Bridge Limestone, exhibiting a gradational contact between the two formations. The first argillaceous bed immediately above the top of the Martin Bridge beds was taken to be the base of the Hurwal Formation .

Following a field investigation, SEM/ EDS and petrographic studies of the obtained samples were carried out. By determining mineralogy and metamorphic textures from these rocks an estimate of the extent to which they were metamorphosed by the Wallowa Batholith could be made.

The batholith extends over miles of area and is in contact with various formations of the Seven Devils terrane. Although the actual batholith-Hurwal contact was rarely exposed in the area of study, batholith-related dikes cut through the Hurwal Formation. The contact aureole extends to approximately 30 from the Wallowa batholith. Except for small bands of coarser grained minerals near the contact, the Hurwal Formation appears relatively unmetamorphosed. The contact was probably faulted or covered by post-batholith deformation.

Mineralogy & Metamorphism

Minerals identified by petrographic analysis include, in order of abundance, quartz, pyroxene(diopside), magnetite, epidote, idocrase, zoisite / clinozoisite, chlorite, garnet, biotite, amphibole, sphene, albite, calcite, and muscovite. Table 1 shows the different samples/thin sections, their mineralogy and observed textures with estimated distance from the batholith contact. Although quartz and pyroxene are the most abundant minerals in all the studied samples, opaque mineral(s) were also present in most samples. From the SEM/ EDS analysis the presence of idocrase, pyroxene, amphibole, garnet, albite, quartz, and zoisite was confirmed. This technique also revealed the presence of muscovite, diopside, and magnetite in some Hurwal rocks. The presence of Ca-rich minerals is interesting as it might allude to a calsic precursor for the Hurwal Formation. The field relationship of the Hurwal with the Martin Bridge limestone could also be a factor worth investigating. However, that would be true if the occurrence was only at the gradational contact between the two formations, but the Ca-rich minerals occur throughout the sampled 500 meters of the Hurwal Formation. It is therefore very important to investigate some of the minerals that give Hurwal rocks their calsic component.

Vesuvianite (idocrase) is most common within 30 meters of the estimated contact with the batholith and occurs primarily as porphyroblasts. Together with diopside and/or grossularite, and with epidote, idocrase has been identified in medium grade rocks (amphibolite facies) (Winkler, 1974). Idocrase can, however, also appear in low grade or greenschist facies in the folowing assemblages: idocrase + chlorite, idocrase + actinolite, and idocrase + epidote. As shown in Table 1, idocrase occurs more often with garnet and diopside than with chlorite and amphibole, pointing to amphibolite facies metamorphic grade. Table 1 also shows the co-occurrence of diopside, idocrase and grossularite in certain samples, a sign of compositional variation within a small area of the rocks.

are predominantly westward vergent. Several high-angle faults with minimal offset ($<$20m) are apparent at the steepest parts of major folds and may have occurred when plastic limits of deformation were exceeded.

Westward transport is indicated along the major thrust fault in the field area. Locally, this fault appears to be a bedding plane fault which was displaced along the ductile lower Martin Bridge unit. The near-surface geometry of the fault can be traced along the face of a cliff and locally, its dip is clearly shallow. Sub-surface geometry is uncertain.

Numerous dikes crop out in the field area and samples of representative types were collected for petrographic and geochemical analysis. Thin section analysis reveals that all samples were metamorphosed under amphibolite grade conditions. Conditions of metamorphism are difficult to constrain precisely for amphibolites, but several features provide some clues. First, the olive-brown pleochroism of hornblende suggests moderate temperatures and relatively low pressures; at high temperatures hornblende is deep brown and at high pressures it is tinted blue. Additionally, the typomorphic texture of ragged, fibrous hornblende grain boundaries is typical of low grade amphibolite conditions; at higher grades grain boundaries become smooth and straight (Spry, 1969). Finally, the presence of epidote in the igneous samples, and the presence of tremolite in the argillaceous sediments (as noted in the field) further constrain metamorphism to low-grade amphibloite conditions; at higher grades, epidote is lost and diopside replaces tremolite.

