

The Formation of Large Garnets at Gore Mountain, New York:  
Experimental partial melting of amphibolite and meta-gabbro

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## **Abstract**

This study examined the hypothesis that partial melting aided the growth of large garnets in the Barton Deposit of Gore Mountain, New York. Samples of meta-gabbro and garnet amphibolite from Gore Mountain were ground into powders. The powders were then subjected to temperatures and pressures resembling the peak conditions of the Adirondack Highlands (800°C and 8 kb) using a piston cylinder press. Water was added to half of the samples to determine if an influx of water had an influence on the melting or garnet growth.

After each experiment, the nickel sample holder was mounted in epoxy and ground to expose the contents of the run products. Melt was not identified within the experimental samples. The results give no evidence that partial melting had an effect on garnet growth, as melt did not appear to form readily under the peak temperature conditions. Additionally, the results of this study show that the simple addition of water did not convert the meta-gabbro into the garnet amphibolite ore. The process must be more complex than purely hydrating the meta-gabbro to become amphibolite as garnets of the hydrated meta-gabbros differed in composition from garnets of the Gore Mountain garnet amphibolite.

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## **Introduction**

The Barton Deposit on Gore Mountain has been mined for its garnet continuously for 105 years. The ore consists of unusually large garnet porphyroblasts, many greater than 10 cm in diameter (Fig. 1)

The origin of the garnets of Gore Mountain has been studied by many, yet there is not a universally accepted explanation for the formation of the garnets. The genesis of the large garnet crystals is generally attributed to an influx of water along the contact between the gabbro and the syenite (Luther, 1976, Goldblum and Hill, 1992). This is also said to have occurred under granulite facies metamorphic conditions (Luther, 1976). If water is added to rocks at this high of temperature and pressure, it would be likely for partial melting to occur. The presence of a partial melt would increase the rate of diffusion thus aiding the growth of the garnet crystals.

In order to test the hypothesis that the garnets grew large because they were in the presence of a partial melt, melting experiments were conducted on samples of the meta-gabbro and the amphibolite from Gore Mountain using a piston-cylinder press. A variety of temperatures and pressures were used to simulate the metamorphism these rocks underwent. In addition water was added to some samples to determine the effects of volatiles.

## **Geologic Setting**

Gore Mountain is located in the Adirondack Mountains of northern New York (Fig. 2). Specifically, it is located in the Adirondack Highlands. The main rock types of the Adirondack Highlands are anorthosite, syenite and gabbro, all of which have been metamorphosed during the Grenville Orogeny up to granulite facies pressures and temperatures (McLelland, 1995). The rocks are of the Grenville province and are Precambrian (~1.1 Ga) in age.

The garnet ore of Gore Mountain occurs within garnet amphibolite at an elevation around 2600 ft on the North slope of the mountain. The amphibolite body is thin, only 50 to 100m wide and occurs in a dipping lens that follows an East-West trend and transitions to the north into olivine meta-gabbro over 1-3m (Fig. 3). The garnet amphibolite is surrounded by meta-gabbro to the north, meta-anorthosite to the east, and meta-syenite to the south. A fault occurs between the meta-syenite and the garnet amphibolite and is one boundary for the ore body (Fig 3). The ore is exposed in multiple open pit quarries (Fig. 4).

***Lithologies***

The olivine meta-gabbro has undergone granulite facies metamorphism. The mineralogy of the meta-gabbro includes clinopyroxene, orthopyroxene, plagioclase, hornblende, garnet, biotite, olivine, and opaque minerals likely to be ilmenite. Coronas of garnet formed between plagioclase and clinopyroxene during the initial metamorphism of the meta-gabbro (Levin, 1960). Additionally, coronas of biotite and hornblende formed at the same time. The composition of the meta-gabbro is almost the equivalent to the composition of the garnet amphibolite except for the amount of water (Table 1). Thus, it is likely that the meta-gabbro was transformed into the garnet amphibolite as water influxed into the margins of the gabbro body.

Sample	Rock Type	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	Total
GM-307	Meta-Gabbro	47.63	0.62	17.09	12.67	0.16	10.56	7.77	2.82	0.54	0.07	99.94
GM-308	Meta-Gabbro	48.10	0.61	17.25	13.02	0.16	10.97	7.77	2.71	0.53	0.07	101.19
GM-407	Amphibolite	46.90	0.66	17.78	12.46	0.16	10.42	8.32	3.04	0.50	0.07	100.32

Table 1. The bulk rock compositions of Gore Mountain rocks completed by Heather Howard, Smith College (unpublished data, 2004). The powders of these samples were used in the experiments.

The transition zone between the meta-gabbro and garnet amphibolite is only 1- 3m wide, but has distinctive characteristics. The size of the garnet crystals increase towards the



amphibolite as they are less than 1mm in diameter in the meta-gabbro, 3mm in diameter within the transition zone, and 50-350mm in the amphibolite (Goldblum and Hill, 1992).

The garnet amphibolite consists of hornblende, garnet, plagioclase, orthopyroxene, biotite and sulfides. There is no olivine and very little if any clinopyroxene. In addition to an increase in garnet size, amphibole and biotite also increase in size (Goldblum and Hill, 1992). The garnet is not zoned and is homogenous throughout the ore body, averaging 13% in mode (Luther, 1976, Goldblum 1988). It is believed that the garnet ore was created as the margin of the olivine meta-gabbro underwent retrograde metamorphism, particularly by an influx of water while the gabbro remained hot (Luther, 1976; Goldblum and Hill, 1992).

The large size of the garnets is attributed to high rates of diffusion (Goldblum and Hill, 1992). Due to the fact that it takes large amounts of water to transform gabbro to amphibolite, it is likely that the influx of water could have aided the growth of the minerals as it increases the ability of elements to diffuse through the system.

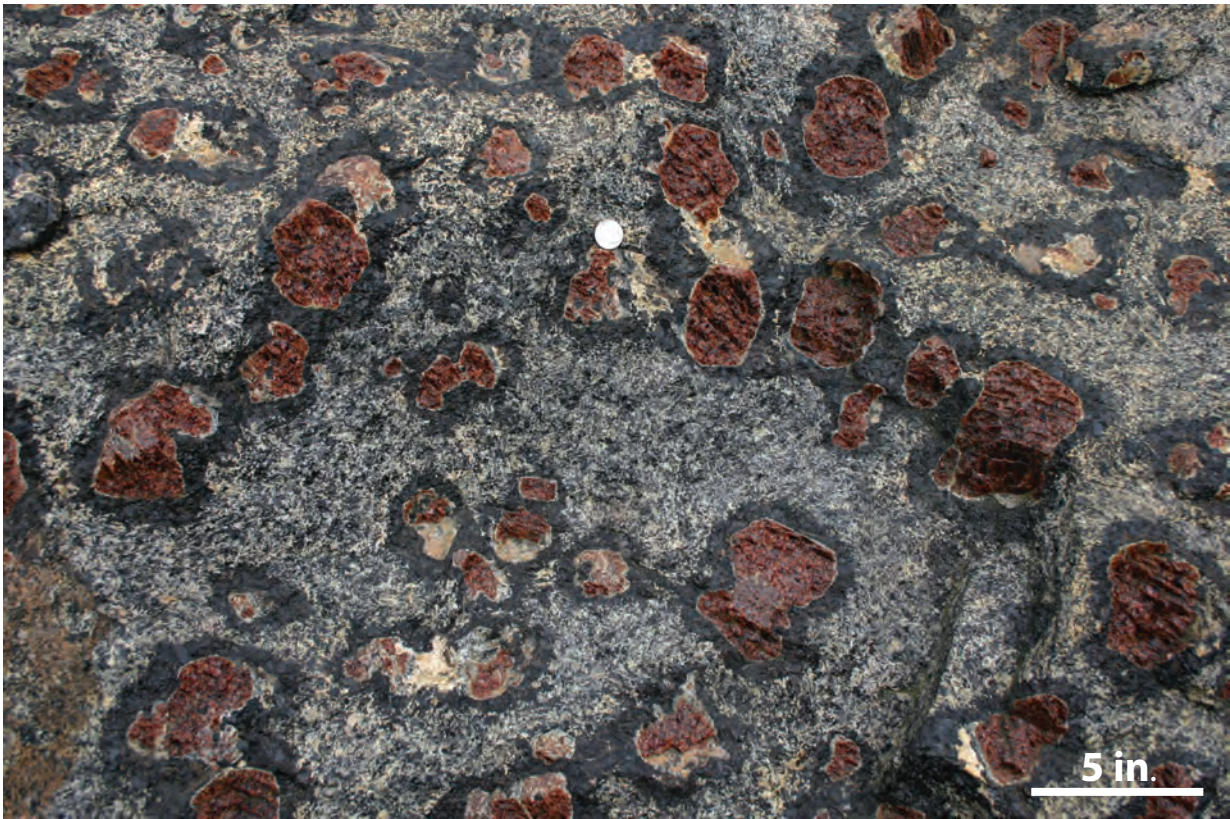


Figure 1. Gore Mountain Garnet Ore. Large garnets surrounded by hornblende occur throughout the amphibolite.

