GARNET GRAIN SIZE ANALYSIS, GARNET COMPOSITION, AND HISTORICAL MINING WITHIN THE EMERALD CREEK AREA, NORTHERN IDAHO

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Jennifer E. Dickison

Major Professor: Kenneth Sprenke, Ph.D.

Committee Members: Robert Heinse, Ph.D., Mickey Gunter, Ph.D.

Department Administrator: Leslie Baker, Ph.D.

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Jennifer E. Dickison, submitted for the degree of Master of Science with a Major in Geology and titled "GARNET GRAIN SIZE ANALYSIS, GARNET COMPOSITION, AND HISTORICAL MINING WITHIN THE EMERALD CREEK AREA, NORTHERN IDAHO," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ____________________________ Date: ________________
Kenneth Sprenke, Ph.D.

Committee Members: ____________________________ Date: ________________
Robert Heinse, Ph.D.

____________________________ Date: ________________
Mickey Gunter, Ph.D.

Department Administrator: ____________________________ Date: ________________
Leslie Baker, Ph.D.

ABSTRACT

Since the 1930's when the first garnet mine opened, and possibly even before then, garnet derived from the mica schist within the Emerald Creek Area has generated wide-spread interest for both the abrasive mining industry and gem hunters. The main purpose of this thesis is to further characterize the garnet composition and distribution within the study area. Within the area, a syncline composed of metamorphosed sediments of the Belt Supergroup Wallace Formation is present. The primary unit containing significant amounts of garnet across the central hinge of the syncline is a garnet mica schist.

Additionally, garnet samples from drainages within the upper and lower schist units of the Wallace Formation were analyzed using electron micro probe analysis, wavelength dispersive x-ray fluorescence, and x-ray diffraction. Compositionally, the garnet consists primarily of almandine (80%) and pyrope (10%), with minor amounts of grossular and spessartine. Inclusions within the grains typically consist of quartz, rutile, zircon and mica.

Samples of the garnet mica schist were collected from the East Fork of Emerald Creek, West Fork of Emerald Creek, and Carpenter Creek drainages. These samples were studied to determine the varying mineral porphyroblasts present within the schist, and to measure the relative garnet grain size. In general, the garnet grain size is largest to the southeast along the syncline where the East Fork of Emerald Creek cuts through the base of the syncline. Although, of the samples collected for this study, the largest garnets were found in the West Fork of Emerald Creek drainage and ranged between 2-4 mm in diameter. Weathered garnets contained within the colluvium from East Fork of Emerald Creek can commonly occur up to 1-4 cm in diameter. No outcrops were found during this study containing these larger garnets, indicating either that portion of the unit has been weathered away or is not exposed.

Finally, this thesis also investigated the historical mining that occurred within the Emerald Creek Area. According to historical accounts, the very first mining company formed in 1939. Mining for the abrasive garnet sands still occurs to this day, and the work conducted during the early days contributed to the success and longevity of the industry.

ACKNOWLEDGEMENTS

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CHAPTER 1. GENERAL GEOLOGY OF THE EMERALD CREEK AREA

1.1 Study Area

The area of focus for this document lies within Townships 43 North and 42 North and Ranges 1 East and 2 East, within Benewah, Shoshone, Latah, and Clearwater counties, Idaho. Figure 1.1 shows the general study area and primary units of schist located within the study area. The study area covers an approximate 22 square mile (35 km) area and lies within the St. Maries and Potlatch 30 x 60 Minute Quadrangles, Idaho as mapped by Lewis et al., 2000 and 2005 respectively.

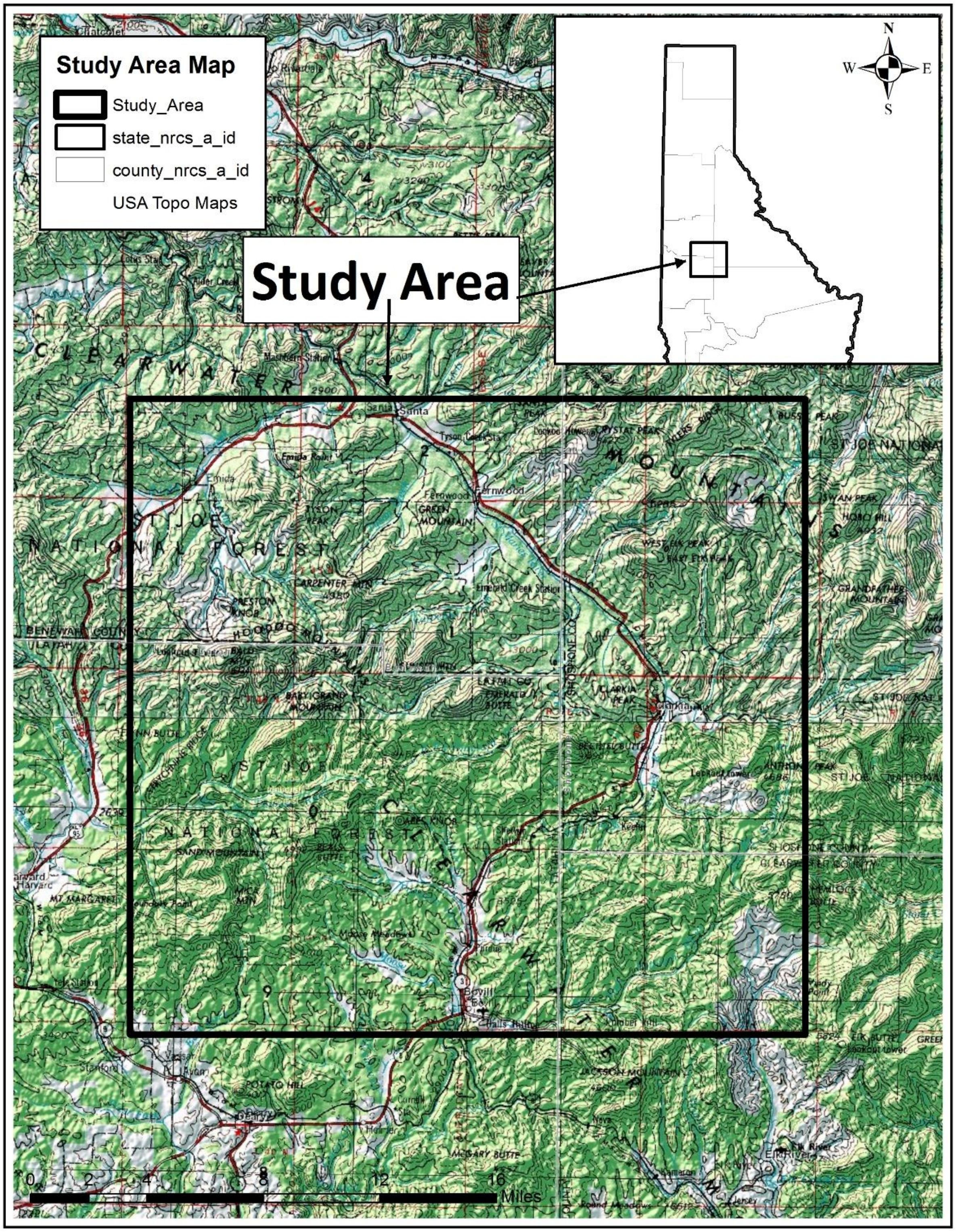

Figure 1.1. Study Area Map.

1.2 Geology

The basement rock mainly includes Belt Supergroup metamorphic sequences of the Wallace Formation including schist, phyllite, quartzite, granofels, siltite and argillite. These formations were first laid down as iron rich mud deposits and were then subjected to at least two metamorphic events. This regional metamorphism created the mica schist containing the garnet porphyroblasts within the Wallace Formation. Basement rock geologic structures in the area consist of a syncline and anticline complex with north-west striking faults. (Lewis et al. 2000)

On top of the basement rock lie basalt flows of the Columbia River Basalt Group and Tertiary sediments. Flowing through much of eastern Washington and northern Idaho during the Miocene, individual basalt flows periodically filled valleys and plugged the natural drainages. These blockages created lakes in the Emerald Creek and Clarkia Basins and as a result, thick sequences of fossiliferous clay rich lacustrine sediments were deposited in the valleys. The Tertiary sediments, which include the lacustrine sediments as well as cobbles, pebbles and sands, lie both below Quaternary sediments and at significantly higher elevations above present stream levels. Since the Miocene, modern drainages have eroded portions of the Tertiary sediments, replacing them with Quaternary alluvial sediments. (Lewis et al. 2000)

The primary rocks of interest are mapped as Ysw by Lewis et al., 2001 as schist and phyllite of the Wallace Formation. Within the emerald creek study area, these rocks have been folded into a syncline and anticline complex which plunges to the northwest. Within the study area, the syncline cutting across the Emerald Creek and Carpenter Creek drainages is of significant interest. This syncline forms an axis line to the northwest beginning in the south near Bechtel Butte and continuing to the north to Emerald Butte, Willow Peak, Carpenter Mountain, and Tyson Peak. (Lewis et al. 2000)

The portion of the Wallace Formation mapped as Ysw, was previously subdivided into four different units which include the upper schist, upper quartzite-gneiss, lower schist, and lower quartzite-gneiss. The Emerald Creek syncline is composed of the upper schist unit. To the southeast near Cat Spur Creek, the schist has been mapped as the lower schist unit. (Hietanen 1963; Lewis et al. 2000)

All four units of the Wallace Formation have been estimated to be 800-2,600 meters in thickness. The upper schist and upper quartzite have both been estimated to be approximately 200 meters thick, each. The lower schist has been estimated to be 200-300 meters in thickness, while the lower quartzite has been estimated to be 200-1,900 meters in thickness. (Hietanen 1984)

The upper schist is also the source of the garnet sands mined in the Emerald Creek area since the early 1900's. The schist in this area is typically fine to medium grained, with thin lamination, and contains both muscovite and biotite. Kyanite, staurolite, and garnet are common accessory minerals within the schist unit. (Hietanen 1963)

Due to the chemical composition and grain size of the garnet within the schist units, the garnet in the study area has been of significant interest to the abrasive mining industry. The garnet is primarily composed of the almandine variety which typically has higher hardness (7-8), and higher specific gravity than other varieties of garnet. The majority of the garnet mined in the Emerald Creek and Carpenter Creek drainages is composed of sand sized grains, ranging from 8 to 80 mesh in size, with the smaller grains typically reflecting a broken or fractured grain, and the larger grains nearly whole and euhedral.

1.3 Metamorphism and Garnet Age Dating

Two phases of metamorphism have altered the schist within the study area, with temperatures higher during the second phase of metamorphism that produced zoning in the garnets. A recent 2012 study utilized Lu-Hf age dating on the whole rock and garnet, as well as Ca zoning within the garnet in the study area. Garnet from the Clarkia area within the upper schist unit produced Lu-Hf dates of 1347 +/- 10 Ma in the core fraction that was combined with the whole rock sample, and 1102 +/- 43 Ma in the rim fraction combined with the whole rock sample. When the core and rim were combined an intermediate value of 1306 +/- 18 Ma was calculated. (Nesheim et al. 2012; Hietanen 1984)

Ca X-ray maps of the garnet from the study area produced Ca zoning that increased slowly as the rim was approached and then produced a sharp increase in Ca at the rim. The study suggested that the Ca zoning with a simple pattern demonstrates a simple growth history and Ca zoning with complex patterns demonstrates a complex growth history. Additionally, the core of the garnet collected from the study area was relatively free of inclusions, while the outer 1/3 to ½ of the garnet contained a significant amount of inclusions. (Nesheim et al. 2012)

In another study, samples of garnet and rock were collected from the Carpenter Creek and Bechtel Butte areas for Lu-Hf age analysis. In the Carpenter Creek sample five garnet fractions and two whole rock fractions analyzed produced a Lu-Hf age of 1064 +/- 10 Ma with a MSWD=4.5. The age populations in the data showed one age, although the Lu concentration in the core of the garnets was 3-5 times greater than in the rim of the garnet. (Zirakparvat et al. 2010)

The sample analyzed from the Bechtel Butte area in the same study yielded an age of 1018 +/- 24 Ma with a MSWD=114 when all the five garnet fractions and whole rock fractions were analyzed together, although the data produced two age populations. When the garnet fractions with the greatest number of inclusions were removed from the age determination, the Lu-Hf age was 1024 +/- 3 Ma with a MSWD=1.5. They concluded from the Carpenter Creek and Bechtel Butte analyses that the garnet grew approximately 1.1 to 1.0 Ga and corresponds to a broad tectonic event in Northwest Laurentia sometime during the Mesoproterozoic. (Zirakparvat et al. 2010)

CHAPTER 2. GARNET COMPOSITION, INCLUSION, AND MORPHOLOGY ANALYSIS WITHIN STUDY AREA

2.1 Analysis Summary

A moderate amount of work has been conducted over the years on the garnet from the Emerald Creek area. In 2012 the author conducted a study on alluvial garnet samples collected within the study area, as well as from samples derived from similar schist units to the south and east of the Emerald Creek area. All samples were derived from either the upper schist or the lower schist of the Wallace Formation as is shown in Figure 2.1. This study intended to compare the composition, inclusions, and grain morphology of the alluvial garnet samples using a variety of analytical methods including, electron micro probe analysis, wavelength dispersive x-ray fluorescence, and x-ray diffraction. All alluvial samples were cleaned to remove any other minerals and screened so that they contained only garnet ranging between -5 mesh (4 mm) and +80 mesh (0.180 mm) (US Standard Tyler Sieve Mesh Sizes). Additionally, microphotographs were taken of each sample for comparison. Due to time and equipment restraints, not all samples were analyzed by each method.

In general, the lower schist unit often contained more highly fractured and deformed garnet as compared to the garnet within the upper schist from the Emerald and Carpenter Creek drainages. Whole garnet grains found in the mountains south and east of Purdue Creek had a pancake-like morphology, while the alluvial garnet typically exhibited a fractured morphology similar to Cat Spur Creek and Schwartz Creek alluvial garnet. Whole grains were more commonly found in the Carpenter Creek and West Fork Emerald Creek drainages as compared to the East Fork of Emerald Creek. The North Fork of the Palouse River alluvial garnet typically contained nearly whole grains as well.

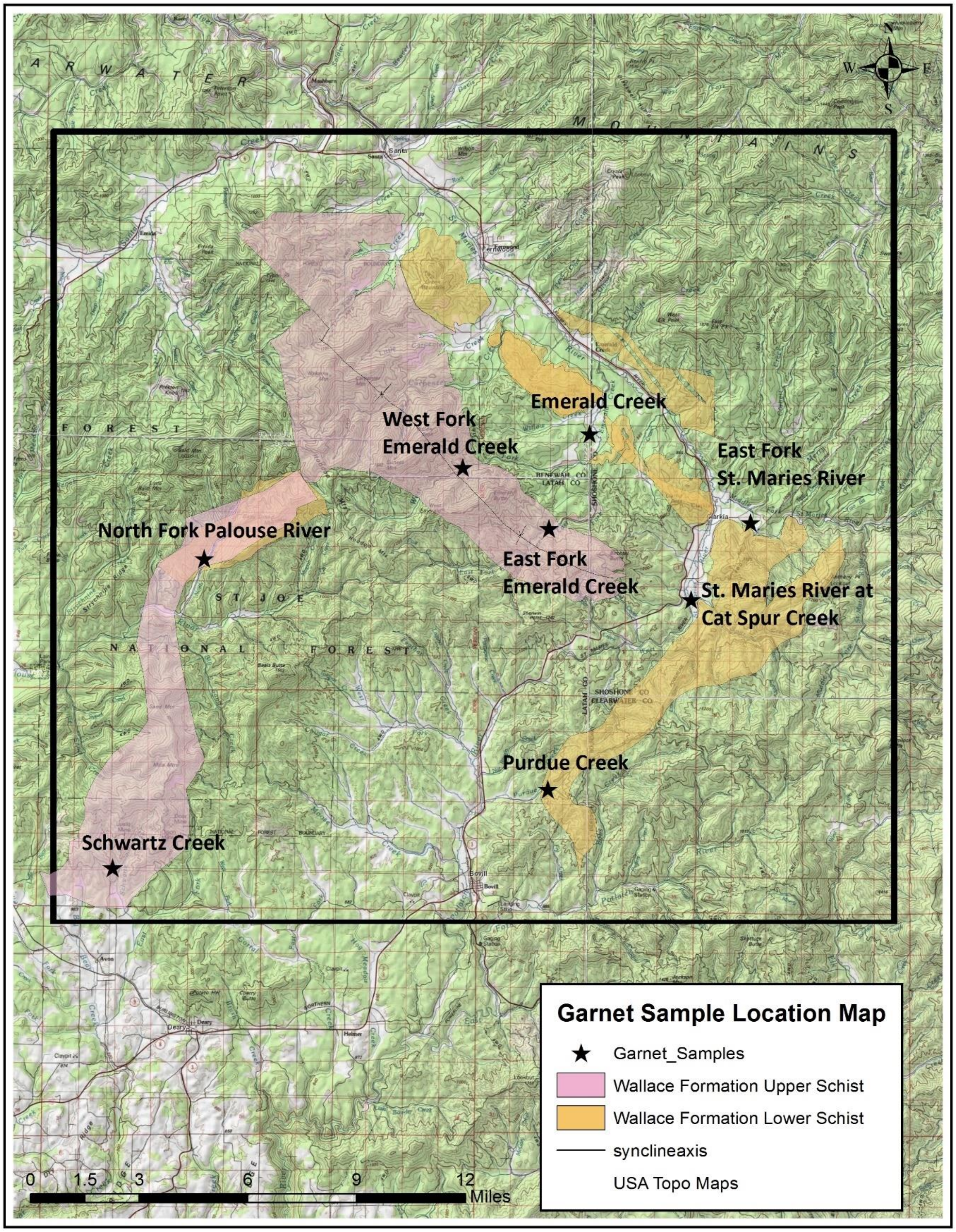

Figure 2.1. Alluvial Garnet Sample Location Map.

