PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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KECK GEOLOGY CONSORTIUM
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Keck Geology Consortium: Projects 2014-2015
Short Contributions— Tectonics of the Ruby Range, MT Project

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GEOTHERMOBAROMETRY AND PETROGRAPHIC INTERPRETATIONS OF CHRISTENSEN RANCH METAMORPHOSED BANDED IRON FORMATION FROM THE RUBY RANGE, MONTANA

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Research Advisor: Dr. Andrew Wulff

INTRODUCTION

The occurrences of metamorphosed banded iron formation (meta-BIF) of the Ruby Range and in the nearby Tobacco Root Mountains of southwest Montana were described by Immega and Klein (1976) as “thin, discontinuous, banded, lenticular bodies”. Recent field observations made around Stone Creek in the Ruby Range confirm this statement, however meta-BIF of a particular locale loosely referred to as the “Iron Mine” differs markedly from this description. The various meta-BIFs of the Ruby Range are found in a group of metasupracrustal rocks including amphibolites, metapelites, calc-silicates, and marbles which form the Christensen Ranch suite. The relative positions of Stone Creek and Iron Mine meta-BIFs are shown in Figure 1 below.

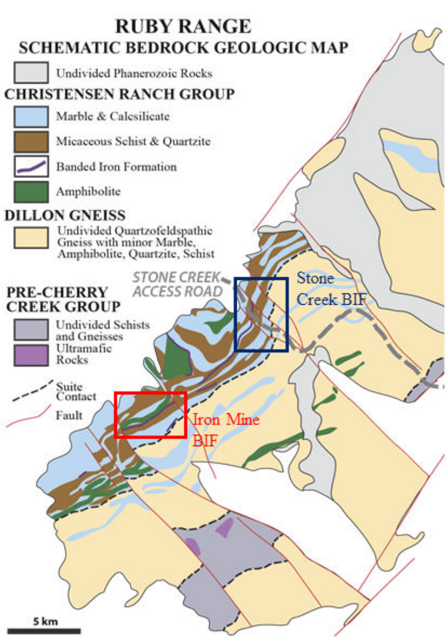

Figure 1. Location of both Stone Creek and Iron Mine meta-BIFs. Geology taken from James (1990).

A diversity of original depositional settings are well known for many Proterozoic meta-BIFs (see Klein, 2005), It is important to note that a deep sea depositional environment (a characteristic of Algoma type BIF deposits (Gross, 1996)) may also produce alternating metals-rich and quartz-rich layers of a BIF due to chemostratification and precipitation of varve-like couplets (Klein, 2005; Trendall, 2002). The goal of this project is to examine and characterize samples of Stone Creek and Iron Mine meta-BIF in terms of composition, texture, location within the Christensen Ranch suite and degree of metamorphism with the goal of not only a greater understanding of the metamorphic history of the Ruby Range meta-BIF but the pressure-temperature conditions of the Big Sky orogeny as a whole.

METHODS

Field Procedure

Stone Creek Road, a service road for the nearby talc mine, is oriented oblique to the regional strike and served to provide ample access to a significant portion of the study area. Outcrops were located initially via traverses perpendicular to the regional strike. Along-strike traverses of the various formations were conducted to locate additional exposures and to detail any variability in unit thickness, composition, or texture. Intermittent samples were collected at representative sections and sections with any notable variability. These iron formations adhered closely to the regional strike and dip (approximately 190°/80°). Sampling of Iron Mine meta-BIF was conducted at regular intervals in an along-strike traverse starting from its northernmost edge.

Sample Preparation

Slabs were cut into thin section billets perpendicular to foliation and perpendicular to any fold hinges. Select slabs were also cut parallel to foliation. Samples were powdered for X-ray diffraction first using a ceramic mortar and pestle, then with a smaller agate mortar and pestle with acetone or methanol to form a slurry. Splits of the powders were packed into sample disks or smear mounts for X-ray diffraction analysis. Polished thin sections were created for petrographic inspection utilizing polarized light microscopy to identify mineral assemblages and characterize their interrelationships. Ambiguous oxide, pyroxene, and amphibole phases were noted and their locations marked on scanned thin section maps for Raman identification. Due to the nature of the Raman effect, the Raman microscope does not perform well with iron-rich phases and iron oxide bonds, but this effect can be mitigated by the use of a 50x composite objective which requires a sub-millimeter working distance to minimize these effects on resultant spectra. Raman microscopy was able to corroborate the identification of minerals observed using polarized light microscopy techniques while also yielding further insight on other phases that are significantly more difficult to identify relying on polarized light microscopy exclusively.