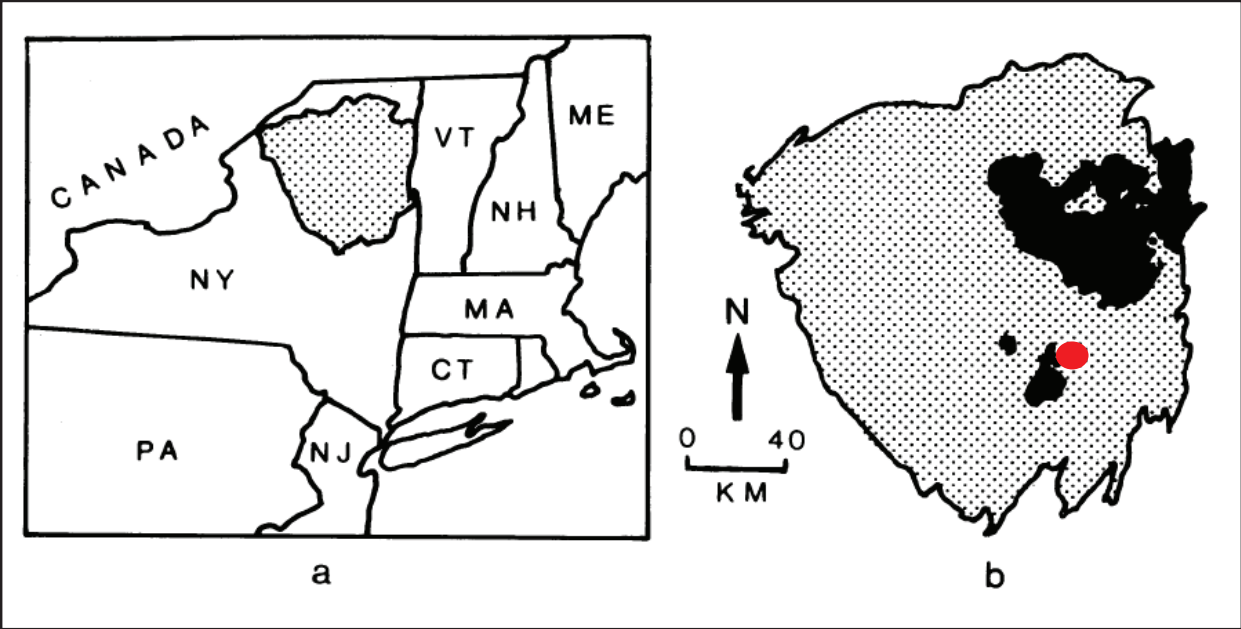


Figure 2. Location Maps of Gore Mountain. (a) The dotted area marks the Grenville rocks of the Adirondack Mountains. (b) The location of Gore Mountain is marked by a red dot. Anorthosite massifs of the Adirondack Mountains are shown in black. (Goldblum and Hill, 1992).

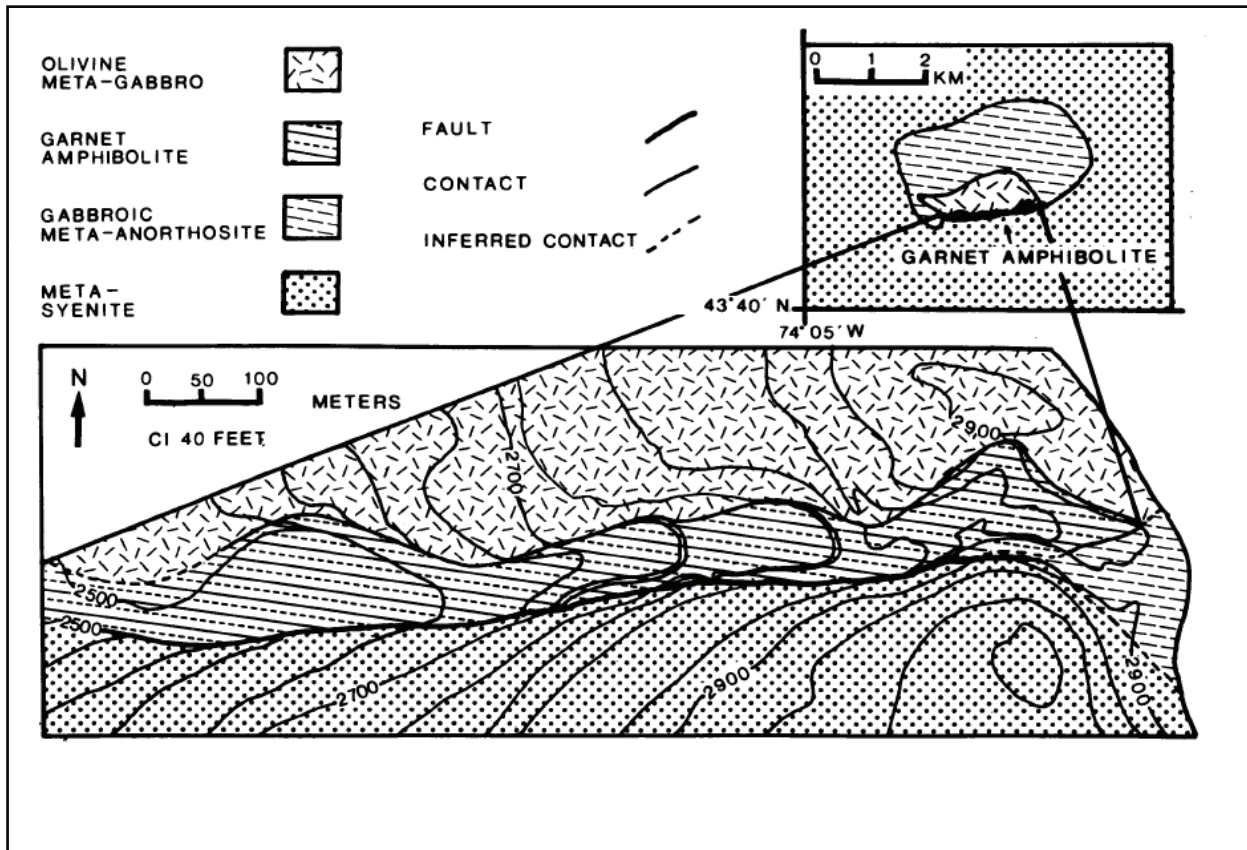


Figure 3. Map of the garnet amphibolite ore body and the lithologies that surround it. Located on the bottom of the north slope of Gore Mountain. (Goldblum and Hill, 1992)



Figure 4. A photograph of one of the open pits previously mined for Gore Mountain garnet.

## **Previous Work**

The majority of work on the garnet ore of Gore Mountain has focused on the mineralogy, petrology, and chemistry of the local rock units. Below are summaries of various research that has been completed over the years.

Levin (1950) describes the garnet ore forming as a result of contact metamorphism as the syenite magma intruded adjacent to the meta-gabbro. He classified the garnet of the Gore Mountain area into four different types; C-type or microscopic corona crystals, P-type or poikiloblastic crystals, X-type or completely recrystallized prophyroblasts, and XH-type which are garnet porphyroblasts greater than an inch that are surrounded by a hornblende shell. Levin (1950) proposes that the garnets of the meta-gabbro and meta-anorthosite formed as a result of the intrusion of the syenite magma. Specifically, he postulates that the largest garnets formed where the syenite magma mixed with the country rock and that the garnets also formed due to contact metamorphism. As the temperature decreased with distance so did the size of the garnets the further away from the contact. This hypothesis is disputed as Buddington (1952) found the garnets within the syenite to have a different composition than the garnets within the meta-gabbro.

### ***The origin of the hornblende rims and chemical analysis of minerals and rocks from Gore Mountain:***

Bartholome (1960) concluded that the garnet porphyroblasts are not present in rocks that have retained relics of their magmatic texture and mineralogy. Thus, the large garnets must have formed in place due to metamorphic processes and are not xenoliths. Bartholome (1960) also determined that the rims surrounding the garnets and the garnets grew concurrently. The hornblende that forms rims around the garnet is richer in magnesium and silica and poorer in

alumina than the hornblende of the matrix (Bartholome, 1960). Additionally Bartholome's (1960) chemical analysis shows that the garnet rim hornblende has more than four times the amount of fluoride than the matrix hornblende however, two different people did the analyses.

***A petrologic look at the origin of Gore Mountain garnet:***

Luther (1976) determined the chemical reaction that transformed the gabbro into the garnet amphibolite. He suggested the following:



(pl=plagioclase, cpx=clinopyroxene, opx=orthopyroxene, ol=olivine, mt=magnetite, h=hornblende, g=garnet)

However, this reaction was determined for conditions at 1 kb and 20°C and does not take into account the changes that occur to minerals and water under 7-8kb and 800°C. Luther (1976) used an electron microprobe analysis to obtain the composition of the garnets. He found that the garnets were weakly zoned, indicating that the environment in which the garnets grew had little variation. Luther (1976) described the rims around the garnet as matrix depletion rims if the reaction above is true.