2.2 Electron Micro Probe Analysis

A total of six samples were prepared for analysis using an Electron Micro Probe. Alluvial garnet collected from Emerald Creek, the East Fork of the St. Maries River, the St. Maries River at Cat Spur Creek, Purdue Creek, Schwartz Creek, and the North Fork of the Palouse River were screened to remove garnet greater than 5 mesh and less than 80 mesh. Each sample had a grain mount prepared for this analysis. The Electron Micro Probe operating conditions were set at 15 kev energy with a beam size of 1 micron. The standards used for peaking and the wave scan, as well as the crystal and element selections for each spectrometer and element count times are shown below in Tables 2.1 – 2.3.

Standards Used For Peaking	
Standard	Elements
Albite	Na, Si
Chromite	Cr, Al, Mg
Spessartine	Mg
Sphene	Ca, Ti
Pyrite	Fe
YAG	Y

Table 2.1. EMP Standards Used for Peaking.

Element Count Times	
Elements	Time sec.
Ti	40
Mg, Ca, Si, Al, Fe, Na	20
Mn, Cr	30
Y	60

Table 2.2. EMP Element Count Times.

Spectrometer Crystal and Element Selections		
Spectrometer	Crystal	Element
1	TAP	Al, Si
2	LiF	Fe, Mn
3	LiF	Cr, Ti
4	PET	Ca, Y
5	TAP	Mg, Na

Table 2.3. EMP Spectrometer Crystal and Element Selections.

During this analysis two points were chosen for each garnet grain selected for a total of 10 to 20 grains per mount. The standard used was Astimex 2, an almandine variety. It was analyzed in between each mount using two, individual point locations. In Table 2.4 below, the analysis order is shown along with the standard interval and the relative standard deviation between the average standard analysis and the known value for the standard. The number of grains analyzed are provided next to each garnet sample. For example; the North Fork of the Palouse River had a total of 20 grains analyzed making a total of 40 analysis points.

Analysis Order and RSD between Average and Known Standards						
Sample	MgO	MnO	CaO	SiO2	Al2O3	FeO
North Fork Palouse River (1 - 20)						
Un 25 almandine std (astimex 2)	2.0959	3.8207	0.0794	0.9885	0.8758	1.0185
Swchartz Creek (1 - 20)						
Un 46 almandine std (astimex 2)	1.6632	0.7954	1.2154	0.8223	1.0886	1.7066
Emerald Creek (1 - 20)						
Un 67 almandine std (astimex 2)	1.3717	4.2415	1.7893	1.1249	0.8726	1.7898
St. Maries River at Cat Spur Creek (1 - 16)						
Un 84 almandine std (astimex 2)	1.2281	10.529	0.8934	0.6826	0.9134	1.0614
Purdue Creek (1 - 16)						
Un 100 almandine std (astimex 2)	1.6278	3.1055	2.5342	0.1384	1.0202	1.6327
East Fork St. Maries River (1 - 10)						
Un 111 almandine std (astimex 2)	1.3914	6.6832	1.2442	0.1708	0.6553	1.2004

Table 2.4. EMP Analysis Order and RSD between Average and Known Standards.

The standards overall produced reliable results with total oxide contents between 99.5 and 100.7 percent. Table 2.5 below shows the analyzed standard results including; the individual point oxide percentages, the averaged two-point oxide content, the standard deviation between the known and analyzed values, and relative standard deviation between the known and analyzed values.

For each grain mount a core (point 1) and rim (point 2) were selected for analysis. Since not all mounts were ground down far enough to expose the core of the garnet, the two individual points were averaged to give a single value, and then all points were averaged to provide a single average oxide percentage for each mount. This data is provided below in Table 2.5. Table 2.6 shows the average oxide detection limit for each oxide. In Table 2.5, the gray shaded cells show values below the detection limit. Table 2.7 provides the garnet variety yielded based on the averaged oxide percentages. All the alluvial garnet collected was primarily of the almandine variety, with minor amounts of pyrope, grossular, and spessartine.

Average Oxide Weight Percentages and Totals											
Sample	TiO2	MgO	MnO	CaO	SiO2	Al2O3	FeO	Na2O	Cr2O3	Y2O3	Totals
Emerald Creek (1 - 20)	0.0018	2.6963	1.6018	1.2198	35.743	20.88	36.282	0.0136	0.0034	0.0498	98.492
North Fork Palouse River (1 - 20)	0.0055	2.1821	3.0837	1.2277	36.056	20.854	35.214	0.019	0.0062	0.0978	98.746
Schwartz Creek (1 - 20)	0.0032	2.3887	3.9181	0.8188	35.854	20.901	34.956	0.0095	0.0057	0.011	98.867
St. Maries River at CSC (1 - 16)	0.0117	3.2029	1.1776	1.3803	35.686	20.789	35.827	0.0197	0.0078	0.0807	98.183
Purdue Creek (1 - 16)	0.0014	3.2332	1.9328	1.2195	36.066	20.958	35.24	0.0095	0.01	0.0305	98.701
East Fork St. Maries River (1 - 10)	0.001	2.9158	1.9202	1.1927	36.619	21.055	36.14	0.0117	0.0044	0.0542	99.914

Table 2.5. Average Oxide Weight Percentages and Totals.

Average Oxide Detection Limits										
Sample	TiO2	MgO	MnO	CaO	SiO2	Al2O3	FeO	Na2O	Cr2O3	Y2O3
Emerald Creek (1 - 20)	0.0088	0.0085	0.0214	0.0095	0.0107	0.0072	0.0267	0.0166	0.0093	0.0194
North Fork Palouse River (1 - 20)	0.0088	0.0086	0.0217	0.0094	0.0106	0.0071	0.0268	0.0167	0.0095	0.0204
Schwartz Creek (1 - 20)	0.0088	0.0085	0.0216	0.0094	0.0107	0.0072	0.0272	0.0166	0.0094	0.0206
St. Maries River at CSC (1 - 16)	0.0088	0.0086	0.0217	0.0094	0.0107	0.0071	0.0267	0.0168	0.0093	0.0192
Purdue Creek (1 - 16)	0.0089	0.0086	0.0217	0.0094	0.0108	0.0071	0.027	0.0167	0.0093	0.0194
East Fork St. Maries River (1 - 10)	0.0089	0.0086	0.0216	0.0094	0.0108	0.0071	0.0273	0.0168	0.0094	0.0193

Table 2.6. EMP Average Oxide Detection Limits

Electron Mirco Probe Garnet %					
Sample	almandine	pyrope	grossular	spessartine	total
Emerald Creek (1 - 20)	81.3	11.2	3.5	4.0	100.0
North Fork Palouse River (1 - 20)	80.1	9.0	3.6	7.3	100.0
Schwartz Creek (1 - 20)	78.4	9.9	2.3	9.4	100.0
St. Maries River at CSC (1 - 16)	79.7	13.4	3.9	3.0	100.0
Purdue Creek (1 - 16)	78.5	13.4	3.5	4.7	100.0
East Fork St. Maries River (1 - 10)	80.2	11.9	3.4	4.5	100.0

Table 2.7. Electron Micro Probe Garnet %.

2.3 Energy Dispersive Spectrometry, Backscattered Electron Imaging, Secondary Electron Imaging, and Microphotographs

To identify inclusions within the individual garnet grains a spot analysis was completed using Electron Dispersive Spectrometry. In addition, Backscattered Electron and Secondary Electron Imaging were used to collect images of individual garnet grains. The BSE images show variations in composition which are expressed as shades of black, gray and white. The SEI images show the topography of individual grains. Garnet samples from each area contained inclusions of quartz, which also tended to be the larger inclusions in each grain. Table 2.8 below lists the identified inclusions within the alluvial garnet from the various areas. Figures 2.2 through 2.22 are BSE, SEI, and microphotograph images of garnet from the various areas.

Inclusions Identified Using EDS	
Sample	Inclusions
Emerald Creek (1 - 20)	quartz, rutile
North Fork Palouse River (1 - 20)	quartz, biotite, zircon
Schwartz Creek (1 - 20)	quartz, zircon, mica, (P, O, Dy white mineral)
St. Maries River at Cat Spur Creek (1 - 16)	quartz, monazite (Ce, La, Pr, Nd)
Purdue Creek (1 - 16)	quartz, mica
East Fork St. Maries River (1 - 10)	quartz, zircon, rutile

Table 2.8. Inclusion Identified Using EDS.

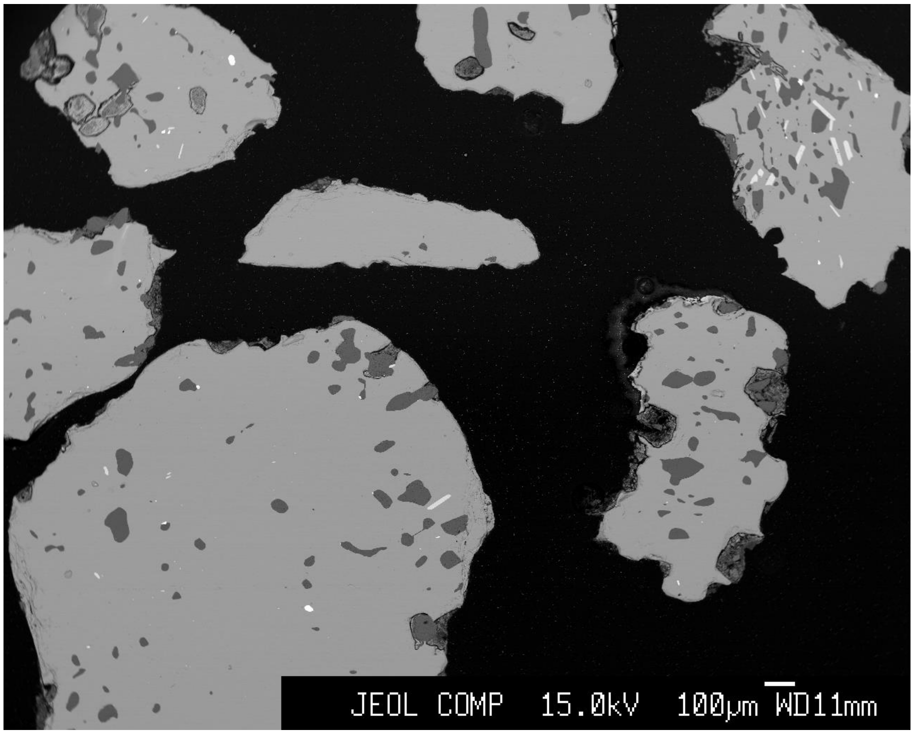

Figure 2.2. BSE Image. Emerald Creek Sample. Dark inclusions are quartz and white elongated inclusions are rutile.

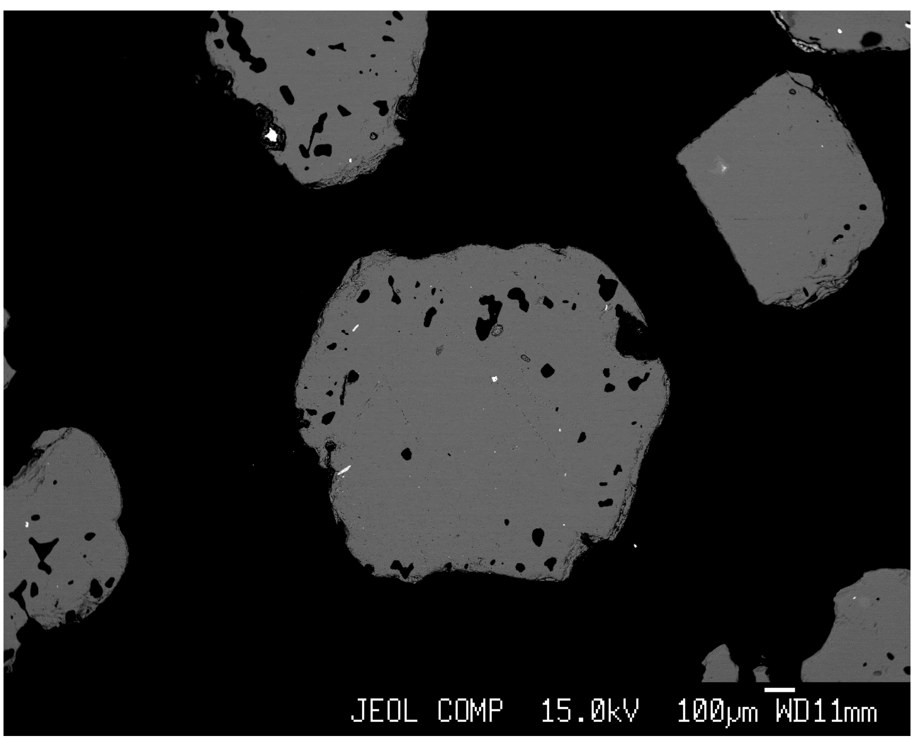

Figure 2.3. BSE Image2. Emerald Creek Sample.

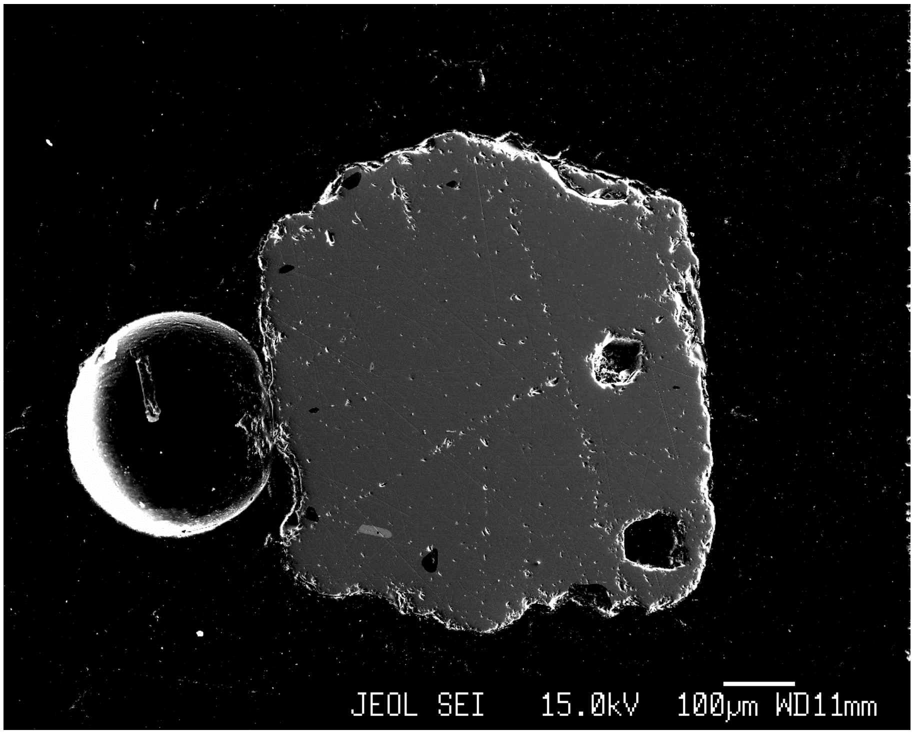

Figure 2.4. SEI Image. Emerald Creek Sample.

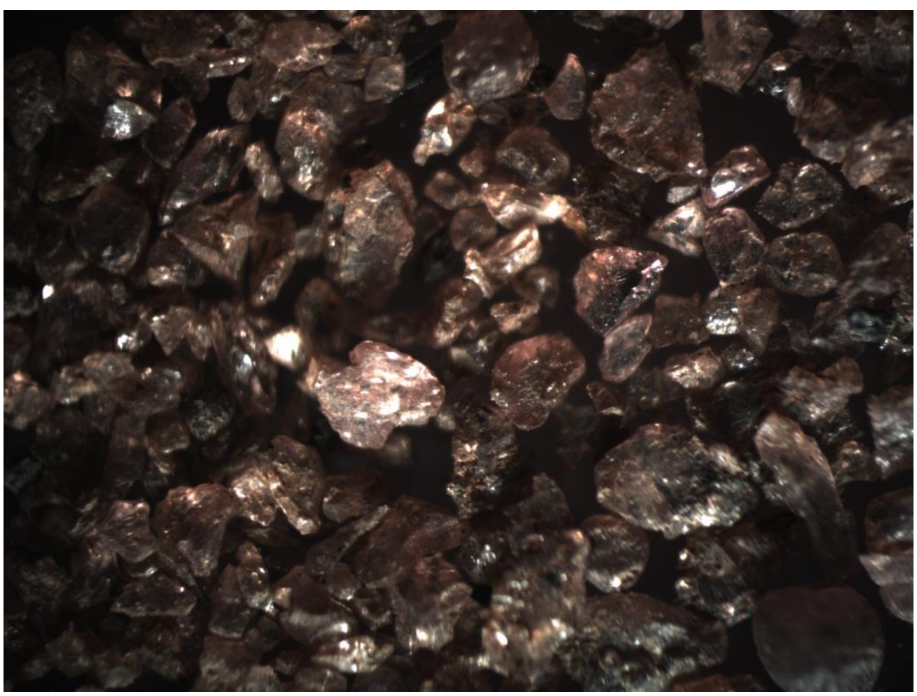

Figure 2.5. Microphotograph. Emerald Creek sample.