RESULTS

Stone Creek Iron Formations

Stone Creek meta-BIFs, while often marked on geologic maps of the area, are in many cases only thin, laterally continuous beds typically less than one or two meters in width. Where exposed these iron-formations are commonly weathered to a dull red-brown and accompanied by distinctive red soil and ant colonies in some places. In outcrop Stone Creek meta-BIFs exhibit alternating magnetite/hematite and quartz bands ranging from less than 0.5 cm to 2.5 cm in width. Banding is continuous, although quartz lenses are not uncommon. Magnetite/hematite bands (containing additional minor silicate mineralization) are dominant, constituting 55% to 80% of the rock by composition with quartz largely responsible for the remainder. Trendall & Blockley (1970) have suggested terminology for the scale of banding in BIF. According to this scheme, banding in the Stone Creek meta-BIFs ranges from mesobands (average thickness of less than one inch) to microbands (0.3-1.7 mm). Grain size of the magnetite/hematite is typically sub-millimeter in scale. Non-quartz and non-iron oxide mineralization is sparse (accounting for two percent or less of total composition), and, where present, generally occurs between quartz and iron oxide bands.

Meta-BIF occurrences are interlayered with a number of different lithologies including amphibolite, marble, and metapelite. Thin (between 0.5 to 2 meter) sections of Stone Creek meta-BIF are bounded on both sides by a single lithology (dominantly metapelite) or form a boundary between disparate lithologies (commonly between metapelite and either marble or amphibolite). The complex folding and faulting of the region makes it difficult to resolve with certainty whether the observed iron formations in the study area are all stratigraphically distinct or if many are simply the expression of the same unit (James, 1990).

Banding variations include highly folded, two-centimeter width monomineralic bands and sub-centimeter scale, planar bedding. Stone Creek meta-BIF (samples 14-JH-1a to 14-JH-10b as well as 14-JH-20) tends to exhibit more well-defined, thin bedded layers. These samples exhibit roughly equal modal percentages (between 40 to 5%, respectively) of both quartz as well as various oxides such as magnetite, hematite and ilmenite. The use of polarized light microscopy also showed anywhere from 5 to 15% amphibole as well as up to 5% pyroxene within Stone Creek meta-BIF. Pyroxenes identified employing Raman microscopy in Stone Creek samples 1c and 6 were found to be strong matches for diopside with some augite and hedenbergite. Most amphiboles from Stone Creek sample numbers 3B, 5, and 6, were identified as clinoamphiboles on the basis of polarized light microscopy techniques, and vary from tremolite to actinolite. Some observed grains have exsolution features showing both actinolite and grunerite. Sample 6 also contains sodium-rich phases loosely identified as possible matches to katophorite or winchite.

Figure 2. Field photograph of tightly folded Iron Mine meta-BIF.

Iron Mine Iron Formations

Unlike its Stone Creek counterparts the meta-BIF of the Iron Mine is well-exposed in almost continuous outcrop. Located near the abandoned Christensen Ranch homestead off of Sweetwater Road, the Iron Mine meta-BIF forms a prominent ridge adjacent to recent unconsolidated sediments. Iron Mine meta-BIF is often highly-folded, with a thickness in outcrop greater than six meters, and forms the crest of a ridge spanning over 100 meters. Folded Iron Mine meta-BIF features thickened, parallel folded hinges coupled with elliptical folds. The intense folding suggests that the Iron Mine BIF may have undergone higher grade metamorphism than that of the Stone Creek BIF. The texture of the iron formation varies from wavy bands to fine, well-laminated bands (up to 0.25 cm), discontinuous quartz lenses, locally folded, of quartz-rich bands, pyroxene-rich and quartz-poor bands, well-layered bands of equal proportions quartz and other phases up to 1.5 cm thick, and poorly developed fabrics with coarse grain sizes of 0.25 cm. Figure 2 showcases a highly folded section of Iron Mine meta-BIF. This variability in texture parallels a pronounced variability in composition as respective portions of the outcrop contain green, pyroxene-rich bands up to 0.5 cm, abundant specular hematite, and garnet-rich zones. Grain-size is typically fine to microscopic. Pyroxene and garnet phases are largely concentrated at the contact between magnetite/hematite and quartz layers. Pyroxenes from sample 13d range from diopside to hedenbergite, but are dominated by augite. Raman spectra of garnets found in sample 18b are strong matches to andradite. Amphiboles in Iron Mine samples 13d and 14 vary from tremolite to actinolite

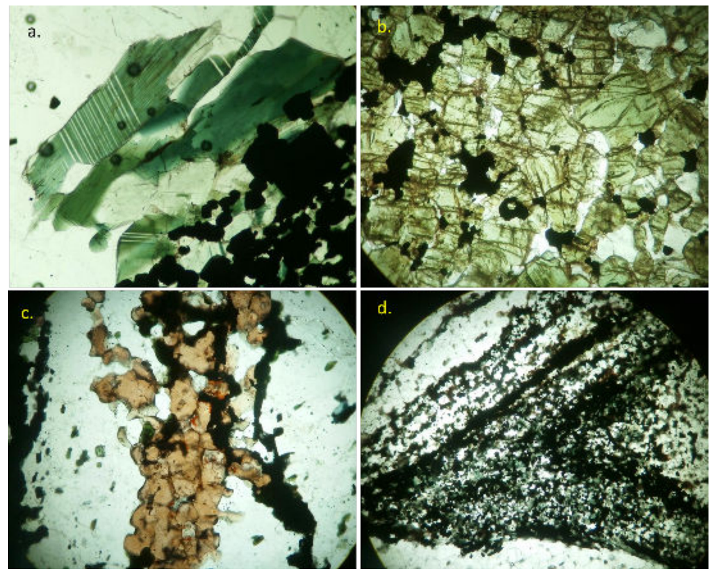

Figure 3. Photomicrographs of representative mineral species. A) Exsolution lamellae showing alternating grunerite and actinolite in sample 14-JH-6. B) Clinopyroxene layer cut parallel to banding in sample 14-JH-13d. C) Discontinuous bands of andradite garnet in sample 14-JH-18b. D) Cross-section of thickened fold hinge with disseminated alkali-amphiboles in sample 14-JH-14. All samples show sub to euhedral iron oxides. All images in plane polarized light.