***Gore Mountain Ore: The result of a shear zone***

Goldblum and Hill (1992) propose that the large garnets formed as a result of the combination of high temperatures and an influx of water within a shear zone between different lithologies. The meta-gabbro deforms in a brittle manner even under granulite facies metamorphism. If the gabbro was strained along a weaker lithology, (such as syenite) fractures would be produced within the meta-gabbro along the contact and thus would provide means for

water to flow through. The presence of water would increase the rate of diffusion aiding the growth of minerals and allowing hornblende to replace pyroxene. The large size of crystals in the amphibolite is likely a result of a high rate of diffusion allowing the minerals to receive the necessary ions to grow larger. Additionally, the strain will cause defects in minerals creating sites that favor additional mineral growth. Observations by Luther (1976) support this as he reported the largest garnets in both the garnet amphibolite and the anorthosite have parallel sets of partings spaced a few millimeters apart. If this is true, that the shear zone must have been actively shearing as the garnets grew.

***Dehydration melting of an amphibolite:***

The peak metamorphic condition of the Adirondack Highlands is thought to be 800°C and 8 kbars (McLelland, 1995). At 10kbars powdered amphibolite begins to melt below 850° (Wolf and Wyllie, 1994). Thus, at 8kbars the amphibolite at Gore Mountains is likely to have begun melting. Although the whole rock body would not be melted at this temperature, magma would begin to develop. With the addition of volatiles, particularly water, the melting point would be lowered thus causing more magma to be generated. Wolf and Wyllie partially melted amphibolite and were able to grow garnet (1993). While garnet grew largest between 925 and 950°C at 10kbars during their experiments, the reaction also occurred at lower temperatures when the amphibolite was under those conditions for longer periods of time. Although the composition of the amphibolite used by Wolf and Wyllie has 6.0% more CaO, 4.15% less FeO, and 3.18% less Al<sub>2</sub>O<sub>3</sub> than the amphibolite of Gore Mountain, the same partial dehydration melting could be applied to the rocks of Gore Mountain.

## **Experimental Modeling**

Using the program MELTS predictions of the experimental results can be predicted for various pressures and temperatures (Asimow and Ghiroso, 1998; Ghiroso and Sack, 1995). The chemical analyses of the gabbro and garnet- amphibolite from the eastern and western sequences were used (Luther, 1977). Pressures of 7kb and 8kb were used with temperatures ranging from 700°C to 1000°C. Water was also added to a number of the models. The garnet calculated by MELTS generally has less calcium in it than the garnet at Gore Mountain for any given model. Not all combinations of temperatures, pressures, and water content produced results from MELTS.

### ***Eastern Gabbro***

#### ***Modeling without water***

MELTS predicts the liquidus of the gabbro to occur at 1388°C at 8kb. At 8kb and 1000°C, the gabbro is expected to be 12.3% liquid, with no garnet formed. At 950°C the gabbro the model predicts that there will be 12.96% garnet along with 9.48% liquid. At 8 kb, MELTS predicts that garnet will begin to form in the eastern gabbro around 975°C and garnet will increase with lower temperatures.

At 7kb the liquidus is expected to be at 1360°C. MELTS predicts that at 900°C and 7kb there will be 13.86% garnet and 3.88% liquid. Additionally, at 900°C and 7kb the gabbro is still expected to contain olivine, hornblende, and biotite, which was not predicted for the models at 8kb.

#### ***Modeling with 5% water added***

At 7kb, with the addition of 5% water, MELTS predicts the liquidus to occur at

1305°C. At 900°C 8.13% garnet is expected along with 39.74% liquid. If the temperature is lowered to 700°C the percentage of garnet increases to 36.35% and the percentage of liquid decreases to 17.13%. At 700°C, MELTS predicts the presence of clinoamphibole, leucite, and biotite, all three of which were not predicted for 900°C.

### ***Eastern Amphibolite***

#### ***Modeling without water***

At 8kb the liquidus of the amphibolite is expected to be at 1322°C. If the temperature of the model is set to 950°C, MELTS predicts that 22.85% of the amphibolite would be garnet, 18.94% would be liquid, and 46.27% clinopyroxene. No hornblende is predicted which is likely the result of the complexity of the thermodynamics of the formation of hornblende. It is likely that much of the clinopyroxene predicted would actually be hornblende. If the temperature is lower to 850°C, the altered amphibolite is predicted to have 36.68% garnet, 33.13% clinopyroxene, 3.68% biotite, 4.03% hornblende, and 7.08% liquid. The MELTS results support the possibility of partial melting under the conditions of metamorphism that was suggested by others. This data helped guide the choice of temperature for the experiments.



## **Experimental Methods**

In general, the run procedure was similar to that of Morse et al. (2004), but using the nickel sample holder of Ayers et al. (1992). Rock samples from Gore Mountain were crushed and ground into powder. Some of each was ground to finer sizes using a micro-mill reducing the largest grain size by half. The coarse amphibolite powder grain size ranged from  $<1\mu\text{m}$  to  $100\mu\text{m}$ , while the fine amphibolite powder ranged in size from  $<1\mu\text{m}$  to  $50\mu\text{m}$ . The coarse meta-gabbro ranged in sized from  $<1\mu\text{m}$  to  $30\mu\text{m}$ , while the fine meta-gabbro ranged in size from  $<1\mu\text{m}$  to  $15\mu\text{m}$ . Two meta-gabbro samples from Gore Mountain were used in experiments, GM-307, GM-308, both of which have similar compositions. Only one amphibolite sample was used (GM-407). Each powder was dehydrated for at least an hour in a  $110^{\circ}\text{C}$  oven before insertion into the sample holders.

### **Sample Assembly:**

The sample assembly consists of many parts as shown in Figure 6. The thermocouple is placed close to the sample powders to ensure an accurate temperature reading. The dimensions of the sample assembly's parts also ensure that the temperature is highest at the center of the nickel sample holder. Because of its good thermal conductivity, the use of a Ni holder reduces temperature gradients during the experiments. Salt sleeves, and magnesium oxide spacers were made custom for each individual experiment. A W-Rb thermocouple was used to monitor and control the temperature of the experiment and is newly made for each run.

Four open gold capsules, welded closed at one end, are placed into holes within a nickel sample holder with an oxidized surface. As each powder was added to the sample holder, the amount of powder was weighed. The amount of powder used for each experiment sample was

between 0.0100 -0.0300g depending on the amount of space available in the gold capsule. If any water was added to the capsule, it was done before the powder was added to the gold capsule, and the amount of water was carefully weighed. Tape was used to cover empty sample capsules as well as previously filled capsules to minimize the possibility of contamination between capsules. Once all of the gold capsules are filled, the nickel sample holder can be placed within a fired prophyllite cup. A small sheet of gold is used to cover the sample capsules and seals the capsules once pressure is applied to the sample assembly. A nickel cap to the nickel sample holder is then placed on top followed by the lid to the fired prophyllite cup. In a few cases, extra space was observed between the nickel sample holder and the fired prophyllite cup. When space was observed, it was filled with graphite powder before the lid is placed.

The next steps in the production of the sample assembly involved placing a graphite furnace within a hollow pyrex sleeve, which was then surrounded by 2 halite sleeves. The lengths of each individual sleeve varied, but the total length of both sleeves together was always equivalent to the length of the pyrex sleeve. A cap to the bottom of the furnace was glued into place, and fits within the pyrex sleeve. The bottom magnesium oxide spacer is then inserted into the furnace, making sure it went down to the bottom of the furnace. The fired prophyllite cup assembly was then placed within the graphite furnace. Next, the top magnesium oxide spacer is placed within the furnace. The sample assembly is almost complete at this point. The last step was to place a fitted rectangle of lead foil around the circumference of the assembly. A small length (1-3mm) of lead foil is folded over the bottom of the sample assembly to hold it in place. The lead foil acts as a lubricant between the sample assembly and the press. Now the sample assembly can be placed within the pressure vessel of the piston-cylinder press. A stainless steel

base plug surrounded by an unfired prophyllite base plug sleeve was then gently placed on top of the sample assembly within the pressure vessel.

### **Thermocouple Assembly:**

Two Type D wires, one W97Re3 and the other W75Re25, were thread into two, four hole thermocouples sleeves. Together the length of the sleeves totaled around 2.5 inches. At the ends of the thermocouple sleeves the wires were then crossed and reinserted into a new hole within the thermocouple sleeve.