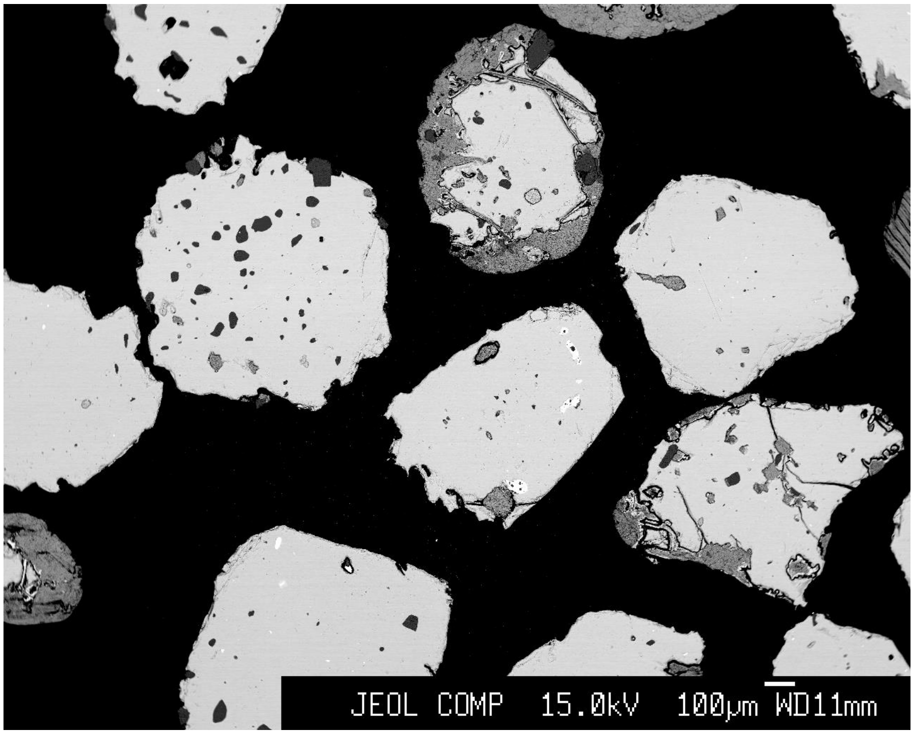

Figure 2.6. BSE Image. North Fork Palouse River Sample. Dark inclusions are quartz and biotite around the edges, and white inclusions are zircon.

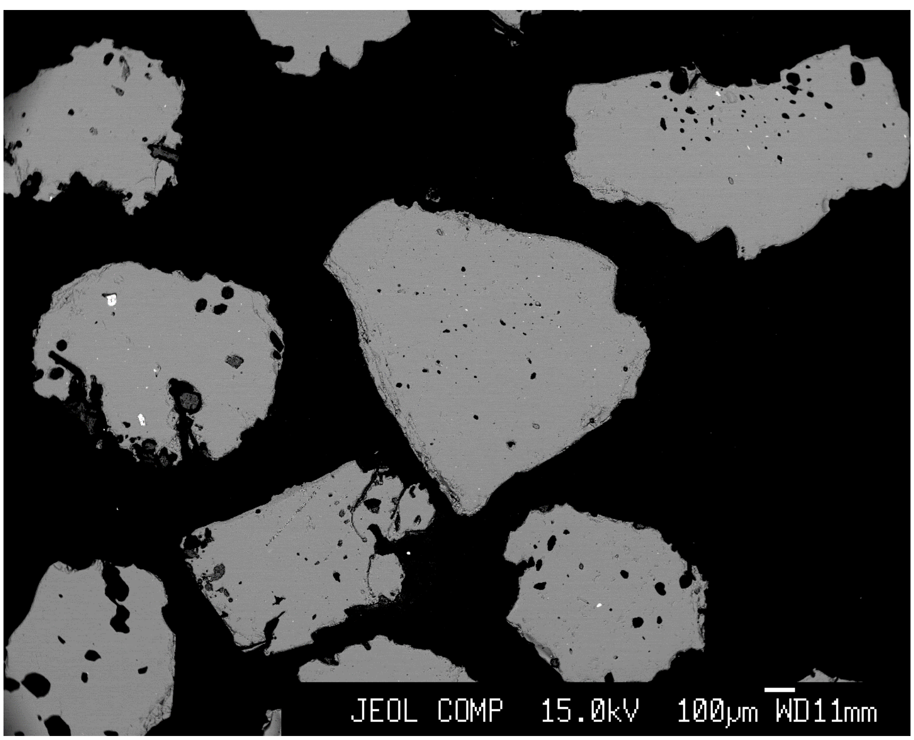

Figure 2.7. BSE Image2. North Fork Palouse River Sample.

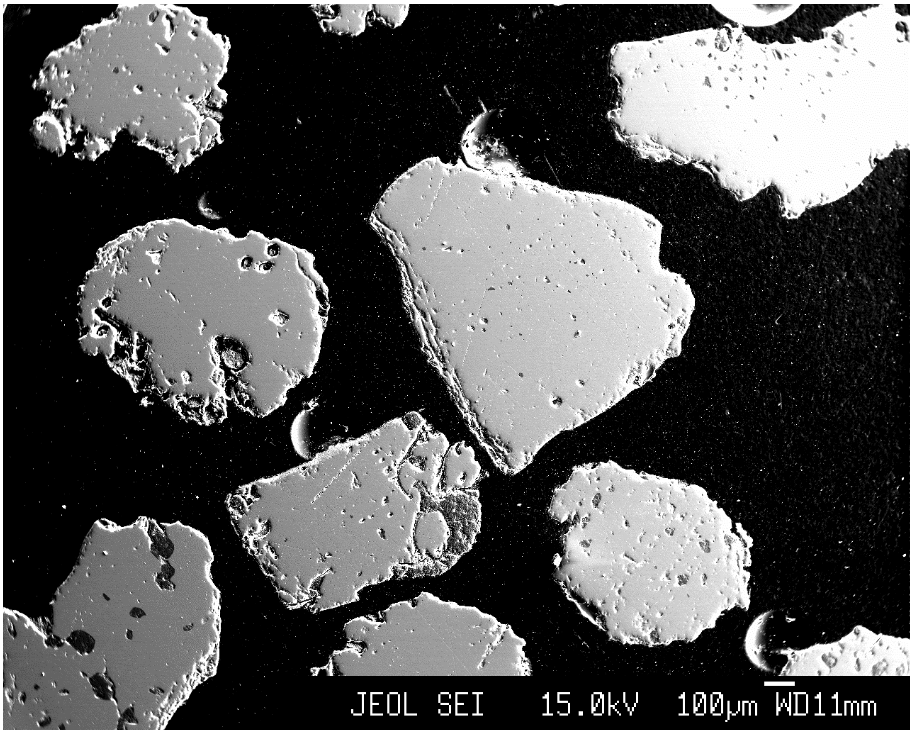

Figure 2.8. SEI Image. North Fork Palouse River Sample.

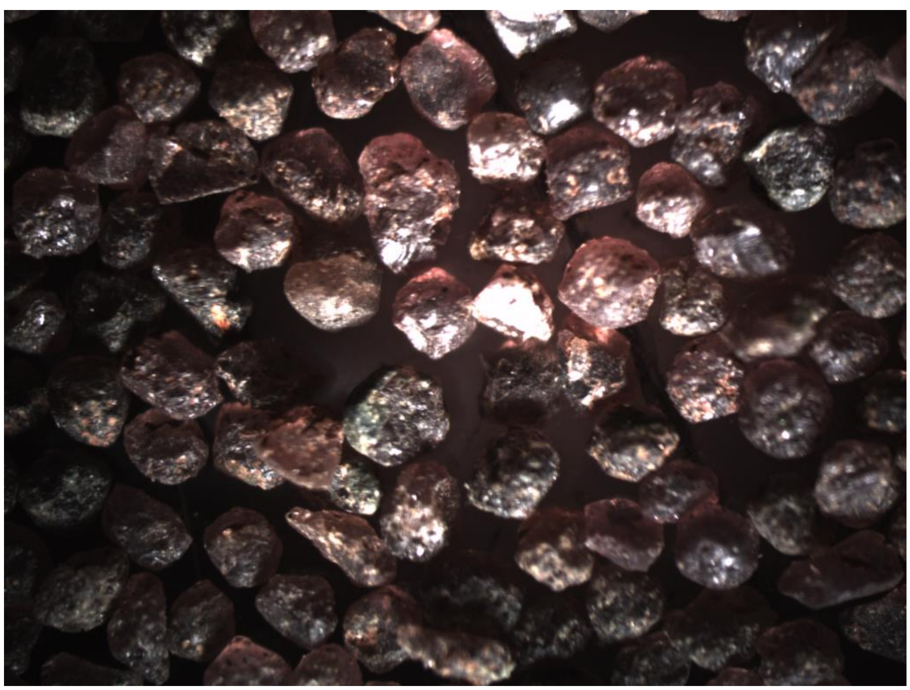

Figure 2.9. Microphotograph. North Fork Palouse River Sample.

Figure 2.10. BSE Image. Schwartz Creek sample.

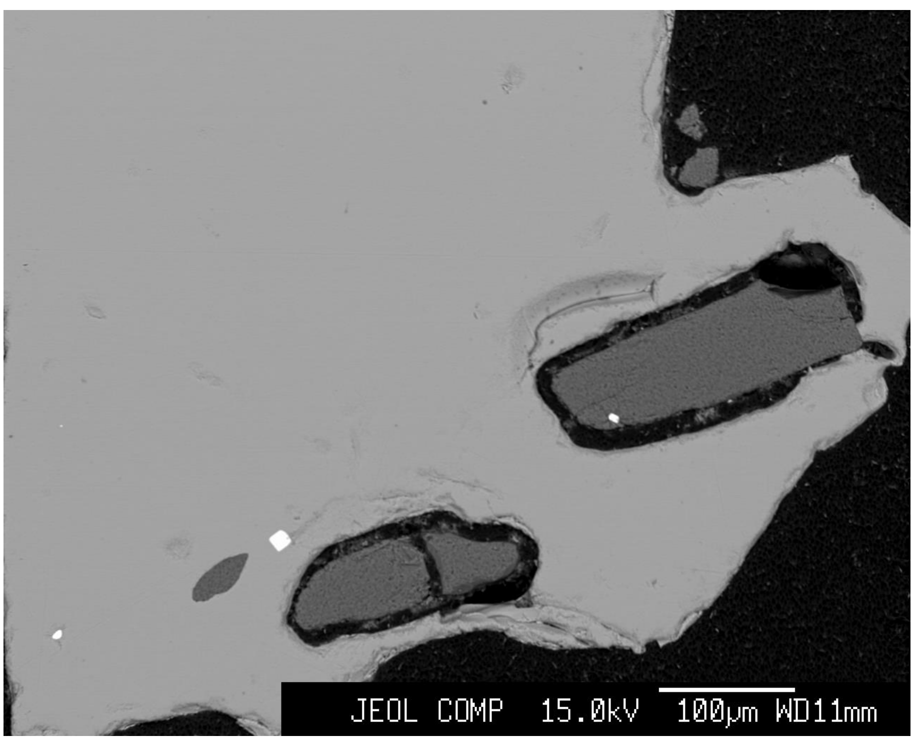

Figure 2.11. BSE Image2. Schwartz Creek Sample. Dark inclusions are quartz, and square white inclusions are zircon.

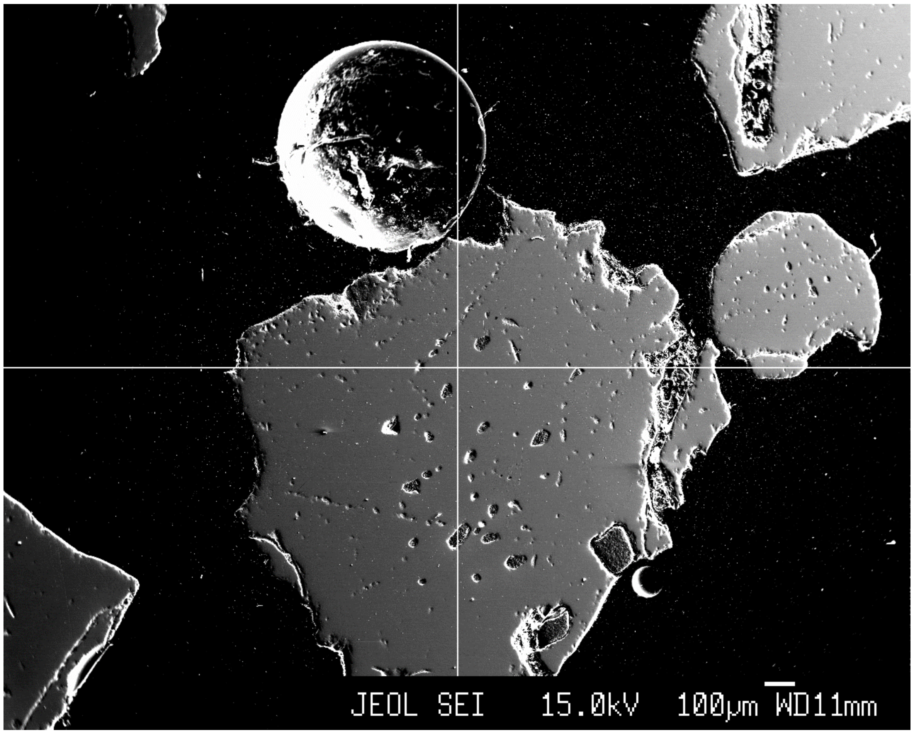

Figure 2.12. SEI Image. Schwartz Creek Sample.

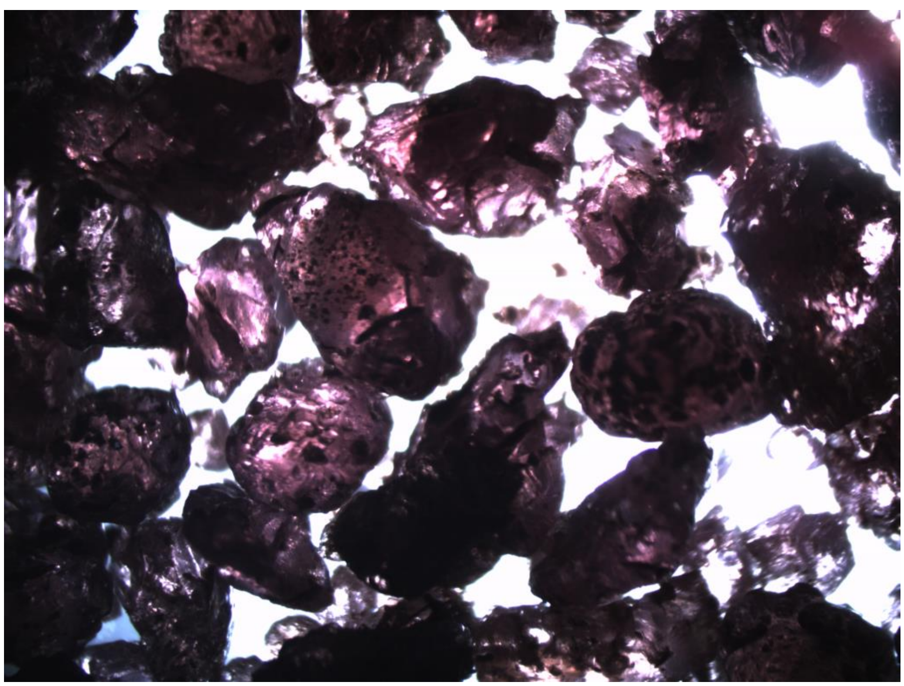

Figure 2.13. Microphotograph. Schwartz Creek Sample.

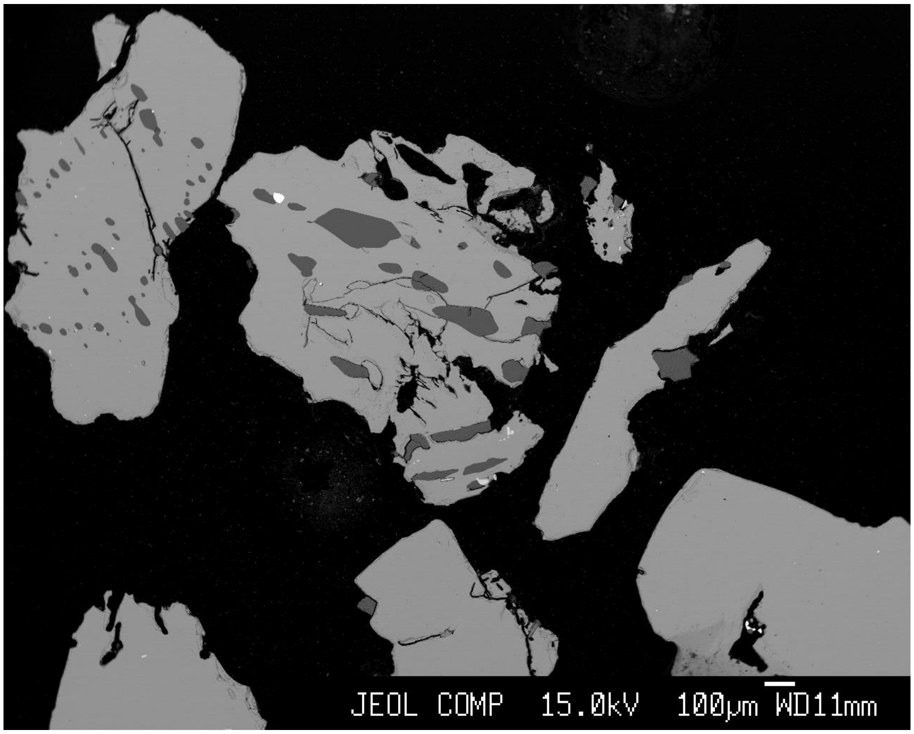

Figure 2.14. BSE Image. St. Maries River at Cat Spur Creek Sample. Dark inclusions are quartz, and the white inclusion is monazite.