Modal percentages of major mineral phases are also highly variable with quartz ranging between 30 and 70%, oxides from 20 to 65%, pyroxene from 0 to 30%, amphibole from 0 to 15%, and garnet up to 10%. In addition to this mineralogical variability, many of the observed Iron Mine thin sections contain pyroxene and amphibole phases with distinct exsolution lamellae. Table 1 provides a more complete representation of major mineral phases observed in select thin sections and Table 2 provides a mineral formulae reference for observed minerals.

Sample number	Sample location	Oxide %	Quartz %	Diopside %	Augite %	Hedenbergite %
14-JH-1c	SC	65	25	7	2	1
14-JH-3b	SC	50	40			
14-JH-5	SC	45	50			
14-JH-6	SC	40	45			
14-JH-8b	SC	50	40	1.5	2.5	1
14-JH-9a	SC	40	45	2	7	1
14-JH-11b	IM	50	40		5	
14-JH-13d	IM	30	40	5	15	5
14-JH-14	IM	45	50			
14-JH-17a	IM	30	60			
14-JH-18a	IM	65	25		3	2
14-JH-18b	IM	40	45		5	
14-JH-18c	IM	20	70			

Table 1. Estimated modal percentages of major phases identified by polarized light microscopy of select samples.

Mineral name	Chemical formula
Quartz (Chert)	SiO_2
Magnetite	Fe_3O_4
Hematite	Fe_2O_3
Pyrite	FeS
Ilmenite	$FeTiO_3$
Diopside	$CaMgSi_2O_6$
Augite	$(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$
Hedenbergite	$CaFe^{2+}Si_2O_6$
Grunerite	$Fe^{2+}{}_7Si_8O_{22}(OH)_2$
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Actinolite	$Ca_2(Mg, Fe^{2+})_5Si_8O_{22}(OH)_2$
Katophorite	$Na(Ca, Na)Fe^{2+}{}_4(Al, Fe^{3+})Si_7AlO_{22}(OH)_2$
Winchite	(Ca, Na)Mg4(Al, Fe3+)Si8O22(OH)2
Andradite	$Ca_3Fe^{3+}2(SiO_4)_3$
Calcite	$CaCO_3$
Siderite	$FeCO_3$

Table 2. Mineral formula chart for reference mineral phases.

GEOTHERMOBAROMETRY

In the nearby Tobacco Root and Gravelly Mountains two-pyroxene and garnet-pyroxene assemblages constrain likely metamorphic temperatures to be 650-700°C, 4-6 kbar and <400°C , 2-4 kbar respectively (Immega and Klein, 1976). Forthcoming electron microprobe analyses and two-pyroxene geothermobarometry techniques outlined by Saxena (Saxena, 1976) should serve to constrain the pressures and temperatures of BIF metamorphism in the Ruby Range and provide an important comparison.

CONCLUSIONS

Preliminary X-ray diffraction and Raman microscope results suggest that the Stone Creek and Iron Mine meta-BIFs represent two separate occurrences of iron formation within the Christensen Ranch suite. This has been inferred on the basis of:

- Distinct compositional differences. Mineral assemblages within Stone Creek and Iron Mine meta-BIF point to differences in protolith compositions.

- Textural differences between each locality. Stone Creek BIFs are well-layered and are characterized by narrower bands than the irregular, folded bands present in the Iron Mine. While this may be partially explained by layer thickening during deformation and metamorphism, this same relationship may be observed in areas of the Iron Mine BIFs that appear to have experienced little to no folding.

- Stratigraphic relationships. Stone Creek and Iron Mine BIFs are generally observed in contact with lithologies that differ between the two locations. Stone Creek BIFs are commonly found adjacent to metapelites and marbles whereas Iron Mine BIFs are generally in contact with metapelites and amphibolites. This may also imply slightly different lithofacies.

FUTURE WORK

Careful attention must be paid to mineral assemblages due to reactions occurring under set Eh-pH conditions as outlined by Klein (Klein, 2005). Examples of such reactions include the formation of amphibole by the reaction between iron-rich carbonates such as siderite and quartz during metamorphism (Klein, 2005). At the time of this writing insufficient compositional data have been collected to make any assertions concerning original depositional or metamorphic conditions. Upcoming scanning electron microscope and electron microprobe analyses as well as ongoing polarized light microscopy, Raman, and X-ray diffraction data collection will provide more data to augment and enrich interpretations of Ruby Range meta-BIFs within the context of the Big Sky orogeny.

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