### **Piston Cylinder Apparatus:**

All runs were completed using the piston-cylinder press shown in Figure 7. The peak metamorphic conditions for Gore Mountain were around 800°C and between 7 and 8 kbars (McLelland, 1995). Because of this and because of the MELTS calculations the sample powders were subjected to temperatures of 800 to 900°C at 5 to 8 kbars for 1-6 days. The lower pressures were used to increase the amount of melt within the samples. To end a run, the power to the graphite furnace is shut off. Because the furnace no longer generates heat to the sample, the flowing water cools the sample quickly (a few seconds to cool several hundred °C). This will immediately quench the sample and all melt should become glass.

### **Post-Run Sample Preparation**

After each run, the nickel cylinder was removed from the sample assembly. It was then glued into a 1-inch phenolytic cylinder holder using epoxy. The sample was ground using a lap wheel until the four samples within the gold capsules were visible. This required the nickel lid and the gold sheet to be ground through. For a better polish, the sample was then polished with

diamond grit down to 1 micron using a different lap wheel. This polished the sample enough to be ready for the Scanning Electron Microscope (SEM). Before the sample could be analyzed using the SEM, it had to be carbon coated using a carbon evaporator.

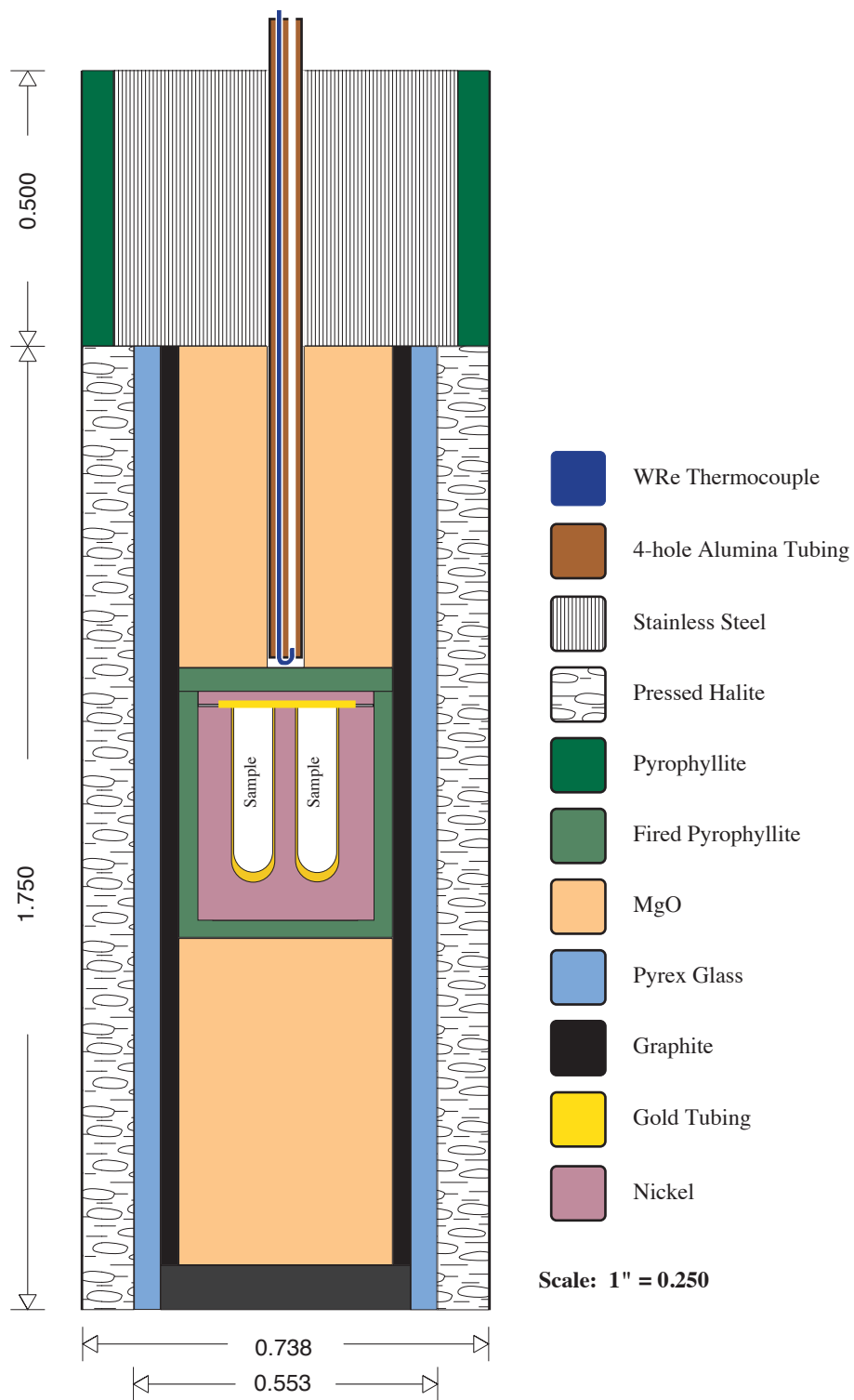


Figure 5. Diagram of Sample Assembly. The various parts and their materials of the sample assembly is illustrated. The rock powder is placed in the area marked sample in the center of the assembly. The thermocouple read the temperature near the top of the samples.

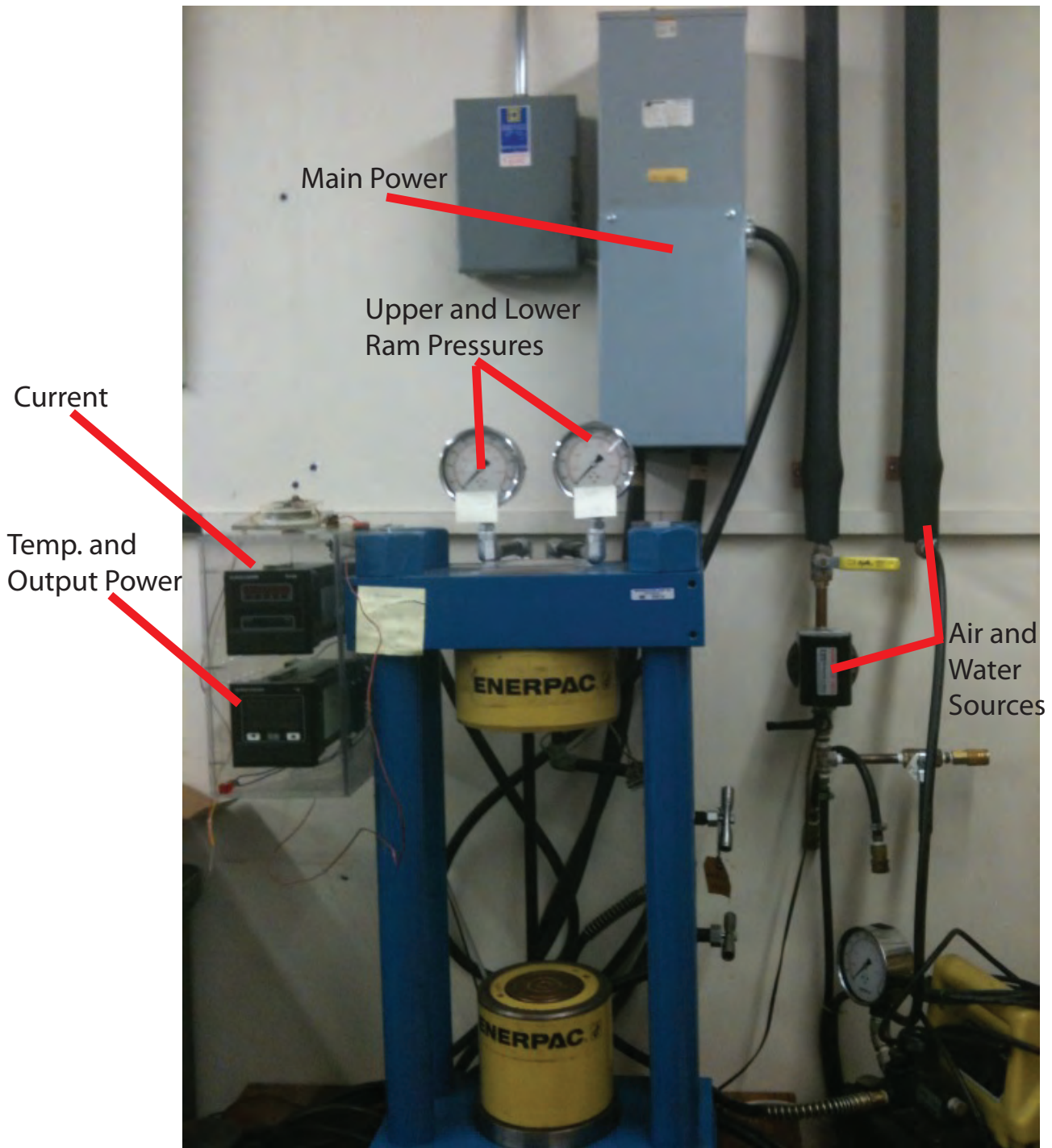


Figure 6. Piston-Cylinder Apparatus. The apparatus puts the samples under high pressures and temperatures to mimic conditions deep within the Earth's crust. The important parts of the press are labeled.