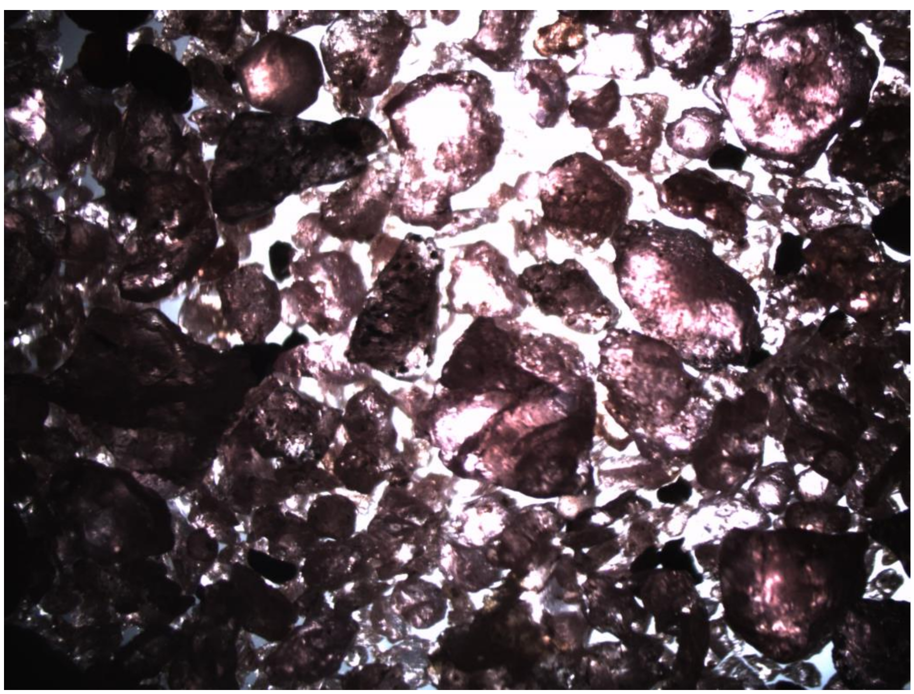

Figure 2.15. Microphotograph. St. Maries River at Cat Spur Creek Sample.

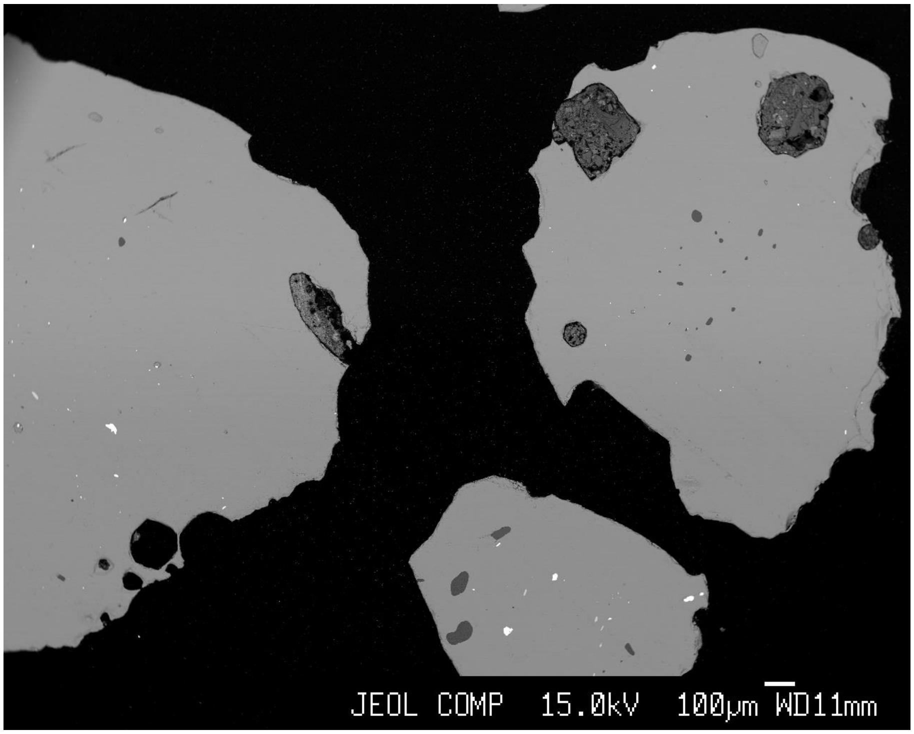

Figure 2.16. BSE Image. Purdue Creek Sample.

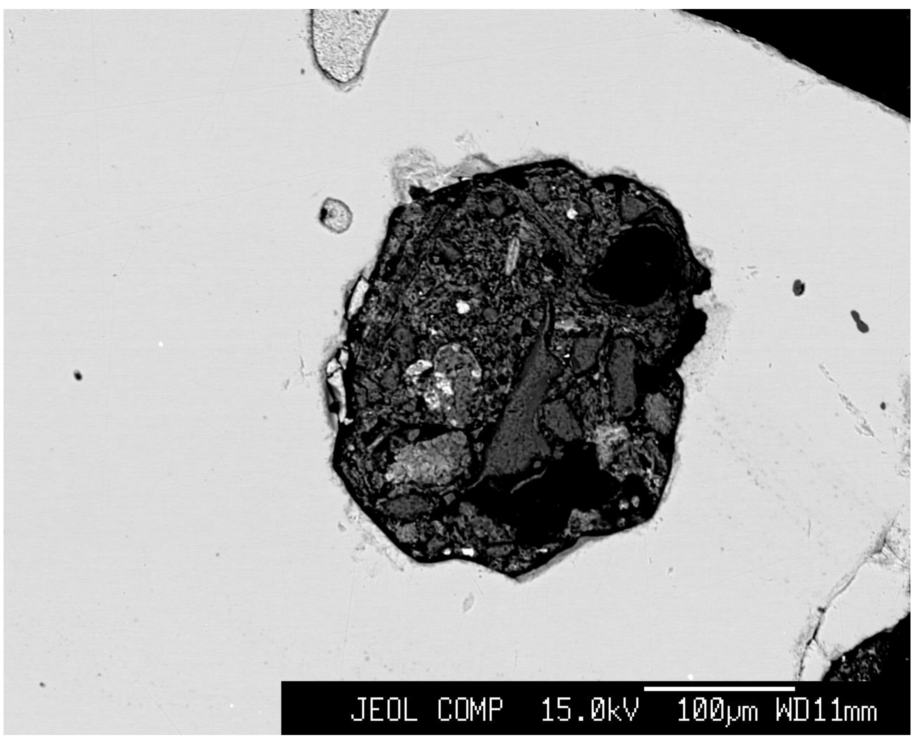

Figure 2.17. BSE Image. Purdue Creek Sample. Multi-mineral inclusion contains quartz and mica. Two other light color shades are also present in the sample, possibly zircon, rutile or some other mineral containing REE's.

Figure 2.18. Microphotograph. Purdue Creek Sample.

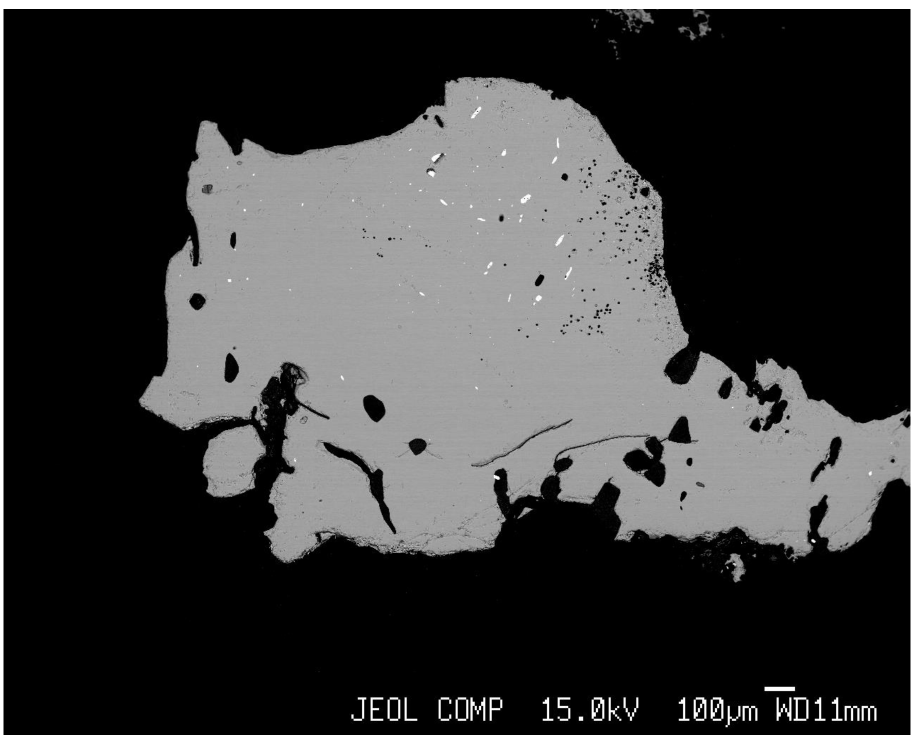

Figure 2.19. BSE Image. East Fork St. Maries River Sample. Dark inclusions of quartz and light inclusions of rutile and zircon.

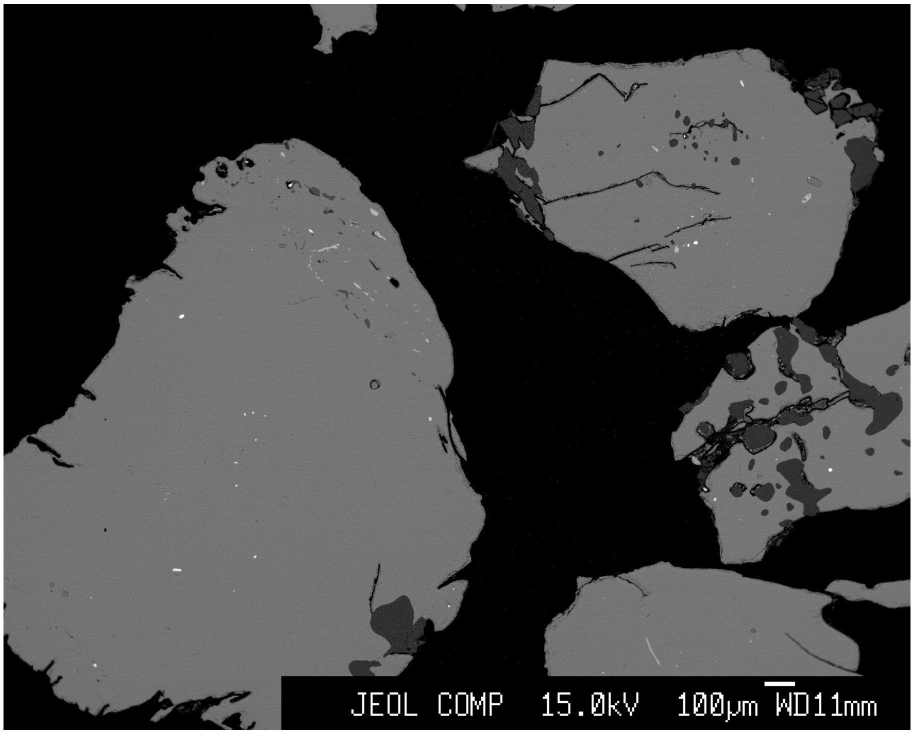

Figure 2.20. BSE Image2. East Fork St. Maries River Sample.

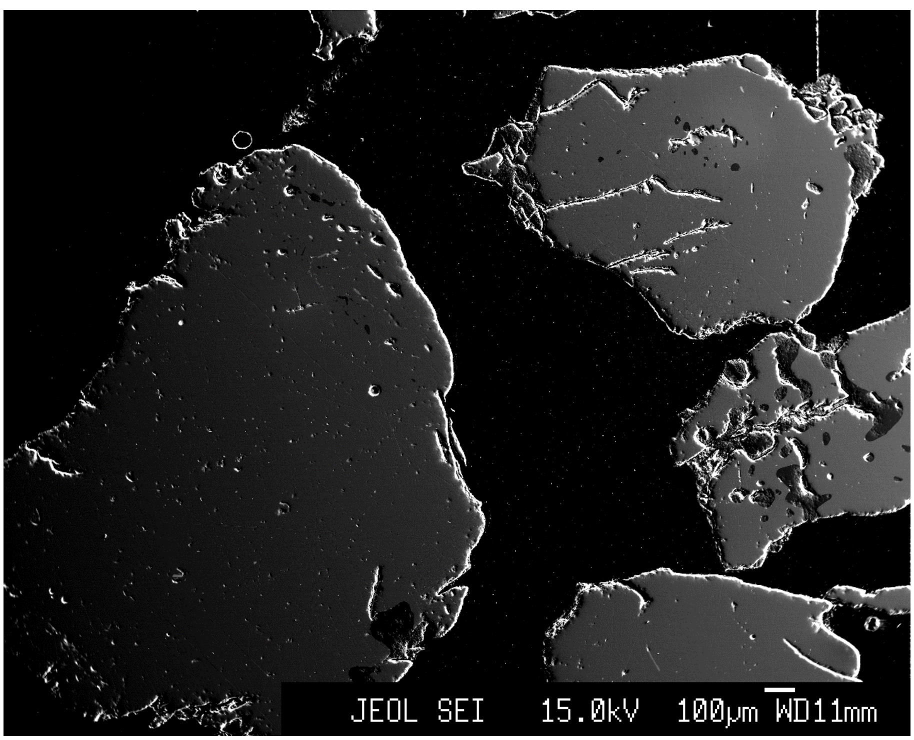

Figure 2.21. SEI Image. East Fork St. Maries River Sample.

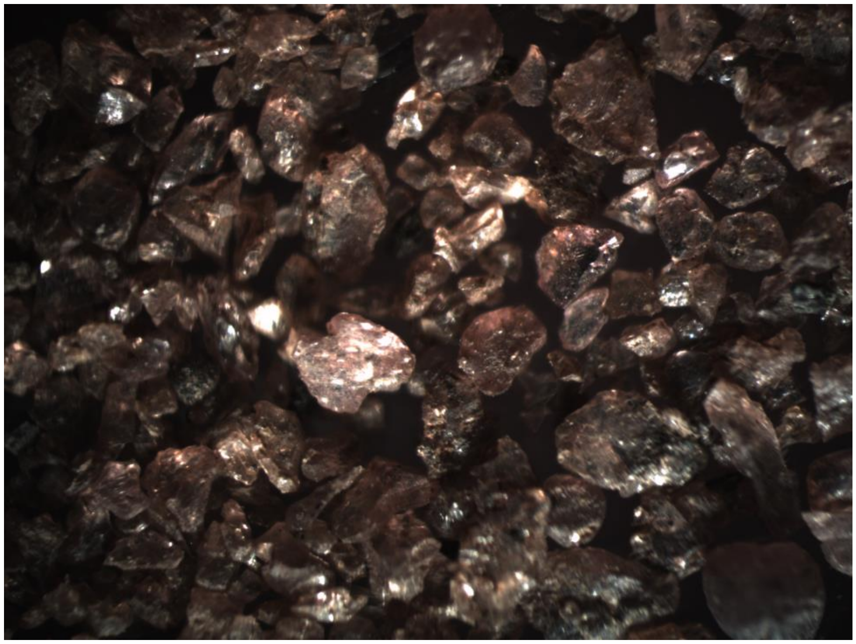

Figure 2.22. Microphotograph. East Fork St. Maries River Sample.

2.4 Wavelength Dispersive X-Ray Fluorescence Analysis

Wavelength Dispersive X-Ray Fluorescence was used on seven samples of the alluvial garnet from various locations within the study area to determine the major elements and trace elements contained within the garnet from the upper and lower units of schist as seen in Figure 2.1.

Unnormalized Major Elements (Weight %):							
	Schwartz Creek	West Fork Emerald Creek	East Fork Emerald Creek	North Fork Palouse River	St. Maries River at Cat Spur	East Fork St. Maries River	Purdue Creek
SiO2	37.61	37.75	38.78	36.94	37.83	38.85	37.57
TiO2	0.192	0.134	0.276	0.218	0.303	0.217	0.080
Al2O3	20.65	20.20	20.24	20.79	20.74	20.68	20.30
FeO*	33.97	36.64	35.63	35.63	35.36	34.93	35.34
MnO	3.816	1.687	1.372	2.466	1.742	1.592	1.618
MgO	2.36	2.49	2.54	2.93	2.82	2.82	2.98
CaO	1.05	1.06	1.25	1.23	1.53	1.51	1.29
Na2O	0.00	0.00	0.00	0.05	0.02	0.04	0.02
K2O	0.07	0.02	0.03	0.10	0.02	0.03	0.04
P2O5	0.090	0.181	0.092	0.085	0.069	0.112	0.156
Sum	99.80	100.13	100.19	100.44	100.43	100.79	99.39
LOI (%)							

Table 2.9. XRF Unnormalized Major Elements.

Normalized Major Elements (Weight %):							
	Schwartz Creek	West Fork Emerald Creek	East Fork Emerald Creek	North Fork Palouse River	St. Maries River at Cat Spur	East Fork St. Maries River	Purdue Creek
SiO2	37.68	37.70	38.70	36.78	37.67	38.55	37.80
TiO2	0.192	0.134	0.276	0.217	0.301	0.216	0.080
Al2O3	20.69	20.17	20.20	20.70	20.65	20.52	20.43
FeO*	34.04	36.59	35.57	35.47	35.21	34.66	35.55
MnO	3.823	1.685	1.369	2.455	1.735	1.579	1.628
MgO	2.36	2.48	2.53	2.91	2.81	2.80	3.00
CaO	1.05	1.06	1.25	1.23	1.52	1.50	1.30
Na2O	0.00	0.00	0.00	0.05	0.02	0.04	0.02
K2O	0.07	0.02	0.03	0.10	0.02	0.03	0.04
P2O5	0.091	0.181	0.091	0.085	0.069	0.111	0.157
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 2.10. XRF Normalized Major Elements.

Unnormalized Trace Elements (ppm):							
	Schwartz Creek	West Fork Emerald Creek	East Fork Emerald Creek	North Fork Palouse River	St. Maries River at Cat Spur	East Fork St. Maries River	Purdue Creek
Ni	0	2	0	14	0	0	0
Cr	47	50	41	44	45	47	50
Sc	79	74	72	49	76	77	90
V	32	33	20	33	32	27	39
Ba	26	9	14	32	13	16	20
Rb	4	1	1	9	1	2	1
Sr	6	3	2	5	2	5	5
Zr	220	163	170	206	164	184	212
Y	423	473	483	753	568	523	405
Nb	2.2	1.5	4.0	2.7	5.8	3.4	2.3
Ga	6	6	5	10	6	6	5
Cu	13	10	7	21	6	7	11
Zn	60	10	58	77	61	56	65
Pb	3	1	1	5	1	3	2
La	43	34	27	30	25	33	49
Ce	84	82	47	59	49	76	97
Th	11	12	10	8	8	12	14
Nd	39	37	22	25	24	34	44
U	7	7	3	5	2	2	3
sum tr.	1106	1008	986	1388	1087	1112	1113
in %	0.11	0.10	0.10	0.14	0.11	0.11	0.11
sum m+tr	99.91	100.23	100.28	100.58	100.54	100.90	99.50
M+Toxide	99.95	100.27	100.31	100.62	100.57	100.93	99.54
w/LOI							
if Fe3+							

Table 2.11. XRF Unnormalized Trace Elements.

Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO.							
	Schwartz Creek	West Fork Emerald Creek	East Fork Emerald Creek	North Fork Palouse River	St. Maries River at Cat Spur	East Fork St. Maries River	Purdue Creek
NiO	0.1	2.1	0.0	18.3	0.0	0.0	0.4
Cr2O3	69.3	72.8	59.6	63.9	65.3	69.2	72.9
Sc2O3	121.6	113.4	109.9	74.9	116.6	118.6	138.4
V2O3	47.2	48.4	29.6	49.1	47.6	39.0	56.6
BaO	28.5	9.5	15.5	36.0	15.0	17.9	22.1
Rb2O	4.2	1.2	1.2	9.3	0.6	2.1	1.4
SrO	6.9	3.6	2.7	5.6	2.6	5.4	5.3
ZrO2	297.4	220.4	229.5	278.1	220.9	248.3	286.0
Y2O3	537.2	600.5	613.5	956.8	720.9	663.8	514.2
Nb2O5	3.1	2.1	5.7	3.9	8.4	4.8	3.3
Ga2O3	7.7	7.6	6.3	13.6	8.1	8.1	7.0
CuO	16.0	13.1	8.3	26.8	7.3	8.7	13.3
ZnO	75.8	11.9	72.7	96.2	76.1	70.7	81.5
PbO	3.1	1.5	1.6	5.3	1.1	2.8	1.7
La2O3	50.9	40.3	31.5	34.8	28.9	38.4	57.0
CeO2	103.6	101.3	57.3	72.3	59.8	93.8	119.7
ThO2	12.7	13.5	11.0	9.3	8.4	12.8	15.6
Nd2O3	45.5	43.1	25.5	29.5	28.2	39.5	50.9
U2O3	7.4	7.7	3.8	5.7	2.6	2.6	3.7
Cs2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0
As2O5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W2O3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sum tr.	1438	1314	1285	1789	1418	1447	1451
in %	0.14	0.13	0.13	0.18	0.14	0.14	0.15

Table 2.12. XRF Major Elements Normalized on a Volatile-free Basis with total Fe expressed as FeO.

2.5 X-Ray Diffraction Analysis

Three samples of garnet were selected for analysis by XRD. These samples included East Fork Emerald Creek, West Fork Emerald Creek, and Schwartz Creek. All three samples were scanned between 10 to 60 degrees two theta with a step of 0.05 and a dwell time of 1.0 seconds. Tables 2.13 through 2.15 show the XRD analysis results from the collected garnet samples and Tables 2.16 and 2.17 show the Jade 8 almandine and pyrope standards. The intensity and two theta positions collected from the three garnet samples were compared to the almandine and pyrope standard intensity and two theta positions.

Similarly colored cells represent similar peaks used for comparison. Figures 3.23 through 3.28 show the graphs of the peak intensities and two theta positions for the individual samples. The XRD analysis indicates all three samples are an almandine/pyrope garnet variety.

East Fork Emerald Creek									
2-Theta	d(Å)	(h k l)	BG	Height	H%	Area	A%	FWHM	XS(Å)
18.762	4.7257		8	23	4.1	83	3.3	0.154	827
20.804	4.2663		10	18	3.2	41	1.6	0.097	>1000
26.595	3.349		15	50	8.8	131	5.2	0.113	>1000
30.957	2.8863		4	214	38	921	36.4	0.183	575
34.709	2.5824		6	563	100	2533	100	0.191	536
36.496	2.46		7	29	5.2	114	4.5	0.167	642
38.16	2.3564		3	123	21.9	545	21.5	0.188	547
39.792	2.2635		2	67	12	362	14.3	0.228	429
42.892	2.1068		3	90	15.9	460	18.2	0.218	453
44.393	2.039		3	18	3.2	92	3.6	0.214	464
48.595	**1.872**		**3**	**121**	**21.5**	**607**	**23.9**	**0.213**	**472**
55.099	1.6655		8	69	12.2	294	11.6	0.182	586
57.546	1.6003		3	150	26.6	809	31.9	0.23	447

Table 2.13. XRD Results. East Fork Emerald Creek Sample.

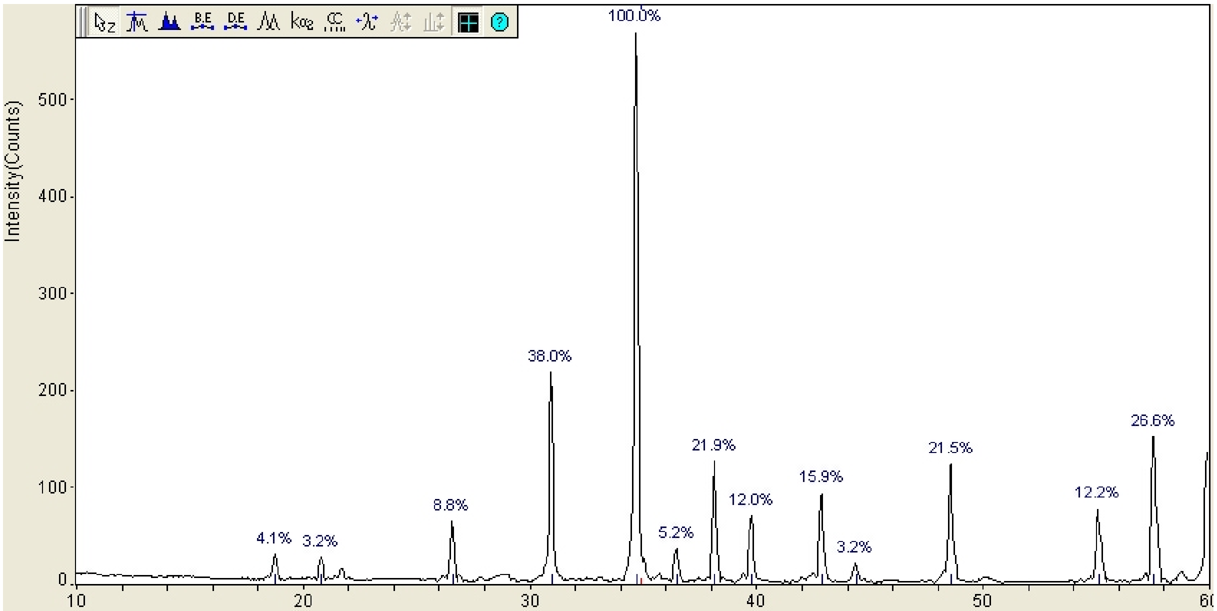

Figure 2.23. XRD Peak Intensity Graph. East Fork Emerald Creek Sample.

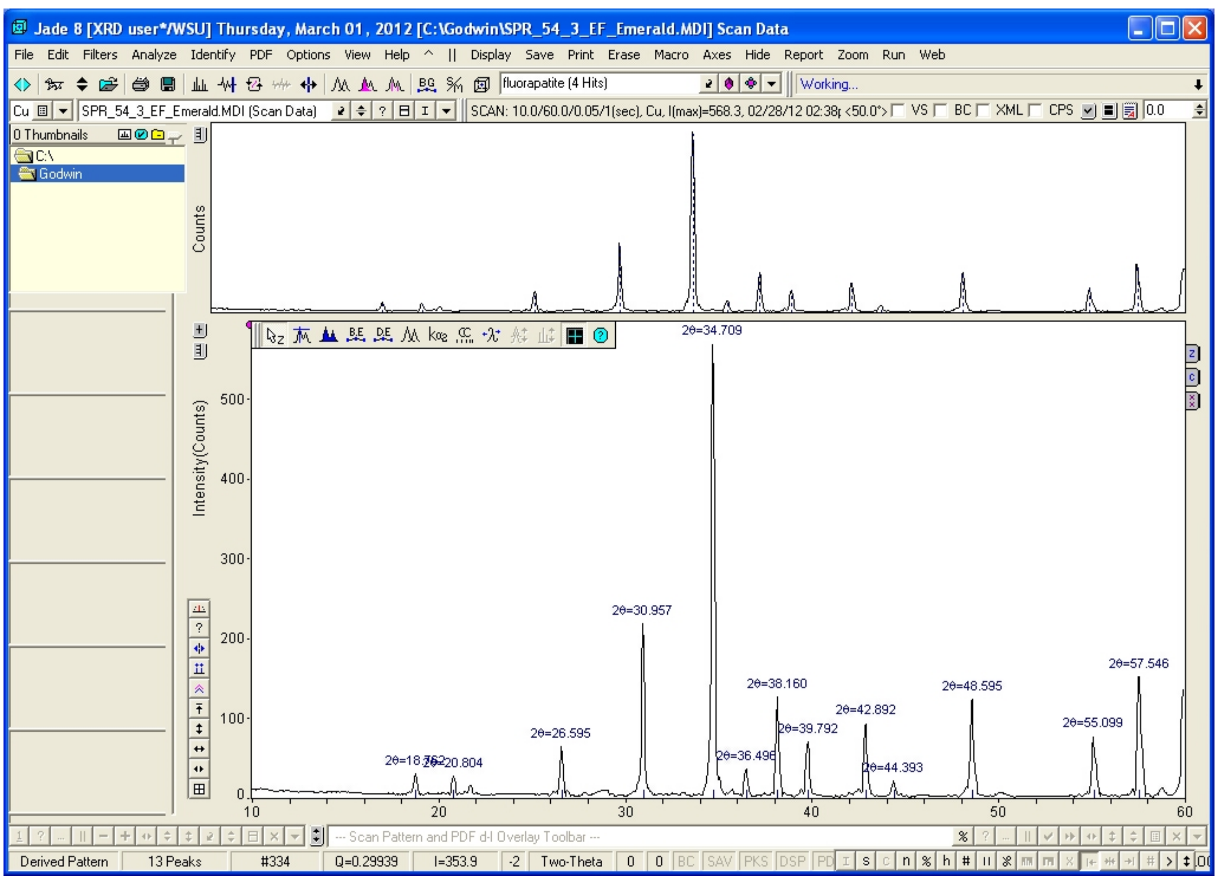

Figure 2.24. XRD Two Theta Graph. East Fork Emerald Creek Sample.

West Fork Emerald Creek									
2-Theta	d(Å)	(h k l)	BG	Height	H%	Area	A%	FWHM	XS(Å)
18.757	4.727		5	22	3.9	119	4.7	0.231	442
26.6	3.3484		3	61	10.7	298	11.8	0.209	488
30.946	2.8874		5	242	42.6	954	37.7	0.168	650
34.715	2.582		5	567	100	2531	100	0.19	542
36.461	2.4623		5	26	4.7	133	5.3	0.214	464
38.185	2.355		4	100	17.6	453	17.9	0.193	527
39.792	2.2635		3	57	10.1	303	12	0.226	435
42.863	2.1081		3	104	18.3	446	17.6	0.183	566
44.343	2.0412		2	19	3.4	105	4.2	0.23	427
48.6	1.8719		2	97	17.2	569	22.5	0.248	394
55.066	1.6664		3	87	15.4	429	17	0.209	494
57.551	1.6002		3	139	24.6	676	26.7	0.206	508
58.736	1.5707		6	14	2.5	37	1.4	0.111	>1000

Table 2.14. XRD Results. West Fork Emerald Creek Sample.

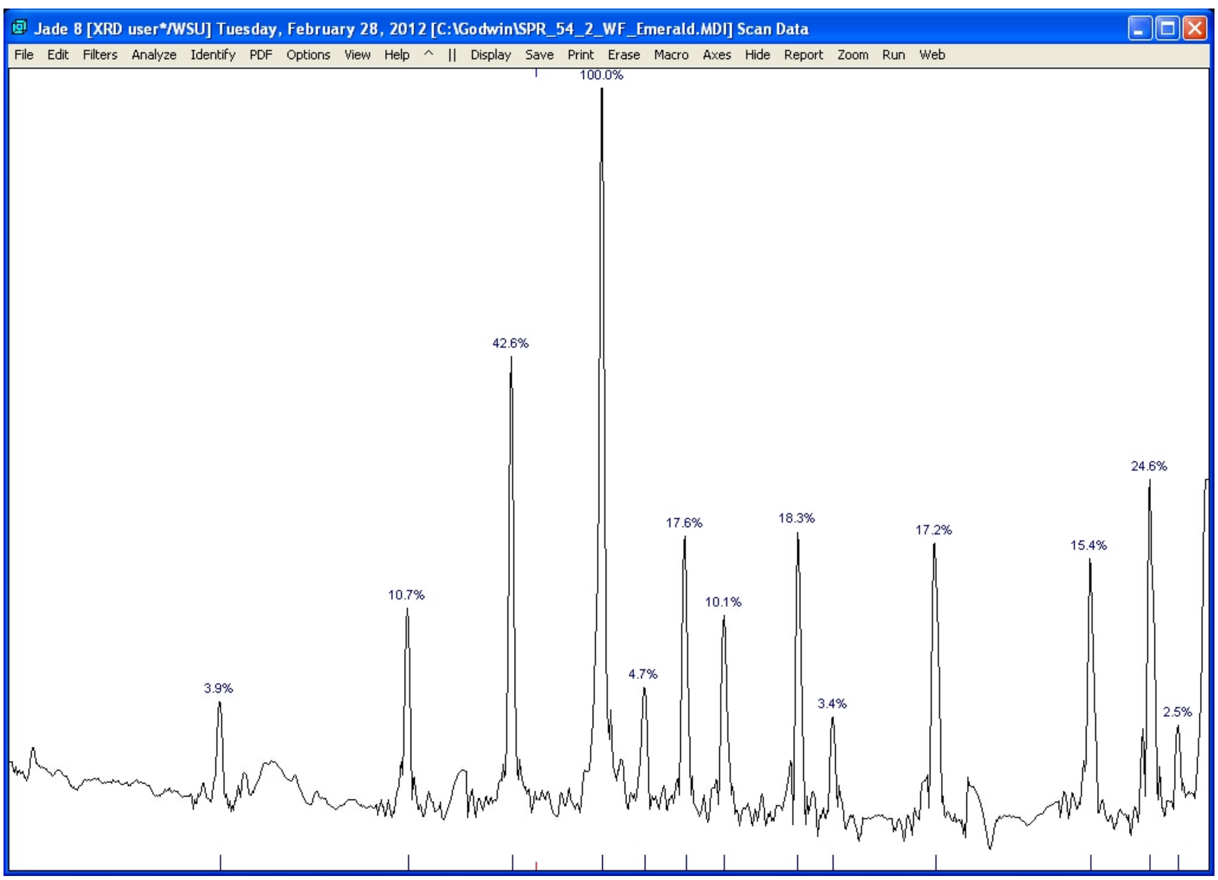

Figure 2.25. XRD Peak Intensity Graph. West Fork Emerald Creek Sample.

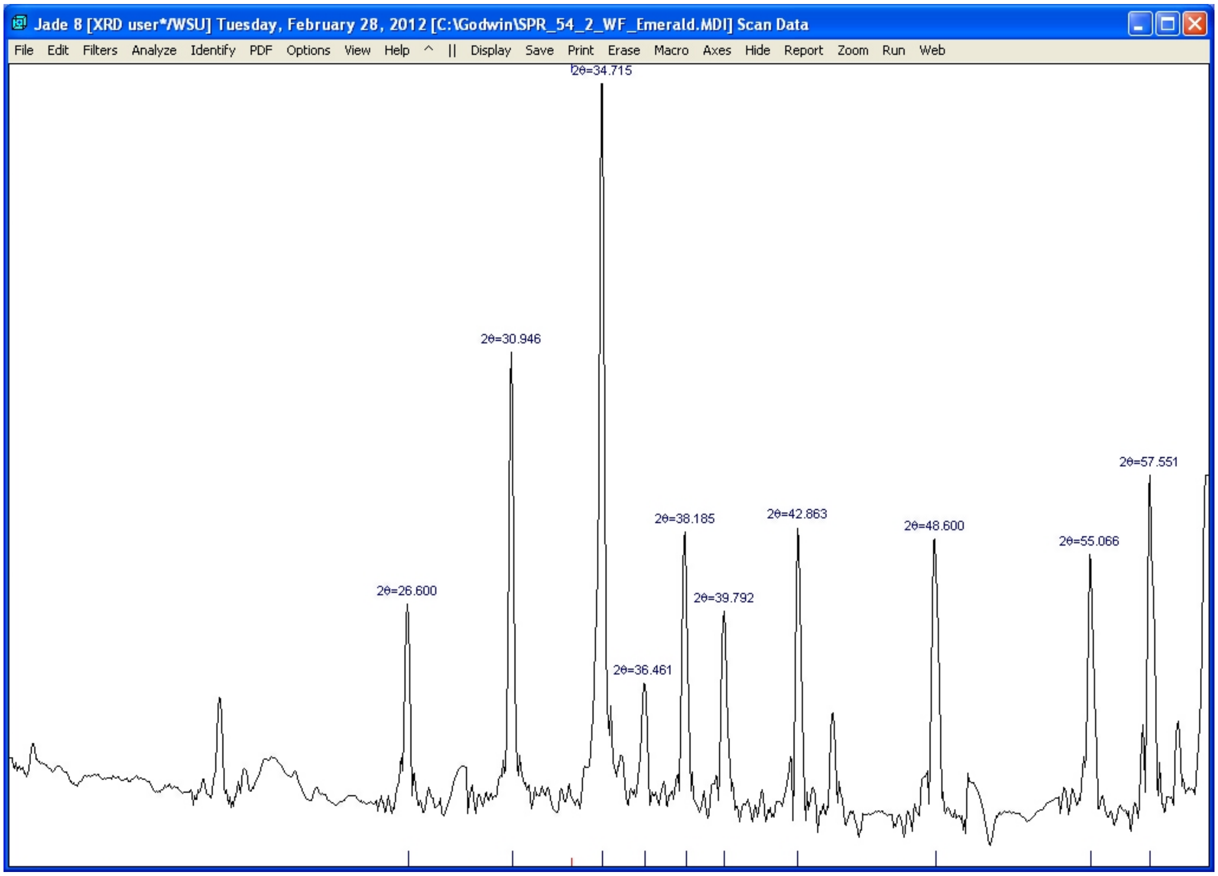

Figure 2.26. XRD Two Theta Graph. West Fork Emerald Creek Sample.