Protolith compositions are also difficult to determine petrographically given the "garbage-can" mineralogy of hornblende which commonly comprises up to 30% or more of the samples. Mineralogy and textures are variable among the samples but two distinct petrographic and geochemical types are evident. In Type I, hornblende is abundant and together with altered plagioclase, comprises the bulk of the rock. Additional minerals include pyroxene, biotite, epidote, and quartz in minor quantities. A representative XRF analysis for this type is as follows:

SiO_2	50%	K_2O	1%
MgO	15%	CaO	10%
Al_2O_3	11%	TiO_2	0.6%
P_2O_5	0.07%	MnO	0.2%
Na_2O	1%	Fe_2O_3	9%

Because high proportions of hornblende in metamorphosed igneous bodies is suggestive of a mafic parent rock (Spry, 1969), the abundance of hornblende in Type I dikes along with the low silica content, suggests a basaltic protolith.

In Type II dikes, plagioclase and quartz are the dominant minerals. Opaques are generally abundant (3-5%) and biotite, muscovite, and epidote may all be present in minor amounts (1-3%). Representative XRF data indicates felsic compositions:

SiO_2	74%	K_2O	0.5%
MgO	0.3%	CaO	1%
Al_2O_3	16%	TiO_2	0.1%
P_2O_5	0.1%	MnO	0.2%
Na_2O	8%	Fe_2O_3	1.5%

Mineralogical and textural differences are somewhat gradational between the two types and may represent, to some degree, a suite of genetically related rocks. The fact that all of the sampled dikes exhibit signs of similar conditions of metamorphism constrains the timing of their emplacement to precede regional metamorphism. The dikes are possibly related to pre-accretionary island arc magmatism.

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Table 1- Hurwal Formation

	Sample	Information		Minerals in Sample (y/n)								
Thin Section	**Dist. from Contact**	**Size in Mm**	**Texture**	**Quartz**	**Pyroxene**	**Opaques**	**C-zoisite**	**Garnet**	**Chlorite**	**Biotite**	**Idocrase**	**Other....**
S1-F	2 to 5 meters	0.5	fine-medium porphyroblastic	y	y	y	epidote	y	y	y	n	hornblende
A1-MBC	5 meters	0.4	fine-medium	y	?	y	n	y, zoned	?	n	n	calcite
An-1	10-15 meters	0.2	fine porphyroblastic	y	y diopside	magnetite	n	grossular	n	n	y,2.8Mm	sphene albite
An-2	15 meters	0.2	fine porphyroblastic	y	y diopside	magnetite	n	grossular	n	n	y,2.8Mm	muscovite
A1-UC	20 meters	0.3	fine	y	y	y	n	y	n	n	y,2.5Mm	
S2-C	23 meters	1 to 2	med-coarse	y	y	y	y	n	n	n	n	
S2	25 meters	0.005	v.fine, banded porphyroblastic	y	y	y	n	y	y	y	y,2.8Mm	
27	27 meters	0.2	fine porphyroblastic	y	y	y	n	y	n	n	y,2.8Mm	sphene
ULA-2	50 meters	0.5 to 1	med-coarse	y	y	y	y	y	n	n	n	
LA-2	55 meters	0.5	medium	y	y	y	n	n	n	y	n	
TA-2	65 meters	.005 to 0.1	fine porphyroblastic	y	y	y	y	n	n	n	y,2.5Mm	
90-L	90 meters	0.4	fine-medium	y	y	n	n	n	n	n	n	
IS6-F	120 meters	0.2	fine near marble dike	y	y	y	y	n	n	n	n	
LA2-PF	125 meters	0.3	fine-medium between marble	y	y	y	y	n	n	n	n	
S7	145 meters	0.2	fine	y	y	y	n	n	n	n	n	
A3-237	237 meters	0.15	very fine banded	y	y	y	n	n	n	n	n	amphibole
253	253 meters	0.1	very fine	y	y	y	?	n	n	n	n	
280-F	280 meters	0.35	fine-medium	y	y	y	n	n	y	n	n	amphibole
401	401 meters	0.1	very fine	y	y	y	?	n	n	n	n	
420	420 meters	0.005	very fine	y	y	y	y	n	n	?	n	

Diopside is usually an indication of low grade metamorphism because of its early formation in the crystallization sequence. The more Mg-rich varieties of the diopside-hedenbergite series are characteristic of thermally metamorphosed Ca-rich sediments (Deer, et al, 1966).