## Results

The general format of the results separates the experiments into the individual powder samples with and without water. The minerals of the samples were labeled in red on many of the images. Crystals circled in red have been chemically analyzed using the SEM and have been given unique names to identify them. Chemical line scans of crystals are shown as red lines across the area of the crystal that was analyzed. The original rock powders used can be seen in Figure 7. They can be compared with the results of experiments to see if any change in crystal size occurred.

<b>Experiment Number</b>	<b>Temperature</b>	<b>Pressure</b>	<b>Duration</b>
1	800°C	8 kbars	1 day 21 hours
2	800°C	8 kbars	1 day 21.5 hours
3	900°C	8 kbars	6 days 3.5 hours
5	800°C	7 kbars	6 hours
6	800°C	5 kbars	2 days 21 hours
7	800°C	6 kbars	4 days

Table 2. A table of all of the successful experiments with the temperature and pressure conditions as well as the duration.

### **Experiment 1:** *800°C, 8kb, 1 day 21 hours*

Two different samples of meta-gabbro (GM-307 and GM-308) were used in this run. The experiment consisted of a dry sample of each and a wet sample of each, containing 6-7% water. The experiment ran for about 21 hours. Due to the similarities between the two samples of meta-gabbro, the results of only one of the powders is discussed below. See Figure 8 for images of both samples of GM-307.

### ***Dry Meta-Gabbro***

The dry meta-gabbro has a wide range of crystal sizes. The majority of crystals are very angular (Fig. 8a). The primary minerals are plagioclase and orthopyroxene. Hornblende and garnet are also present, but less abundant. Clinopyroxene, olivine, and sulfides occur in minor amounts. Some of the plagioclase crystals have an abundance of inclusions. Fractures can be seen in the largest crystals (Fig. 8a). Many holes can be seen as highly charged areas (very bright) within the secondary electron images of the sample (Figs. 8a and 9a). The holes are irregularly shaped and occur primarily around grain boundaries. Other highly charged areas include fractures within grains. In BEI photos, garnet is the brightest mineral, hornblende is gray and plagioclase is dark gray to black. Orthopyroxene and clinopyroxene are bright, but not as bright as garnet (brighter than hornblende).

A greater magnified image of the same sample of dry meta-gabbro can be seen in Figure 10a. One plagioclase crystal in view stands out as it has many inclusions. A chemical analysis of the inclusions was attempted, however the total compound percent was too low making it likely to be inaccurate. The two garnets circled (Grt-1.dg.1 and Grt-1.dg.2) were chemically analyzed (Fig. 10a). The garnets are very similar in composition. The greatest difference in chemistry occurs in the amount of iron, however this is only a 0.55% compound difference, which is equivalent to a difference of 0.046 numbers of ions per formula of FeO. Thus despite the textural difference of appearance of the two garnets, they are almost identical in composition. Remnant olivine is found only in this experiment's samples of dry meta-gabbro. No crystal zoning was strikingly apparent looking at the compositional image of the sample.

The chemistry of other minerals was determined; however they are not located within the image above. Clinopyroxene occurs within the dry meta-gabbro. The chemical formula of one of



the clinopyroxenes present, Cpx-1.dg.1, is  $\text{Na}_{0.09}\text{Ca}_{0.85}\text{Mg}_{0.76}\text{Fe}_{0.22}\text{Al}_{0.11}(\text{Al}_{0.08}\text{Si}_{1.92}\text{O}_6)$ . The composition of an olivine crystal was also found, the crystal, Ol-1.dg.1, has the chemical formula:  $\text{Na}_{0.042}\text{Mg}_{1.19}\text{Fe}_{0.76}(\text{Si}_{1.01}\text{O}_4)$ . The olivine has almost double the weight percent of magnesium versus iron, however it is closer toward the middle of the Fayalite-Forsterite spectrum. The chemistry of a plagioclase crystal, Pl-1.dg.1, was determined to be:  $\text{Na}_{0.59}\text{Ca}_{0.40}\text{K}_{0.02}(\text{Al}_{1.44}\text{Si}_{2.56}\text{O}_8)$ . Additionally the composition of an orthopyroxene, Opx-1.dg.1, was found to be:  $\text{Na}_{0.03}\text{Mg}_{1.64}\text{Fe}_{0.25}(\text{Si}_{2.05}\text{O}_6)$ .

### ***Wet Meta-Gabbro***

The sample of wet meta-gabbro contains a larger amount of hornblende than the dry meta-gabbro sample. In fact, hornblende is the predominate mineral of the modified wet meta-gabbro. Orthopyroxene and plagioclase are still present, but much less abundant as evident when comparing Figure 8a to 8b with plagioclase shown as the darkest mineral. Inclusions also occur within plagioclase crystals of the wet meta-gabbro. The abundance of garnet does not appear to have changed between the dry meta-gabbro and the wet meta-gabbro. The crystals are angular to sub-angular. The nature of the highly charged areas of the secondary electron image has changed (Compare Fig. 8a to 8b and Fig. 9a to 9b). The holes appear to be vesicles of some sort as they are rounded and not as irregularly shaped as they were within the dry sample. The overall appearance of the wet meta-gabbro is much cleaner, or rather less chaotic looking. The wet sample has an overall smooth texture while the dry sample does not.

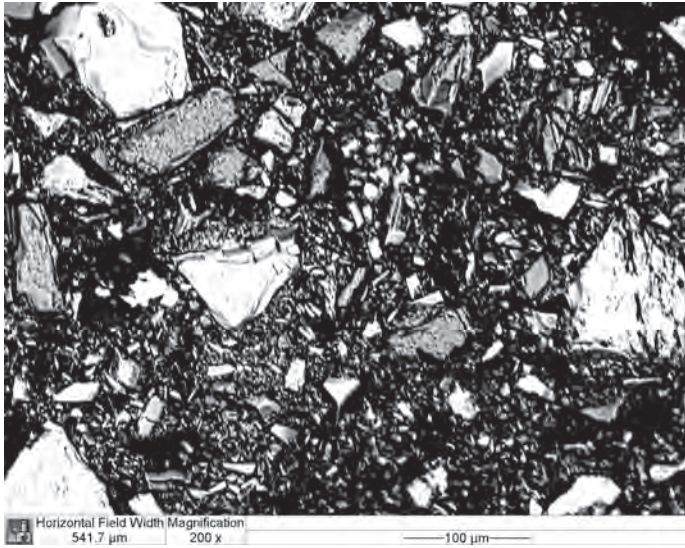
Some zoning is evident within a hornblende crystal (Fig. 10b). Two separate chemical analyses were completed on different parts of the crystal (Table 2). An analysis of the center of the crystal was taken (Hbl-1.wg.1) along with one of the edge of the crystal (Hbl-1.wg.1a) (See Fig. 10b). There is a major difference in composition of the two hornblendes. The center of the

crystal is richer in calcium, titanium, and potassium, while the edge of the crystals is greater in iron. The other elements that constitute hornblende are only varying in small amounts between the different parts of the crystal.

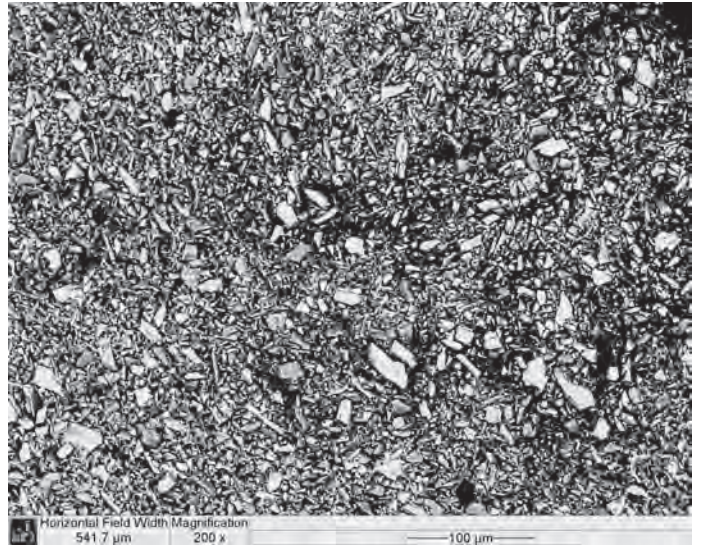
A crystal of garnet, Grt-1.wg.1, occurs between the two different parts of the hornblende crystal (Fig. 10b). It is small compared to the hornblende crystal and its edges are rounded, although it is not circular in shape. The garnet appears to have formed before the outer, chemically different edge of the hornblende did as most of its edge touches the center part of the hornblende. The edge of the hornblende crystal even separates from the center part of the crystal near its contact with the garnet.

A second garnet, Grt-1.wg.2, was analyzed within Figure 10b. This garnet is slightly different from the first garnet, Grt-1.wg.1. Grt-1.wg.2 is rectangular in shape with angular edges. It has slightly more magnesium, aluminum, and calcium, but with less silica, iron, manganese and potassium than Grt-1.wg.1 (Table 3). The difference for each individual compound is less than 3.5%.