Schwartz Creek									
2-Theta	d(Å)	(h k l)	BG	Height	H%	Area	A%	FWHM	XS(Å)
18.807	4.7146		9	21	3.6	67	2.5	0.133	>1000
26.635	3.344		6	21	3.6	77	2.9	0.155	754
30.982	2.8841		4	194	32.8	881	33.4	0.193	533
34.741	2.5801		7	591	100	2636	100	0.19	542
36.494	2.4601		4	34	5.7	184	7	0.231	422
38.191	2.3546		3	106	18	504	19.1	0.202	499
39.836	2.2611		3	78	13.1	368	14	0.202	499
42.901	2.1064		3	75	12.7	411	15.6	0.234	418
44.393	2.039		5	17	2.8	68	2.6	0.174	605
48.604	**1.8717**		**2**	**108**	**18.2**	**637**	**24.2**	**0.251**	**388**
55.099	1.6655		3	81	13.7	458	17.4	0.241	418
57.549	1.6002		4	153	25.9	803	30.5	0.224	461
58.755	1.5702		4	14	2.3	63	2.4	0.196	542

Table 2.15. XRD Results. Schwartz Creek Sample.

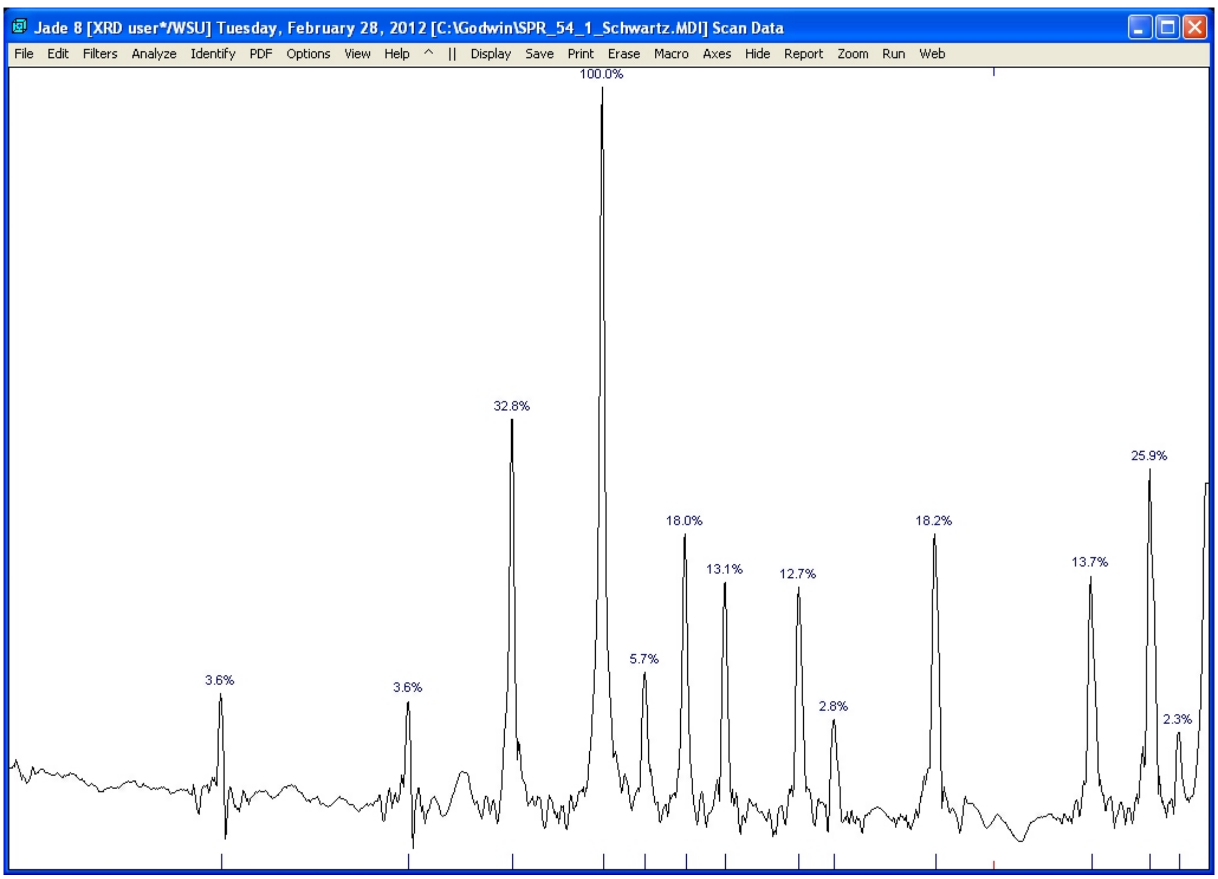

Figure 2.27. XRD Peak Intensity Graph. Schwartz Creek Sample.

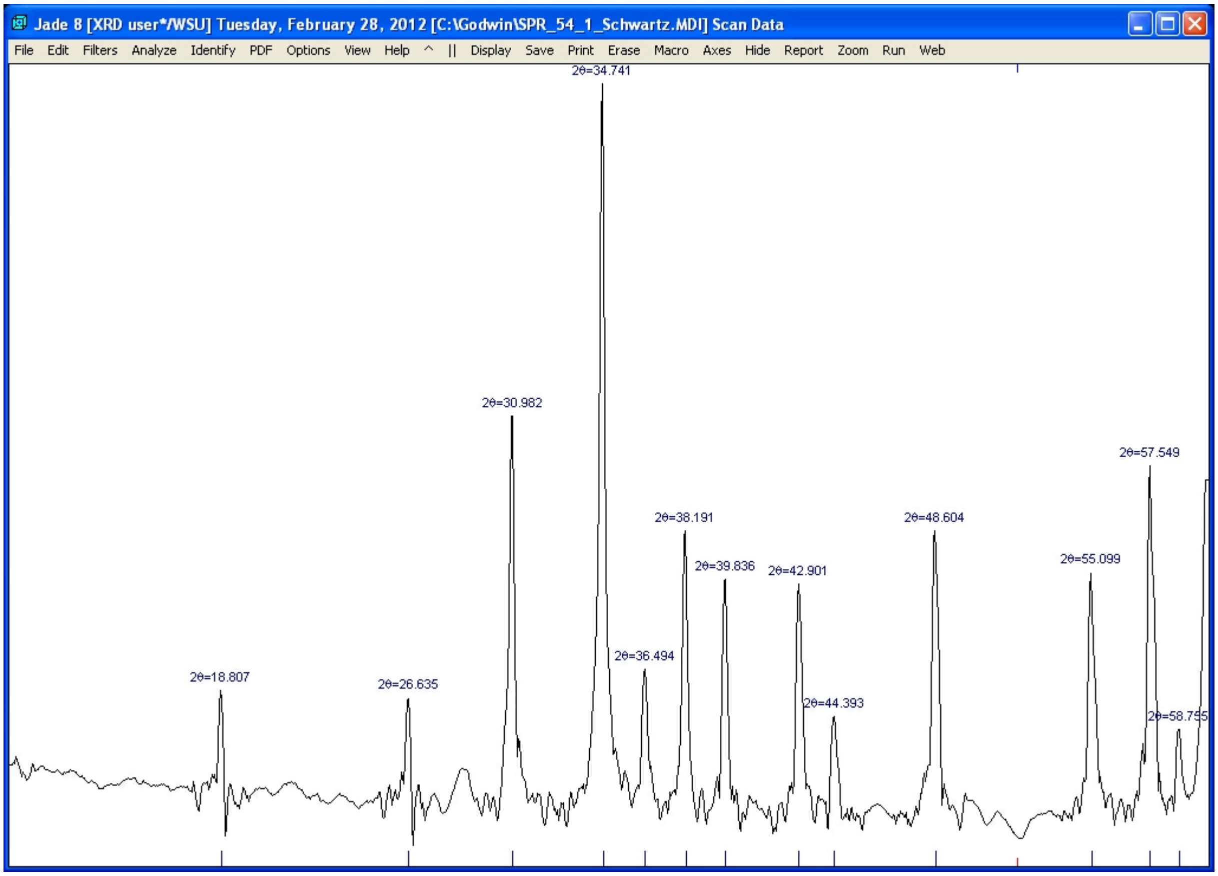

Figure 2.28. XRD Two Theta Graph. Schwartz Creek Sample.

Almandine						
2-Theta	d(Å)	I(f)	(h k l)	Theta	1/(2d)	2pi/d
18.845	4.7051	7.5	(2 1 1)	9.423	0.1063	1.3354
21.794	4.0747	3.2	(2 2 0)	10.897	0.1227	1.542
28.965	3.0802	4.3	(3 2 1)	14.482	0.1623	2.0399
31.013	2.8813	32.6	(4 0 0)	15.506	0.1735	2.1807
34.784	2.5771	100	(4 2 0)	17.392	0.194	2.4381
36.54	2.4571	3.7	(3 3 2)	18.27	0.2035	2.5571
38.226	2.3525	20.6	(4 2 2)	19.113	0.2125	2.6708
39.852	2.2602	9.6	(4 3 1)	19.926	0.2212	2.7799
42.948	2.1042	15.1	(5 2 1)	21.474	0.2376	2.9861
44.43	2.0374	3.5	(4 4 0)	22.215	0.2454	3.084
48.662	**1.8696**	**19.3**	**(6 1 1)**	**24.331**	**0.2674**	**3.3607**
50.012	1.8223	0.5	(6 2 0)	25.006	0.2744	3.448
51.335	1.7784	0.1	(5 4 1)	25.668	0.2812	3.5332
53.912	1.6993	0.3	(6 3 1)	26.956	0.2942	3.6976
55.169	1.6635	14.1	(4 4 4)	27.585	0.3006	3.7771
56.407	1.6299	0.3	(5 4 3)	28.204	0.3068	3.855
57.628	1.5982	27.1	(6 4 0)	28.814	0.3128	3.9313
58.832	1.5684	2.7	(5 5 2)	29.416	0.3188	4.0062

Table 2.16. Jade 8 Almandine XRD Standard.

Pyrope						
2-Theta	d(Å)	I(f)	(h k l)	Theta	1/(2d)	2pi/d
18.807	4.7145	0.9	(2 1 1)	9.404	0.1061	1.3328
21.75	4.0828	0.2	(2 2 0)	10.875	0.1225	1.5389
28.906	3.0863	0.8	(3 2 1)	14.453	0.162	2.0358
30.95	2.887	46.8	(4 0 0)	15.475	0.1732	2.1764
34.712	2.5822	100	(4 2 0)	17.356	0.1936	2.4333
36.464	2.462	17.2	(3 3 2)	18.232	0.2031	2.552
38.147	2.3572	22.2	(4 2 2)	19.073	0.2121	2.6655
39.769	2.2648	17.4	(4 3 1)	19.884	0.2208	2.7743
42.858	2.1084	11.8	(5 2 1)	21.429	0.2372	2.9801
44.337	2.0414	2.5	(4 4 0)	22.169	0.2449	3.0779
48.559	**1.8733**	**17.4**	**(6 1 1)**	**24.28**	**0.2669**	**3.354**
49.906	1.8259	3.2	(6 2 0)	24.953	0.2738	3.4411
51.226	1.7819	0.2	(5 4 1)	25.613	0.2806	3.5261
53.796	1.7027	0.4	(6 3 1)	26.898	0.2937	3.6902
55.05	1.6668	12.6	(4 4 4)	27.525	0.3	3.7696
56.285	1.6331	0.4	(5 4 3)	28.143	0.3062	3.8473
57.502	1.6014	29.4	(6 4 0)	28.751	0.3122	3.9235
58.704	1.5715	1	(5 5 2)	29.352	0.3182	3.9983
59.889	1.5432	44.1	(6 4 2)	29.945	0.324	4.0716

Table 2.17. Jade 8 Pyrope XRD Standard.

2.6 Garnet Analysis Conclusions

Although garnet was collected over a broad area, and differences in the metamorphic grade of the schist within these areas typically increases to the south, the EMP and XRF analyses showed the garnet from all areas to be very similar. By calculating the mineral formula based on the average oxide contents for each sample, all garnet samples were determined to be approximately 80% almandine 10% pyrope with minor amounts of grossular and spessartine.

The XRF and EMP data correlated very well with slight differences in the garnet type typically less than 1% relative standard deviation, although the Purdue Creek sample had a relative standard deviation of 1.7% between the two methods. The XRD results indicated an almandine/pyrope garnet.

For the trace elemental analysis, Zr and Y were both identified in all garnet types, although the North Fork of the Palouse River sample had nearly double the amount of Y compared to all the other samples. Individual inclusions of zircon were also common in many of the garnets.

The XRD data was inconsistent with the other two methods, although it did point toward an almandine/pyrope garnet type. The difficulty and results are most likely due to user inexperience or the database of standards used may have not been representative.

CHAPTER 3. PETROLOGY OF THE UPPER SCHIST

3.1 Upper Schist Garnet Grain Size and Porphyroblast Analysis

Within the syncline study area, eight samples of schist (SS1 through SS8) were collected by the author from outcrops along existing logging roads. Due to the inherent weatherability of schist very few outcrops naturally occur within the study area. In fact, the colluvium lying over the schist can vary anywhere between 5-30 feet in thickness depending on the area. Although schist samples were collected across the syncline from three drainages, they most likely they represent the unit as it is compositionally closer to the hinge than the base, as is evidenced by the analyzed garnet grain sizes found. Most of the larger garnets in the southeast portion of the syncline are found in the colluvium or in the streams, indicating that most of the original host rock has been weathered away. The author was unable to find a schist sample containing large garnets.

The garnet grain size is not uniform over the Emerald Creek syncline. In general, the largest garnets are found in the southern portion of the syncline in the East Fork Emerald Creek drainage, and the smallest grains found to the north in the Tyson Creek drainage. In an unpublished study conducted by Nicholson et al. 2006, it was concluded that the garnet grain size is greatest near the base of the syncline and decreases as the hinge is approached. They also conclude that the garnet formed at varying pressures, where near the base larger garnets formed in a tensile environment and near the hinge in a compressive pressure environment which formed smaller garnet crystals. This also produced zoning trends in the garnet due to the differing types of pressures, where garnets near the base exhibited an increase in SiO_2 and Al_2O_3 from the core to the rim. The opposite was seen in garnet near the hinge. (Nicholson et al. 2006)

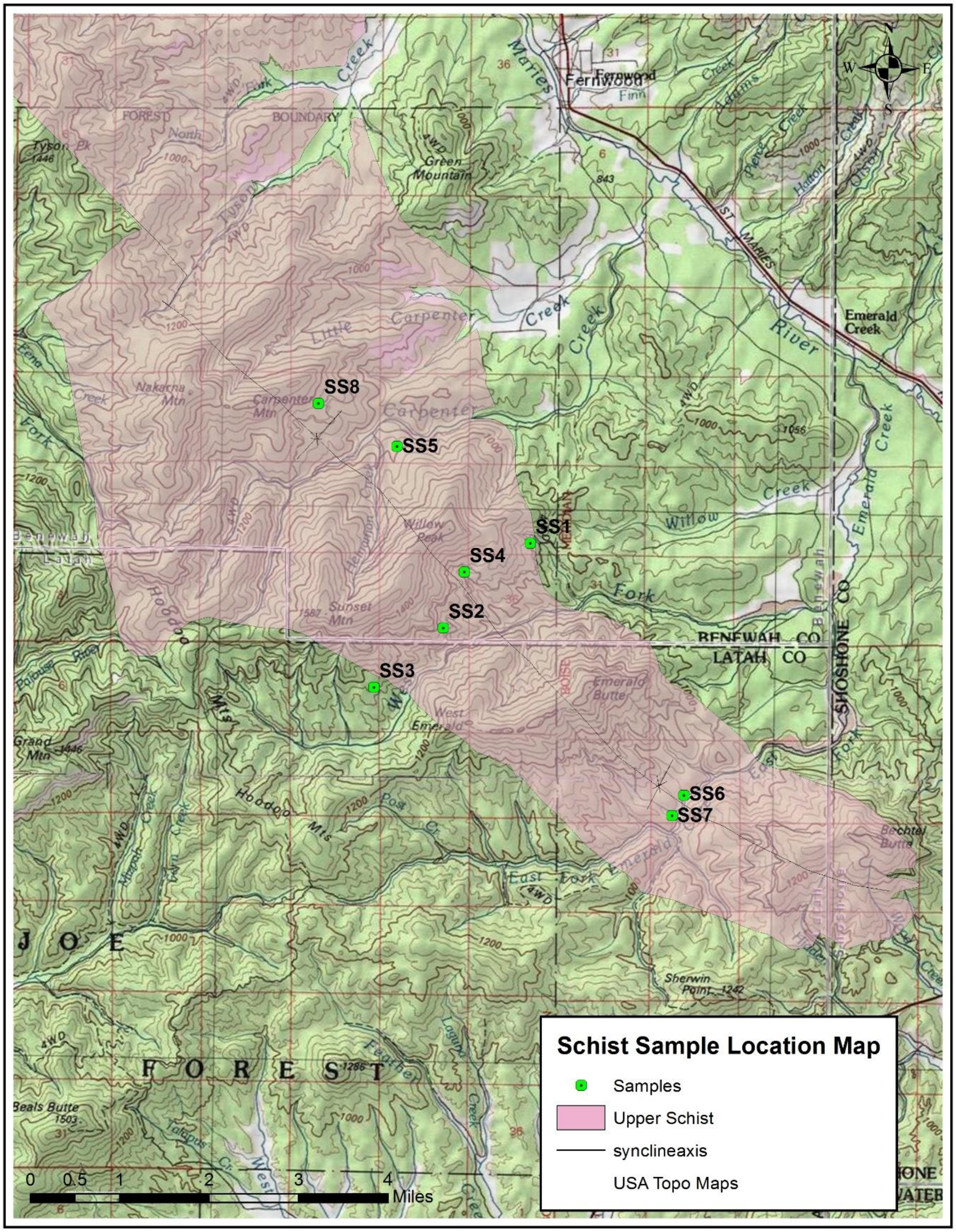

Figure 3.1. Schist Sample Location Map.