The presence of biotite, an index mineral, marks the onset of PT conditions that characterize the biotite zone. During thermal metamorphism of many argillaceous rocks, biotite becomes the initial mineral that recrystallizes, usually exhibiting a coincidental decrease in chlorite and muscovite (Deer, et al, 1966). This appears to be the trend, judging by the diminished occurrence of muscovite compared to that of biotite. Because of the $Fe^{+2/+3}$ composition of biotite, it can be associated with lower metamorphic grade. As pointed out by Deer, et al, 1966, biotite composition is often influenced by the presence of other ferromagnesian minerals present.

Minerals like chlorite are most characteristic of the greenschist facies. Chlorite is, in fact, widely distributed in low grade metamorphic rocks (Yardley, 1989). Considering the relatively low modal proportions of chlorite in the Hurwal rocks, we can infer greenschist facies conditions to have prevailed during the metamorphic event.

Minerals of the epidote group occur principally in regionally metamorphosed rocks that mark the threshold of the change from greenschist to amphibolite facies. Their formation is favoured by shearing stress and low temperatures even though they may form in the absence of stress.

An investigation of the garnets found in these rocks points to a grossularite composition. In thin section the garnets were a yellow to a brownish red color. The color of grossularite is largely dependent on the amount of Fe and Mn present (Deer, et al, 1966). From the SEM/ EDS analysis of garnet, both Mn and Fe were detected and must have imparted the coloring to the garnets. This variety is supposed to be characteristic of both thermally and regionally metamorphosed impure calcareous rocks and of rocks that have undergone calcium metasomatism (Yardley, 1989).

Metamorphic Textures

Different metamorphic textures were exhibited by the different samples studied. These textures (see Table 1) are a function of the metamorphic grade as well as of the distance from the contact. There an observed change in grain size that corresponds with distance from the batholith. The occurrence of certain mineral assemblages that are indicative of changing metamorphic grade can also be noted. For instance, chlorite, diopside and grossularite represent a low grade assemblage that denotes greenschist metamorphic conditions. The majority of the Hurwal rocks,however, are fine-grained, which could be a result of the angle at which the batholith intrudes this formation, near the batholith, and due to regional deformation farther from the contact. Another possible reason, as was suggested by Taubeneck (1958), could be the forceful injection of the intrusive rocks at the time of emplacement. Because of the added stress, more nucleation sites would be produced, leading to the growth of many fine grains. This may account for the fine-grained nature of the Hurwal rocks that would otherwise be expected to have a coarser texture due to their proximity to the heat source, the batholith.

Conclusion

Based on the mineralogy, the Hurwal Formation can be classified as mostly being an argillaceous and shaley formation metamorphosed to greenschist facies. The presence of diopside co-existing with idocrase and grossularite may indicate amphibolite facies conditions. Both thermal and deformational events seem to be responsible for the metamorphism exhibited by the rocks of the Hurwal Formation. The agents of metamorphism are mainly the batholith, closer to the contact, and the regional deformation farther from the contact aureole. The smaller batholith-related dikes baked the rocks but no conclusive evidence that they recrystallized any of the rocks with which they are in contact is immediately obvious. With greater distance from the batholith contact, the Hurwal rocks appear unmetamorphosed owing to the regional metamorphism which resulted in very low to low grade metamorphic conditions.

The metamorphic minerals evident from the petrographic and SEM/ EDS analyses include diopside, grossularite, biotite, muscovite, epidote, zoisite, hornblende, idocrase, tremolite/actinolite, sphene, and quartz. The prevalence of a Ca component, coupled with the occurrence of Mg, in the Hurwal rocks suggests the bulk composition to have been dolomitic, rather than calcitic, in nature. This would account for the calcic or limy composition of the Hurwal Formation throughout the sampled column.

The Wallowa Batholith, therefore, metamorphosed the Hurwal rocks to greenschist, and to a lesser extent, amphibolite facies of fine to medium grain size. The texture appears to be slightly hornfelsic, as was observed by Reich and Winter, 1984, with porphyroblasts of idocrase and, sometimes, diopside. Owing to the ubiquitous occurrence of Ca-rich minerals and the Mg compositions manifested in the metamorphosed rocks, we can infer that the bulk composition must have been dolomitic, rather than calcitic, in nature.