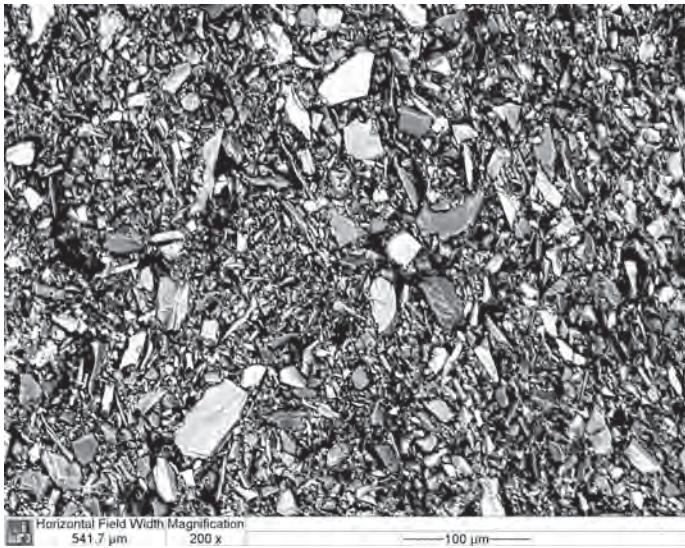
Coarse Amphibolite GM -407



Coarse Meta-Gabbro GM-307



Milled/Fine Amphibolite GM -407



Milled/Fine Meta-Gabbro GM-307

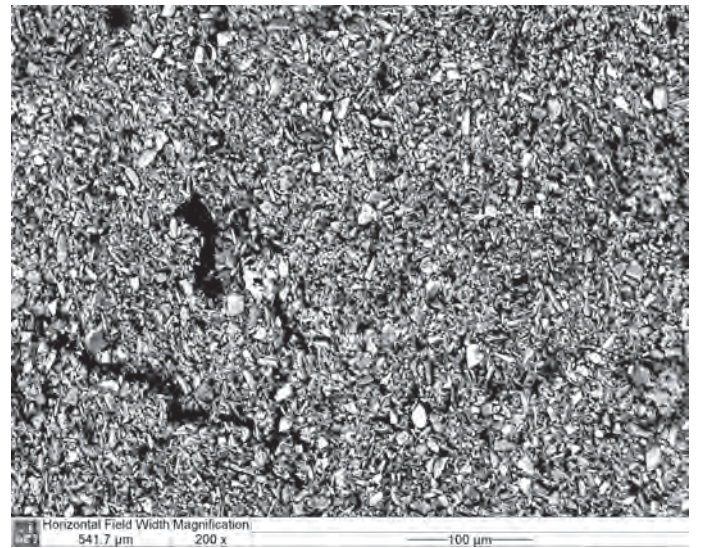


Figure 7 . The sample powders used in experiments. The variation in crystal sizes can be seen between each powder. Both amphibolite powders have larger crystals than either meta-gabbro powder.

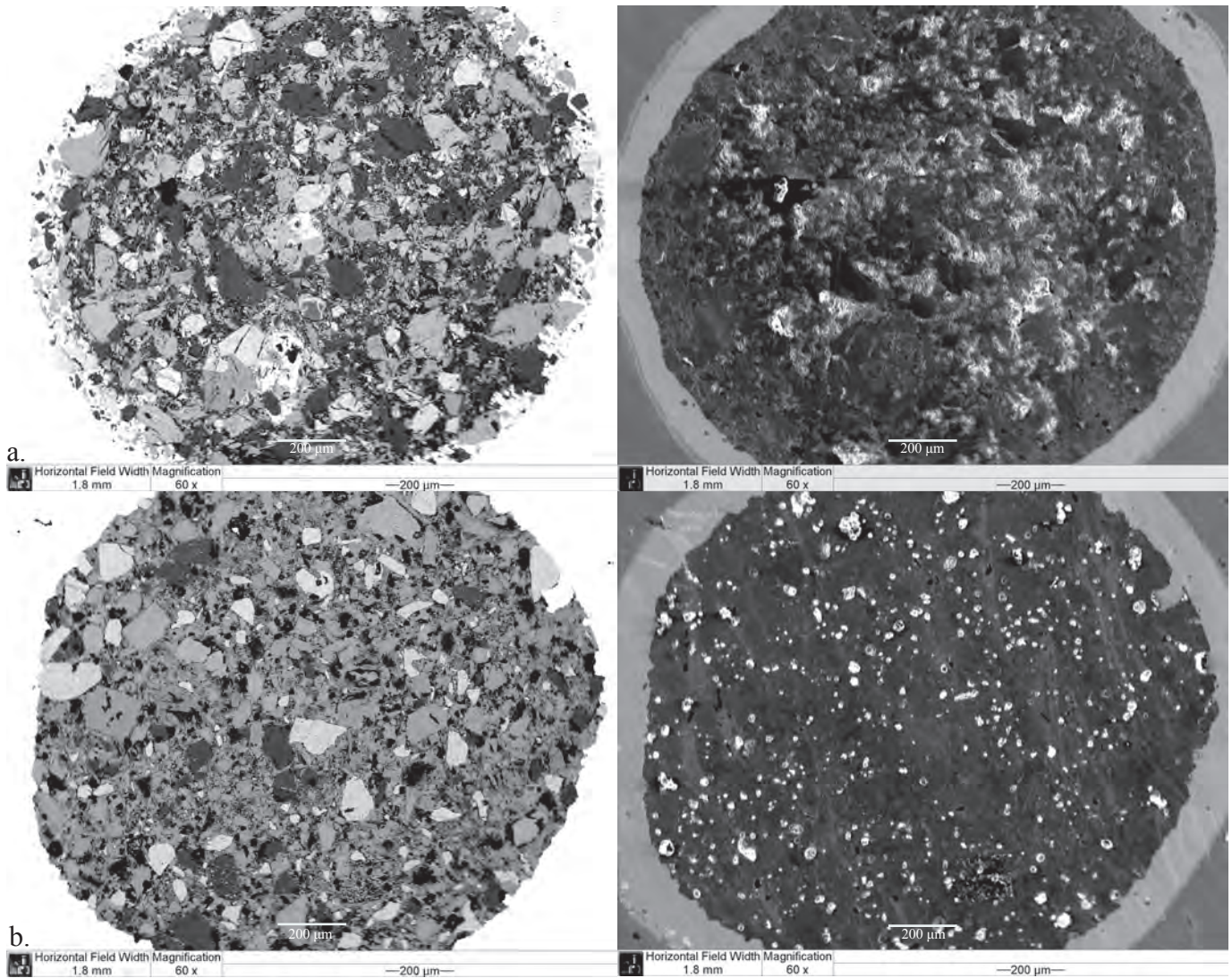


Figure 8. Meta-gabbro samples from Experiment 1 (800°C and 8kbars) shown at 60X magnification (GM-307). (a)The dry meta-gabbro sample in BEI on the left and the dry meta-gabbro sample shown in SEI on the right. (b) The wet meta-gabbro sample shown in BEI on the left the wet meta-gabbro sample shown in SEI on the right.