Sample SS1, as is shown in Figure 3.2, is a thinly laminated muscovite/biotite schist, collected from the West Fork Emerald drainage along the west side of the drainage contains garnet ranging in size from 2-4 mm. Large kyanite and possibly sillimanite porphyroblasts are also present. The sillimanite porphyroblasts are roughly square in shape and approximately 2 plus centimeters wide and 1 cm thick. In one porphyroblast of sillimanite, it appeared that garnet inclusions were distributed throughout. The kyanite porphyroblasts are approximately 4-5 cm long and 0.5-1 cm thick. Square muscovite porphyroblasts are also present and are approximately 8x8 cm wide and 4 mm thick. All porphyroblasts are oriented parallel to bedding. Sample SS4 was collected near SS1 and was nearly identical in composition to SS1, although the garnet porphyroblasts were slightly smaller ranging between 1-2 mm in size. No photo was taken of sample SS4. In all photos the clear ruler displays centimeters and millimeters on the smaller incremented side.

Figure 3.2. Sample SS1. West Fork Emerald Creek.

Sample SS2, shown in Figure 3.3, was also collected from the West Fork Emerald Creek drainage, although farther to the southwest than SS1. The garnet porphyroblasts also range between 2-4 mm and are on average closer to the 4 mm size. A small percentage of sillimanite porphyroblasts appear to be present. The schist itself is highly competent, possibly containing a larger percentage of quartz in the matrix than SS1. In fact, it was nearly impossible to break the rock with a sledge hammer.

Figure 3.3. Sample SS2. West Fork Emerald Creek.

Sample SS3 was collected along the West Fork Emerald Creek drainage to the southwest of SS2, just outside of the mapped upper schist unit. This sample contained garnet porphyroblasts that ranged between 3-11 mm and numerous muscovite porphyroblasts approximately 1 mm wide and 5 mm long. The host rock was a very hard silica rich quartzite with light and dark bands. Most of visible crystals occurred in the darker bands, as shown in the picture below (Figure 3.4) which was taken perpendicular to lamination.

Figure 3.4. Sample SS3. West Fork Emerald Creek.

Two samples were collected from the Carpenter Creek drainage. Sample SS5 was collected from the east side of the drainage and SS8 from the west side. Both samples consisted of a thinly laminated garnet mica schist. Within both samples, abundant garnet, mica and staurolite porphyroblasts were present. The garnet ranged between 1-2 mm, the muscovite was shaped in approximate 1.5 cm squares, and the staurolite was approximately 1 cm long and 2-3 mm wide. Many of the staurolite porphyroblasts were twinned as in shown in Figure 3.5. This photo was taken perpendicular to lamination, and Figure 3.6 of photo SS8 is roughly parallel to lamination.

Figure 3.5. Sample SS5. Carpenter Creek drainage (east side).

Figure 3.6. Sample SS8. Carpenter Creek Drainage (west side).

Samples SS6 and SS7 were both collected from the East Fork Emerald Creek drainage along the west side. Both samples consisted of a very finely laminated garnet mica schist with garnet, muscovite and staurolite porphyroblasts. In sample SS6, the garnet crystals were approximately 1-2.5 mm in size. The muscovite porphyroblasts were approximately 1-1.5 cm squares and 0.5 cm thick. Only minor small staurolite porphyroblasts were present, and all visible porphyroblasts were well distributed throughout the schist. The schist was light gray with significantly less laminae coloration as compared to the samples from Carpenter Creek. No photo was taken of SS7, as the only significant difference was there were no visible staurolite porphyroblasts present in that sample. Figure 3.7 shows sample SS8, which was taken perpendicular to lamination.

Figure 3.7. Sample SS6. East Fork Emerald Creek drainage.

3.2 Carpenter Creek and West Fork Emerald Creek Drill Core

Within the Carpenter Creek and West Fork Emerald Creek drainages, core was extracted by diamond core drilling by Granatus Septem, LLC. Table 3.1 and Figures 3.8

through 3.10 were provided by Granatus Septem, LLC. for use in this study. Three drill holes were completed by Granatus Septem, LLC. Two holes were located within the Carpenter Creek drainage and one in the West Fork Emerald Creek drainage. All three holes were drilled within the upper schist unit near the syncline axis. Table 3.1 shows the garnet extracted from the crushed core by mesh size. Both Carpenter Creek holes produced very similar sized garnet, while the West Fork Emerald Creek hole produced a small percentage of 8 to 12 mesh garnet and significantly less 30 mesh as compared to Carpenter Creek. In the figures below, the Carpenter Creek core sample contained garnet between 1-2 mm on average, while the West Fork Emerald Creek core samples contained garnet between 2-4 mm on average. In Figure 3.8 two staurolite porphyroblasts are visible in the Carpenter Creek core sample. The West Fork Emerald Creek sample in Figure 3.9 contains a large kyanite porphyroblast identified by the Granatus Septem, LLC. Geologist. (Granatus Septem, LLC. 2018)

	Carpenter Creek 1	Carpenter Creek 2	West Fork Emerald Creek
Mesh Size	Weight %	Weight %	Weight %
8	0	0	3
12	1	0	13
20	47	41	44
30	23	25	8
40	12	15	13
50	9	9	9
60	5	6	5
80	3	4	4

Table 3.1. Garnet Size by Mesh from Drill Core. (Granatus Septem, LLC. 2018)

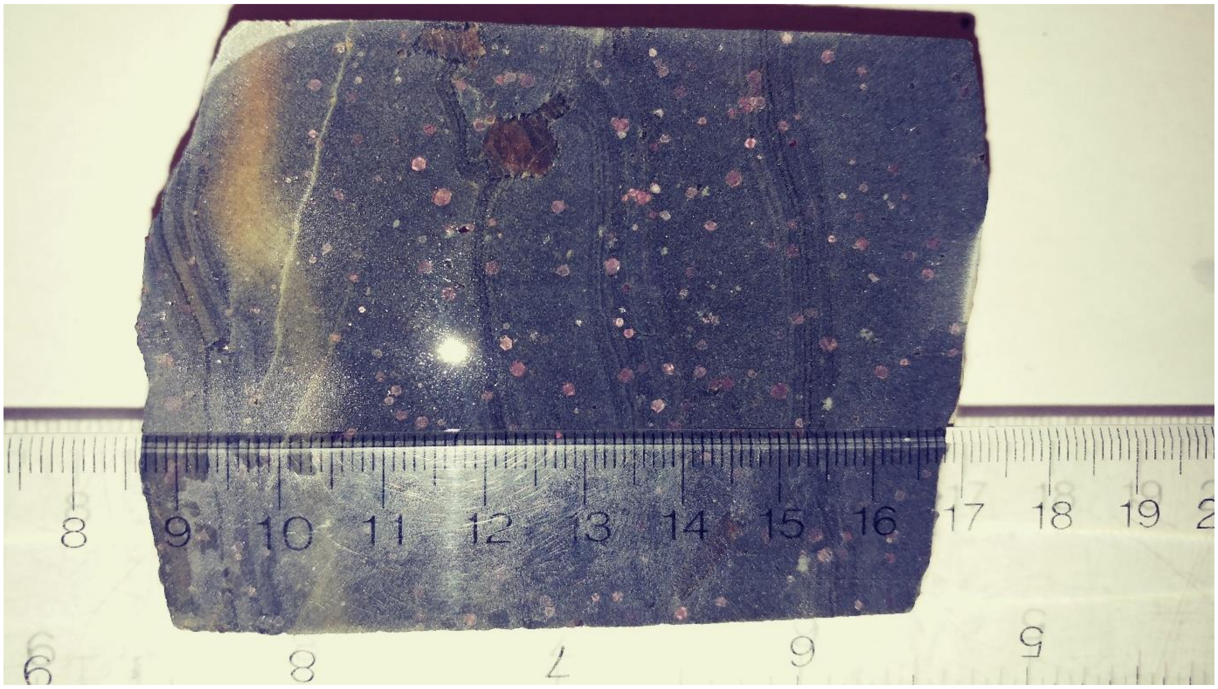

Figure 3.8. Drill Core. Carpenter Creek. (Granatus Septem, LLC. 2018)

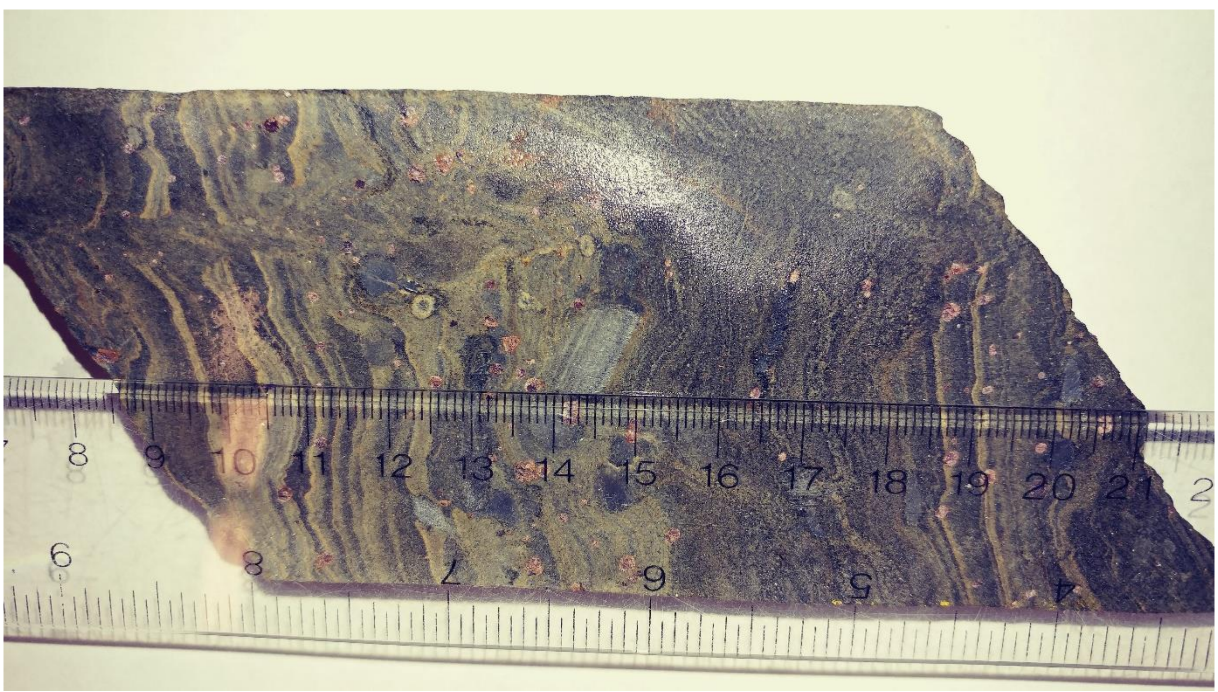

Figure 3.9. Drill Core. West Fork Emerald Creek. (Granatus Septem, LLC. 2018)

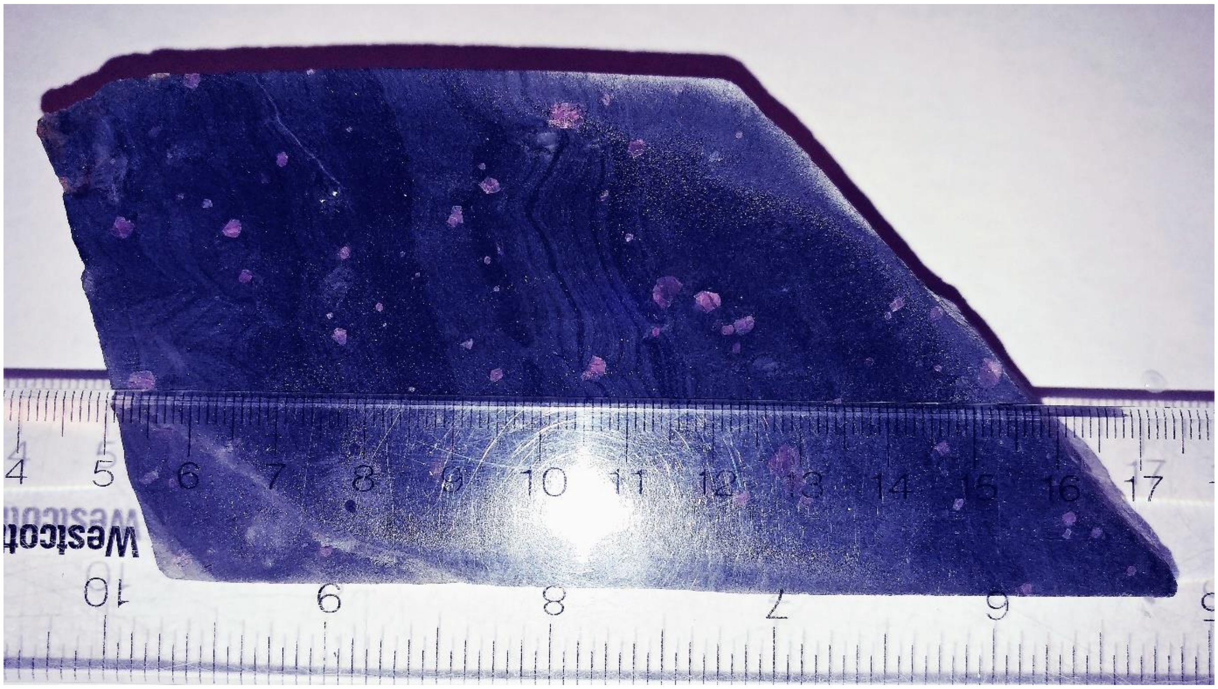

Figure 3.10. Drill Core2. West Fork Emerald Creek. (Granatus Septem, LLC. 2018)

CHAPTER 4. HISTORICAL MINING OF THE EMERALD CREEK AREA

4.1 1930's and 1940's

During the late 1930's and into the early 1940's, the very first garnet mining activity in the Emerald Creek drainage began. Garnet Mines, Inc. was formed by John Gordon Peters and Hershell Tripp. Peters lived in the Fernwood area, and Tripp was a grocer in the Spokane WA area. Maps dated December of 1939, show the various claims they owned under Garnet Mines, Inc. in the East and West Forks of Emerald Creek. They had a total of eight claims and one lease located along the West Fork of Emerald Creek. See Figure 4.1. (Emerald Creek Garnet, Ltd. 2017)

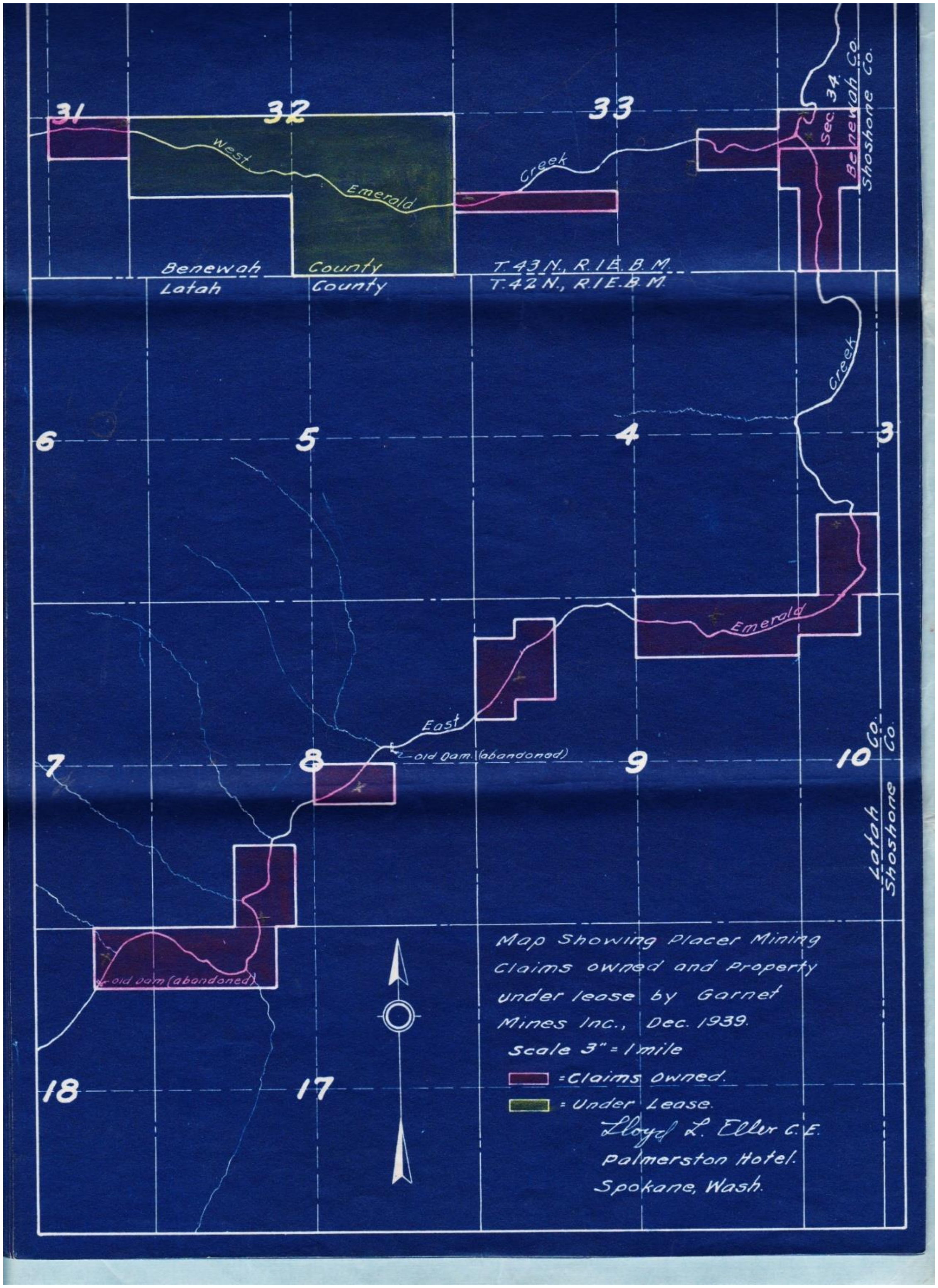

Figure 4.1. Mining Claims/Leases owned by Garnet Mines Inc., December 1939.