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The Deformational History in the Vicinity of Pete's Point, Eagle Cap Wilderness Park, Northeastern Oregon

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INTRODUCTION

The Jewett Lake region in the Wallowa Mountains has undergone severe deformation characterized by repeated folding, faulting, metamorphism, uplift, and erosion. This deformation has not been closely studied since the advent of plate tectonic theory, thus the possible tectonic causes of the deformation have not been evaluated. Instead, much of the deformation and metamorphism in the region has been attributed to emplacement of the Wallowa Batholith. In the current study, I intend to develop a structural and metamorphic history of my field area, just south of Jewett Lake (Figure 1). This history will aid in evaluating possible causes of deformation and stress in the context of mass displacement due to batholith intrusion as well as what is now known about plate tectonics and accretion.

LITHOLOGIES

There are two major formations present in the field area; the Martin Bridge Formation and the overlying Hurwal Formation. The Martin Bridge and Hurwal Formations occur throughout northeastern Oregon and western Idaho as the upper members of the accreted Wallowa arc terrane. The Martin Bridge Formation is predominantly a massive and thinly bedded platform limestone (Vallier, 1974) with localized reefs (Nolf, 1966). Lying conformably atop the Martin Bridge is the Hurwal Formation, a transgressive-regressive sequence of shale and limestone (Brooks and Vallier, 1978). By examining fossils in both formations, Smith and Allen (1941) have concluded that the Martin Bridge Formation was deposited during the Upper Triassic, mostly during the Carnian. It appears that the boundary between the two formations closely approximates the boundary of the Carnian and the Norian. The top of the Hurwal Formation has never been observed; it is assumed that the majority of deposition occurred during the Norian, however, the exact time that deposition ceased is unknown.

In the Jewett Lake region, the Martin Bridge Formation can be subdivided into an upper and a lower member. The younger, upper member is a dark grey, rhythmically layered limestone and silty limestone which is only present locally and is not observed in my study area. The older and more prominent unit is a light to medium grey metamorphosed limestone with minor siltstone interbeds. The member is not exposed in its entirety anywhere in the region, but the thickness is in excess of 200 m. Two distinctive beds of a dark grey, coarse grained limestone fossil mash approximately 1 m in width contain fragments of crinoids, brachiopods, limpets, sponge spicules, and well-rounded clasts of sandstone and shale. Though distinctive, these layers cannot be used as regional marker beds because they are extremely localized. In thin section, the rocks consist primarily of twinned calcite grains and minor amounts of diopside and quartz indicating amphibolite facies metamorphism. The Martin Bridge limestone has been ductilely deformed, producing both annealed and mylonitic fabrics.

The Hurwal Formation can be subdivided into three members. The lowermost member is a 20 m transitional zone consisting of interbedded argillite and limestone. This member grades from thick beds of limestone with sparse layers of argillite at the base upward to predominantly argillite and sandstone beds. Above this transitional zone is a 0-100 m thick grey, tan, or rusty, rhythmically weathered bedded argillite with minor limestone and sandstone. Capping the Hurwal Formation is at least 200m of black, rhythmically bedded argillite and siltstone with very minor limestone, which weathers to a rust color. The entire Hurwal Formation has been metamorphosed to amphibolite facies, as indicated by the thin section mineral assemblage of amphibole+feldspar+diopside, with minor amounts of calcite, quartz, and opaques.

In the field, distinction between the two upper members was based primarily upon coloration of weathered surfaces and the relative abundance of limestone. The separate members were examined by X-Ray Fluorescence (XRF) Spectrometry to compare chemical compositions. The upper, rust colored member contains generally higher concentrations of calcium, although the variation of calcium content within the members is greater than the variation between members. The rust colored member also contains lower concentrations of iron, which may seem contrary to megascopic observations of rust staining. However, the coloration could be due to the oxidation state of the iron. The rust colored member was observed to have a characteristic presence of pyrite; perhaps the iron in the grey unit is in the form of magnetite or hematite. Oxidation states cannot be determined by XRF Spectrometry. Finally, when analyzed for ten major elements, the rust colored member had lower concentration totals. It is plausible that sulfur, which was not analyzed, contributes significantly to the composition of the rust colored member, accounting for the