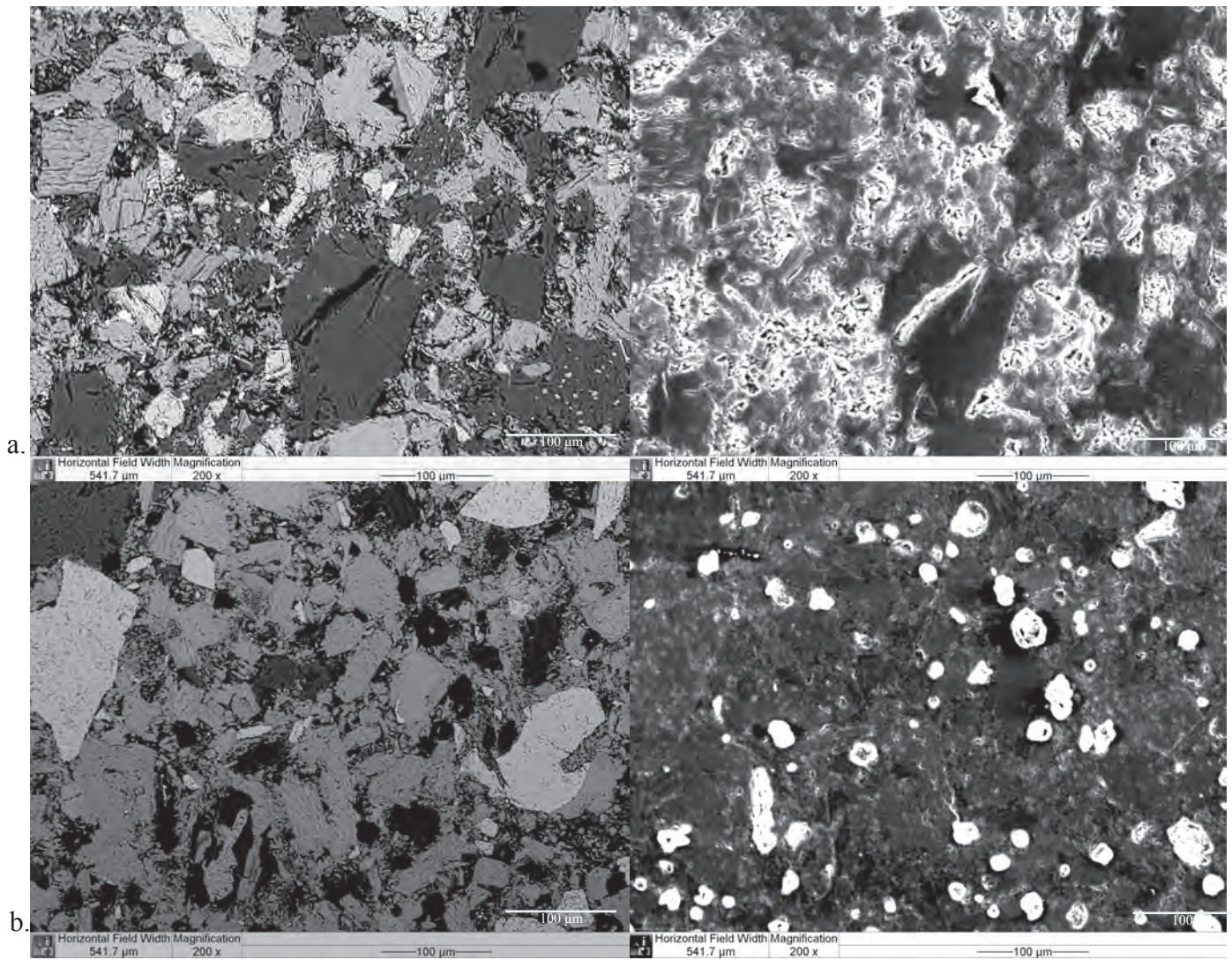


Figure 9 . Meta-gabbro samples from Experiment 1 (800°C and 8kbars) shown at 200X magnification (GM-307). (a)The dry meta-gabbro sample in BEI on the left and in SEI on the right. (b) The wet meta-gabbro sample shown in BEI and in SEI on the right.

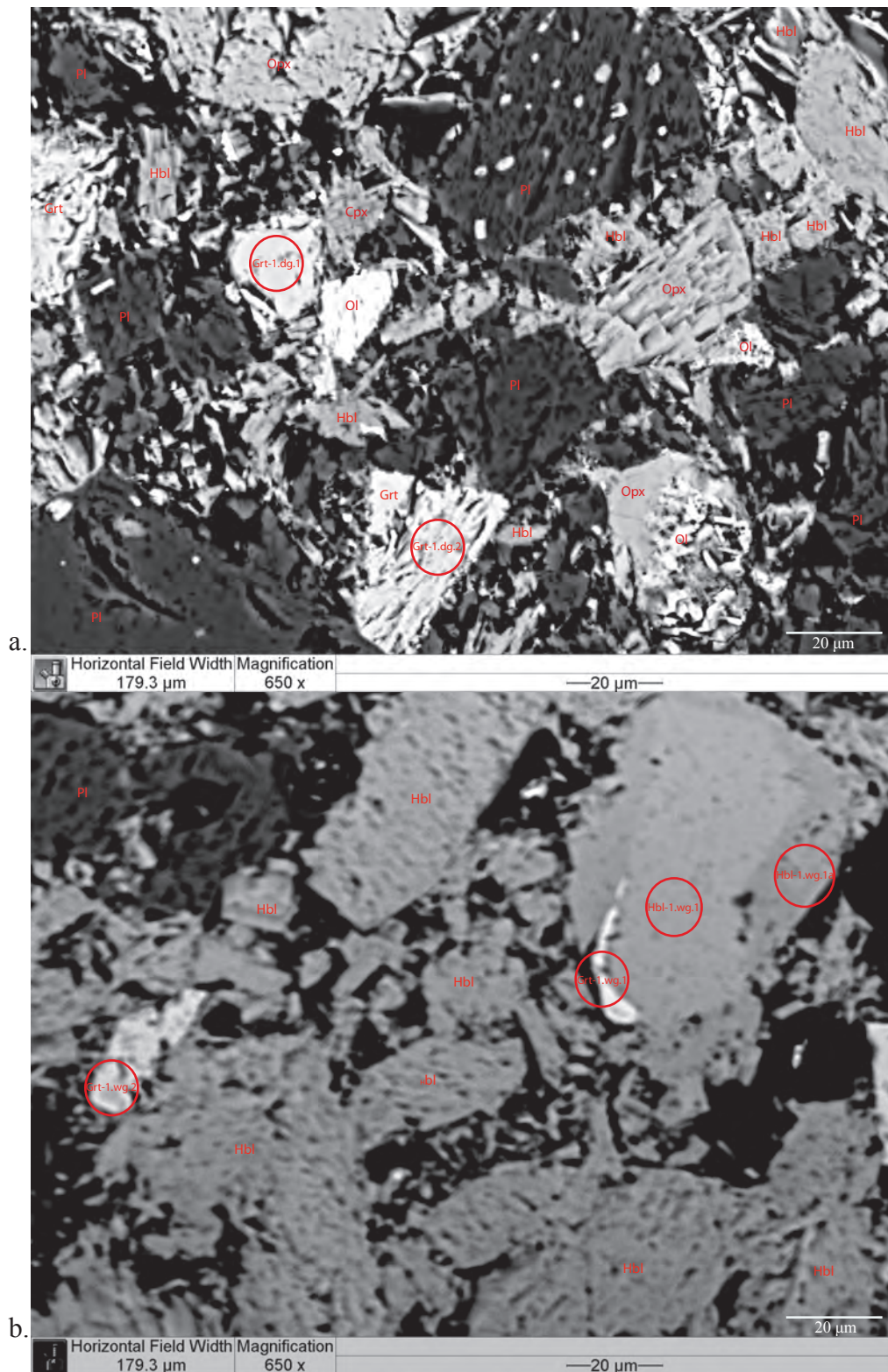


Figure 10. Meta-gabbro samples from experiment 1 shown at 650X magnification with mineral identifications (GM-307). The circled crystals have been chemically analyzed around the center of the circle. (a)The dry meta-gabbro sample in BEI. (b)The wet meta-gabbro sample shown in BEI.

Exp 1	Hbl-1.wg.1		Hbl-1.wg.1a		Difference	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.59	0.77	3.23	0.91	0.64	0.15
MgO	12.79	2.92	13.38	2.91	0.59	0.00
Al <sub>2</sub> O <sub>3</sub>	13.89	2.51	17.26	2.97	3.37	0.46
SiO <sub>2</sub>	39.45	6.04	41.79	6.10	2.34	0.06
K <sub>2</sub> O	1.57	0.31	0.14	0.03	1.44	0.28
CaO	11.46	1.88	8.23	1.29	3.23	0.59
TiO <sub>2</sub>	2.16	0.25	0.58	0.06	1.58	0.19
MnO	0.04	0.01	0.19	0.02	0.15	0.02
FeO	10.34	1.32	12.41	1.52	2.07	0.19
		23.00		23.00		
Total	94.30	16.00	97.20	15.82		

Table 3. Table of the composition of a hornblende from the wet meta-gabbro of Experiment 1. Hbl-1.wg.1 is the center of the crystal. Hbl-1.wg.1a is the edge of the crystal.

	Grt-1.wg.1		Grt-1.wg.2		Difference	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	0.55	0.08	0.42	0.06	0.13	0.02
MgO	8.14	0.91	9.85	1.13	1.71	0.22
Al <sub>2</sub> O <sub>3</sub>	22.15	1.96	22.45	2.03	0.31	0.08
SiO <sub>2</sub>	42.20	3.16	38.89	2.99	3.31	0.18
K <sub>2</sub> O	0.20	0.02	0.07	0.01	0.13	0.01
CaO	4.75	0.38	5.59	0.46	0.84	0.08
TiO <sub>2</sub>	0.04	0.00	0.04	0.00	0.00	0.00
MnO	0.62	0.04	0.52	0.03	0.11	0.01
FeO	21.53	1.35	20.47	1.31	1.07	0.04
		12.00		12.00		
Total	100.18	7.90	98.30	8.03		

Table 4. Table of the composition of garnets from the wet meta-gabbro of Experiment 1.

**Experiment 2: 800°C, 8kb, 1days 21.5 hours**

Two different samples of amphibolite (GM-407) one coarse, and one milled to a finer grain size were used. The coarse amphibolite powder grains range from less than 1µm to 100µm. The finer amphibolite powder grains range from less than 1µm to 50µm. For each type (coarse and fine), a dry sample and a wet sample were used. Between 5 and 6 weight percent water was added to the wet samples. The samples were held at 800°C and 8kb for around 45.5 hours. See Figures 11 and 13 for images of all samples.