(Emerald Creek Garnet, Ltd. 2017)

At some point in the late 1930's W.R. Tompkins, owner of Western Foundry Sand Co. became interested in Garnet Mines, Inc. In a letter dated July 12th of 1938 from Milnor Roberts, a Mining Engineer out of Seattle Washington, to W.R. Tompkins, Milnor summarized test work completed on the alluvial material from the Emerald Creek drainage. Roberts completed a variety of test work including, sizing of the garnet contained within the alluvial material, concentration using a Wilfley table, concentration using a Wetherill magnetic separator, concentration using a Richards Pulsator Jig, and concentration using a Hartz Jig. According to the letter, the Wilfley table worked well if the material was screened into different fractions prior to running over the Wilfley table. In one test, he split the material into plus 20 mesh and minus 20 mesh fractions, while in another test he used minus 6 to 10 mesh, 10 to 14 mesh, 14 to 20 mesh, 20 to 28 mesh, and minus 28 mesh fractions although the 10 to 14 mesh was so small it was added to the 14 to 20 mesh fractions. He also determined that roughly half of the material could be screen off at a 6 mesh cut with little to no loss in garnet. (Emerald Creek Garnet, Ltd. 2017)

Of the other concentration methods he tested, he determined the Wetherill magnetic separator was too weak to have any effect on the garnet, and the Richards Pulsator Jig did not form a good jig bed with hydraulicking as an added problem. Of the jigs, only the Hartz Jig produced a clean garnet concentrate. He used a plus 10 mesh and a minus 10 mesh split to concentrate the garnet with the Hartz Jig, most likely with the plus 6 mesh material already screened out. Robert's final recommendations included using several Wilfley tables with the material split into three or four sized fractions and perhaps a Hartz Jig to concentrate the course fraction. (Emerald Creek Garnet, Ltd. 2017)

As indicated in a letter to Clyde W. Stewart, the then current President Garnet Mines Inc., dated March 22, 1940 from Royal S. Handy, a metallurgist out of Kellogg Idaho, the company was still in the testing and planning phase of operations. Handy proposed a list of equipment that would be needed to get a plant up and running. Figure 4.2 is a hand drawn flow sheet proposing a way to treat the alluvial sands to recover garnet. Figure 4.3 shows the actual first field process plant to run up Emerald Creek. The photo was taken some time during 1940-1941. (Emerald Creek Garnet, Ltd. 2017)

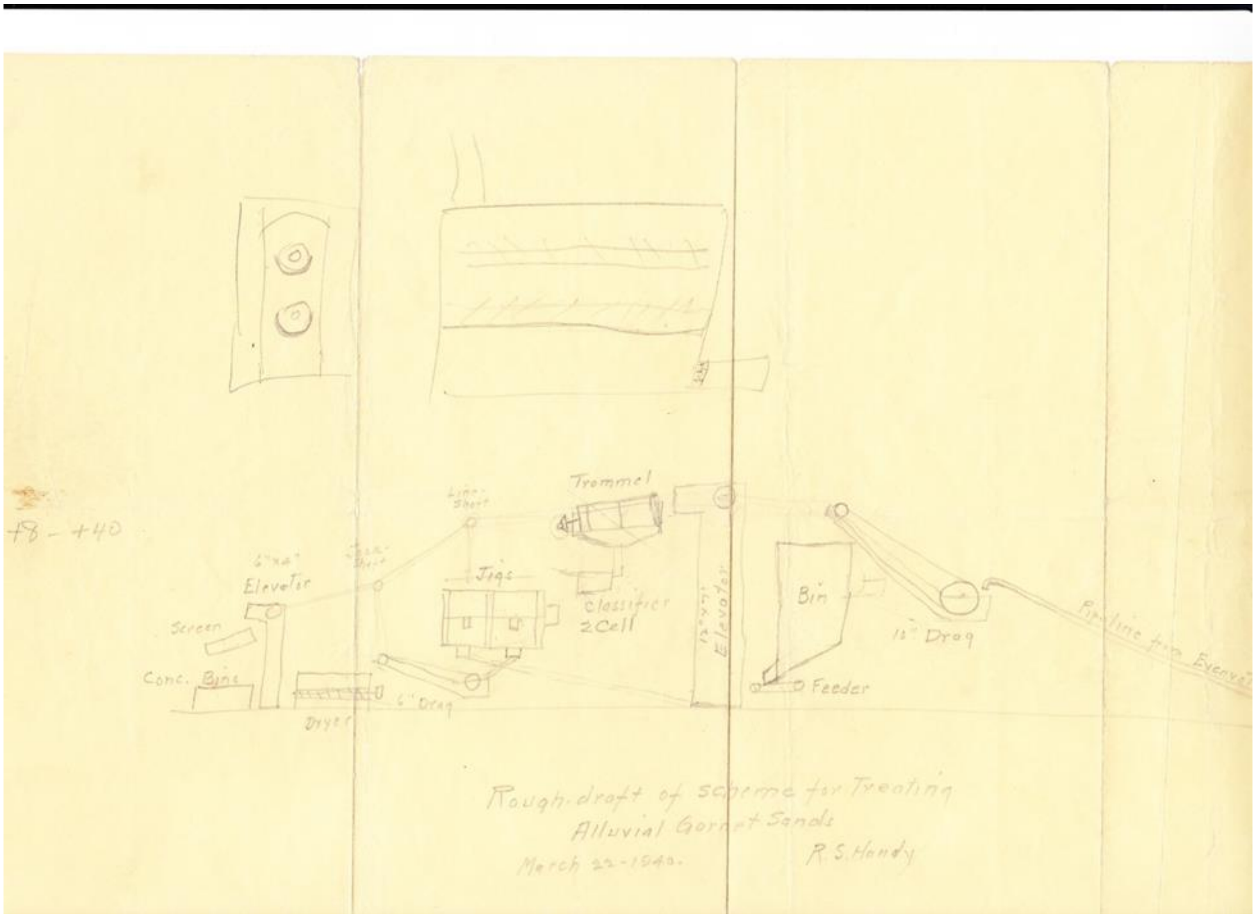

Figure 4.2. 1940 Hand drawn field process flow sheet. (Emerald Creek Garnet, Ltd. 2017)

Figure 4.3. 1940 or 1941 first field process plant. (Emerald Creek Garnet, Ltd. 2017)

According to a historical account of the area written in 1995, after Tompkins invested and took partial control of the company, during World War II the very first mill and wash plant were built in the Emerald Creek area. This account describes the first mining equipment as a steel wheeled farm tractor with a winch tied to a tree with pulley lines carrying a Bagley bucket system that was used to dig the alluvial material. The buckets dumped the alluvial material onto a flat belt which carried the material to the plant. The plant itself utilized vibrating screens and a Hartz Jig which, according to this account was built sometime in 1941 or 1942. The Bagley bucket system was a series of rotating buckets. (Dickison and McCall 2018) (Emerald Creek Garnet, Ltd. 2017)

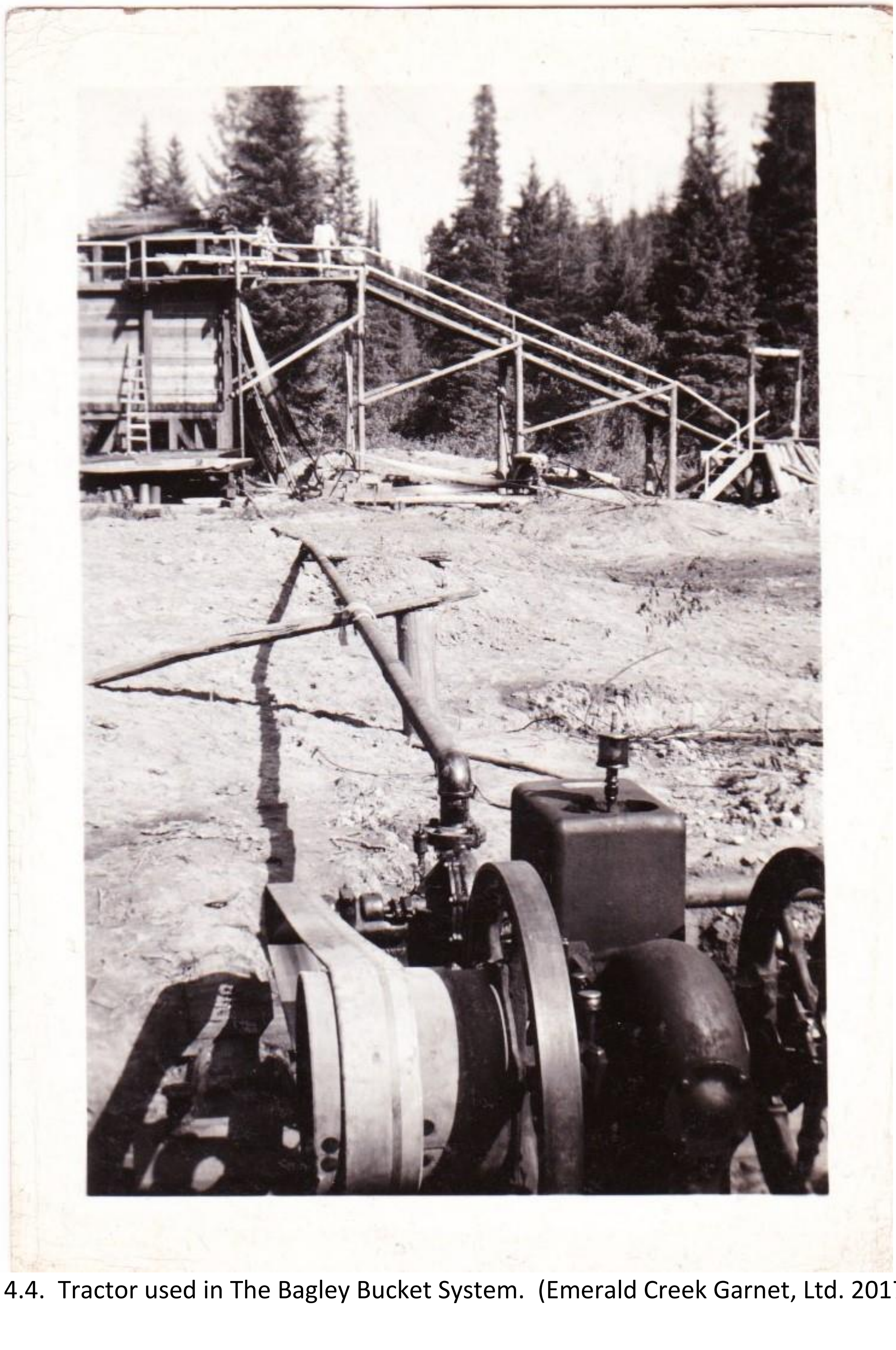

Figure 4.4. Tractor used in The Bagley Bucket System. (Emerald Creek Garnet, Ltd. 2017)

1941 marked the third year of operations for Garnet Mines Inc., and in a letter to its stockholders dated March 15, 1941, Clyde Stewart the president of the company explains the advancement work completed. This included purchasing an additional 520 acres of land containing garnet deposits, increasing capitol stock, arranging financial stability, and completing assessment work on the various mining claims owned by the company. (Emerald Creek Garnet, Ltd. 2017)

During 1942, the company was still trying to get up and running and acquire additional financing as indicated from a letter dated May 7th, 1942 from W.R. Tompkins to Fred Dugan, Tompkins's lawyer. Later that year, in September Fred Dugan sent out letters to stockholders indicating that the garnet mine was unable to open that year due to the lack of capitol and machinery which the war was making it difficult to acquire. The company offered to buy back the stock as they did not know when they would be able to proceed. (Emerald Creek Garnet, Ltd. 2017)

In May of 1943, Garnet Mines Inc. furthered their work to acquire additional financing. Fred Dugan, the new president of Garnet Mines Inc. sent a letter dated May 12th, 1943 proposing a finance agreement between Garnet Mines Inc. and Guy C. Meyers where Meyers would provide $50,000 dollars so the company could purchase additional machinery and in return Meyers would receive both stock in the company and return payment for the loan. They would construct a mill that would be able to produce 1000 tons in a four-month season. Later that same month, Garnet Mines Inc. decided to proceed on their own financing, as it seemed that Meyer's terms were not acceptable as indicated in a letter dated May 29th, 1943 from Fred Dugan to Tompkins. It was Dugan's hope that once the war was over they would have greater access to the required labor and resources. In 1943 Dorothy McCall, Bud McCall's mother, worked in the jig plant on the second shift and in fact during the war due to the shortage of male laborers, other women worked in the jig plant as well. (Dickison and McCall 2018) (Emerald Creek Garnet, Ltd. 2017)

In April of 1944, Dugan writes to J.G. Peters, the mine manager, that he feels things are beginning to look up and that they are "getting on the right track at last." He goes on to say that they "should have a better output, both in quantity, and also in quality, cleaner, brighter, better-looking and more saleable, and also more free from dust in use. Cleanliness is next to godliness, but in our case it is also next to profits." Near the end of April, from a letter dated April 28th, 1944, from Tompkins to Peters, they discuss the screen sizes that need to be used in the jigs such to promote a good bed. Tompkins recommends using a 0.140" screen to let the 8-mesh garnet through while rejecting the plus 6 mesh material. Tompkins also indicates in the letter that with the 8-mesh garnet he intends "to get it tested in the new type of throwing blast machines." He felt it could potentially be their "best seller and most valuable size." (Emerald Creek Garnet, Ltd. 2017)

Figure 4.5. Date unknown, possibly 1940's. Dump truck unloading.
(Emerald Creek Garnet, Ltd. 2017)

Figure 4.6. 1945 Bunkhouse up Emerald Creek. (Emerald Creek Garnet, Ltd. 2017)

Figure 4.7. Date Unknown. Jig plant. 1945? (Emerald Creek Garnet, Ltd. 2017)

Figure 4.8. Date Unknown. Dragline crossing the bridge. 1945?

(Emerald Creek Garnet, Ltd. 2017)

4.2 1950'S AND BEYOND

At some point after 1954, Garnet Mines Inc. sold and became Idaho Garnet, owned by Lowell Thompson. Then during the 60's Idaho Garnet sold to Sunshine Mining Company. Around this time Emerald Creek Garnet, owned by Earl Syler, formed and began mining in the Emerald Creek drainage. In the 70's Bud McCall purchased Emerald Creek Garnet and the portion owned by Sunshine and merged them into Emerald Creek Garnet Milling Company. Bud mined in the area from 1973 until 1991 when the company sold again. (Dickison and McCall 2018)

During the years when Bud owned the company, the first year of business was tough but eventually the market picked up. Baker water filtration, which filtered ocean water to create fresh water, bought a significant amount of garnet. Additionally, the garnet was sold for sand blasting and water jet cutting. When asked what it was like to own Emerald Creek Garnet, Bud said that "it was a challenge. You had to try everything." He liked it out in the field best. (Dickison and McCall 2018)

Most of the years of mining that occurred prior to the 80's utilized a dragline and trammel system to extract the garnet from the alluvial material. At one time, Bud had 5 or 6 complete field wash plants that used this system. Then, Bud introduced the first excavators to the field process, which at first were only thought to be good for digging ditches but have been used to dig the alluvial material much more effectively than the dragline which had a difficult time penetrating the denser gravel and cobbles. (Dickison and McCall 2018)

CHAPTER 5. SUMMARY AND CONCLUSIONS

5.1 Summary

Upon conclusion of this study, which analyzed the upper schist of the Wallace Formation within the Emerald Creek syncline with respect to garnet grain size and inclusion content and analyzed the composition of garnet contained in both the upper and lower schist of the Wallace Formation within the broader study area and investigated the history of mining in the Emerald Creek area, several conclusions may be drawn.

5.2 Conclusions

Garnet growth appears to have begun approximately 1 Ga, according to Lu-Hf age dating, and occurred during the Mesoproterozoic during a broad tectonic event in Northwest Laurentia.

Compositionally, the garnet within both the upper and lower units of the Wallace Formation is very similar, containing approximately 80% almandine, 10% pyrope, and minor amounts of grossular and spessartine. The most common inclusions within the garnet are quartz, mica, rutile, and zircon.

The garnet within the Emerald Creek syncline increases in grain size as the base of the syncline is approached and in general decreases in grain size traveling from Bechtel Butte to Carpenter Mountain along the syncline axis. Perpendicular to the syncline, the outer flanks of schist typically contain little to no garnet, and the garnet content tends to increase as the axis is approached.

Within the upper schist in the Emerald Creek syncline, the garnet tends to occur in bands, although within these bands, the garnet is well distributed. Additionally, the exposed schist that has not been weathered away, typically contains garnet crystals ranging between 1-4 mm, and most likely formed in a compressive pressure environment. Most of the schist which hosted the larger crystals which appear to have formed in a tensile pressure environment, appears to be weathered away in the southeast portion of the syncline and is not exposed and may not exist in the northeast portion of the syncline.

Schist containing larger garnet crystals is most likely to contain a higher overall garnet weight percentage.

Historically, the early days of mining began slowing and progress was halted during WWII. After WWII, progress picked up and much of the work done during those days has contributed to the long success of garnet mining for abrasive uses, which continues to this day in the Emerald Creek area.

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