***Coarse Dry Amphibolite***

This sample is predominately hornblende. Plagioclase is the second most common mineral. Garnet and orthopyroxene are also major constituents of the amphibolite. The crystals are angular to sub angular. The largest crystals are less than 200µm wide, but greater than 150µm wide (Fig. 11a). There are large crystals of every major mineral that occurs within the amphibolite. Many of the highly charged areas within the secondary electron image are vesicles that are believed to be due to a fluid created as the amphibolite reacted to the rise in temperature and pressure. The fluid is a super critical H<sub>2</sub>O fluid that vaporizes upon quenching the experiment and is believed to be from the dehydration of hornblende, although it may have exsolved from a melt on quench. The vesicles are around 10µm wide.

A closer look at the coarse amphibolite further reveals the angular nature of the crystals (Fig.12a). No zonation is apparent in either the amphibole or the garnet. There could be minor chemical variation within plagioclase crystals along the edges of holes, however they are likely



variations in thickness. The coarse dry amphibolite does not appear to have reacted much to the rise in temperature and pressure.

### ***Coarse Wet Amphibolite***

The mineral assemblage of the coarse wet sample is very similar to the dry sample. Its major minerals are hornblende, plagioclase, garnet and orthopyroxene with minor clinopyroxene. Comparing Figure 11a to Figure 11b, there may be a larger percentage of plagioclase within the wet sample. The crystals are sub-angular to sub-rounded and have a similar range in size. There does appear to be more vesicles within the wet sample. The majority of crystals within the wet sample are not zoned; however there are a few hornblende crystals that appear to be zoned.

A more highly magnified view of the coarse wet amphibolite can be seen in Figure 12b. The plagioclase crystals appear to be less angular than other minerals. The large garnet crystals appear to have been fractured and broken in to pieces during the experiment. The composition of one garnet crystal, Grt-2.wa.1, was determined to be:  $\text{Ca}_{0.30}\text{Fe}_{1.35}\text{Mg}_{1.24}\text{Mn}_{0.04}\text{Al}_{2.01}(\text{Si}_{3.00}\text{O}_{12})$ . The calcium content is only 3.7 weight percent, and the amount of magnesium is 11.0 weight percent, while the iron content is 21.4 weight percent.

### ***Fine Dry Amphibolite***

The finely powdered amphibolite is composed majorly of hornblende and plagioclase. Garnet and orthopyroxene are also present in significant amounts. Small vesicles occur within the sample (Fig. 13a). The crystals are generally angular and have a smaller range in size than previous samples. Further milling the amphibolite clearly created a finer powder. There does not appear to be any organization of crystals occurring or any major pockets of smaller sized crystals within the sample (Fig. 13a).

Looking at the fine, dry amphibolite in a closer view in Figure 14a, the nature of the sample can be seen more easily. The vesicles occur primarily on crystal boundaries especially around plagioclase crystals. There does not appear to be any zonation of crystals. Two garnet crystals within the sample were analyzed (Grt-2.da.1 and Grt-2.da.2). They were almost identical in composition. The average composition for the garnets is:

$\text{Ca}_{0.30}\text{Fe}_{1.38}\text{Mg}_{1.23}\text{Mn}_{0.04}\text{Al}_{2.03}(\text{Si}_{2.99}\text{O}_{12})$ . This is the same composition as a garnet from the wet coarse amphibolite sample (Grt-2.wa.1).

### ***Wet Fine Amphibolite***

This sample is also composed primarily of plagioclase and hornblende with less, but significant amounts of garnet and orthopyroxene. Figure 13b shows the complete sample of the wet, fine amphibolite. There are two distinct ranges in crystal sizes. Pockets of smaller sized ( $\sim 1\mu\text{m}$ ) crystals occur within the sample. This phenomenon does not occur within the equivalent dry sample. The pockets appear to have the same mineralogy and proportions as the larger crystal areas. A large amount of rounded vesicles can be seen in the secondary electron image of Figure 13b. The vesicles are much larger than they were in the dry fine amphibolite sample. There are vesicles within the pockets of fine crystals however; they are smaller and less abundant than in the majority of the sample.

Figure 14b shows a place within the sample where the coarser area adjacent to the finer area. Chemical analysis of the finer area was difficult because of the small size of the crystals. Once again, looking at Figure 14b, it is clear that the vesicles are larger within the coarse area of the sample. Two garnets were analyzed within the coarse area and one was analyzed within the fine area. The garnet within the fine area was compared to the average composition of the

garnets within the coarse area because the coarse garnets were similar (Fig. 14 b). The garnet within the fine area has 6.6% more magnesium, 8.7% more silica, and 1.4% more calcium than the coarse garnets. The same fine garnet has 11.7% less alumina and 8.2% less iron. The fine garnet has a clearly different composition than the coarse garnets.

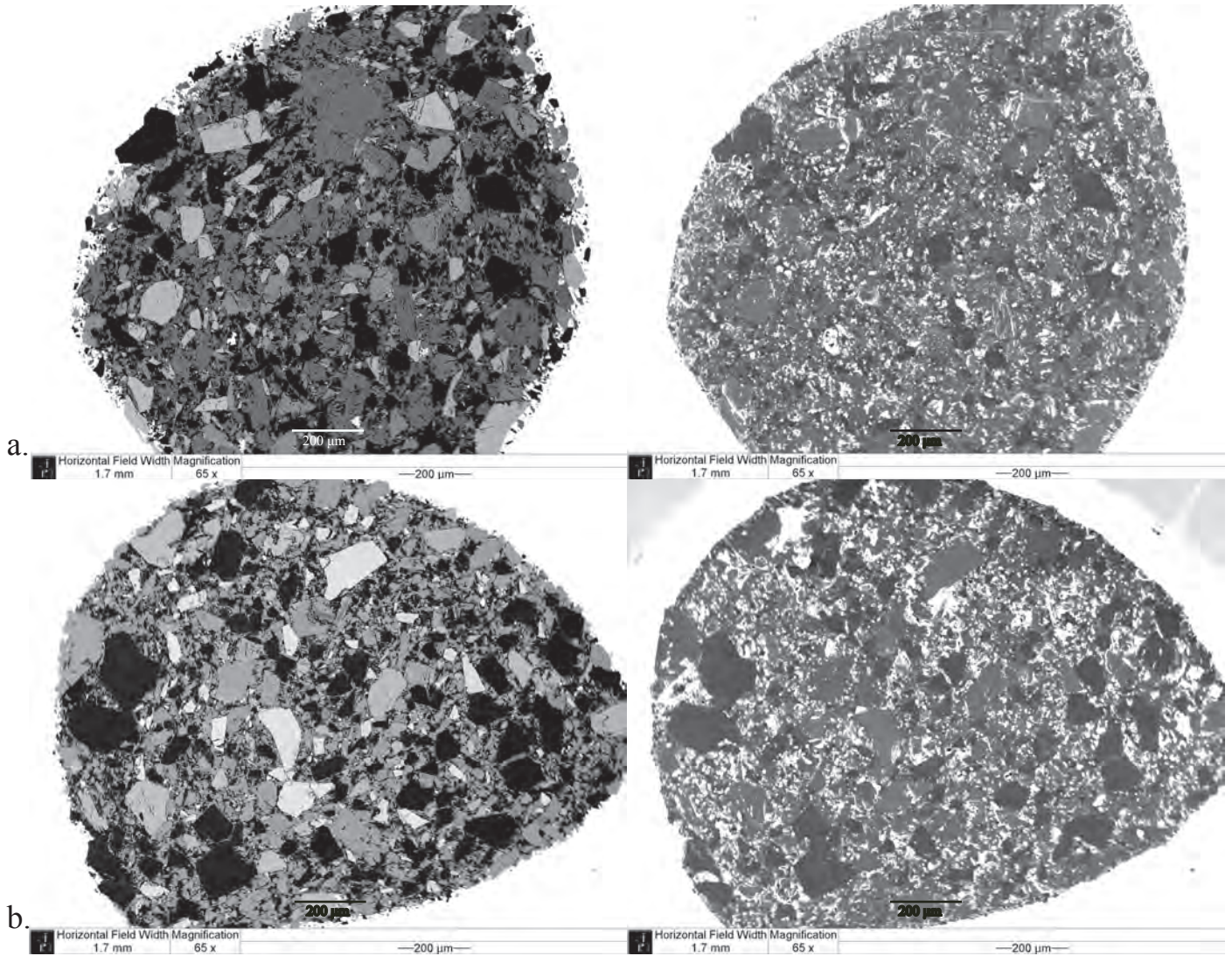


Figure 11. The two coarse amphibolite samples from experiment two held under 800°C and 8kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the coarse amphibolite. (b) The wet sample of the coarse amphibolite with 5.74 weight percent water added.

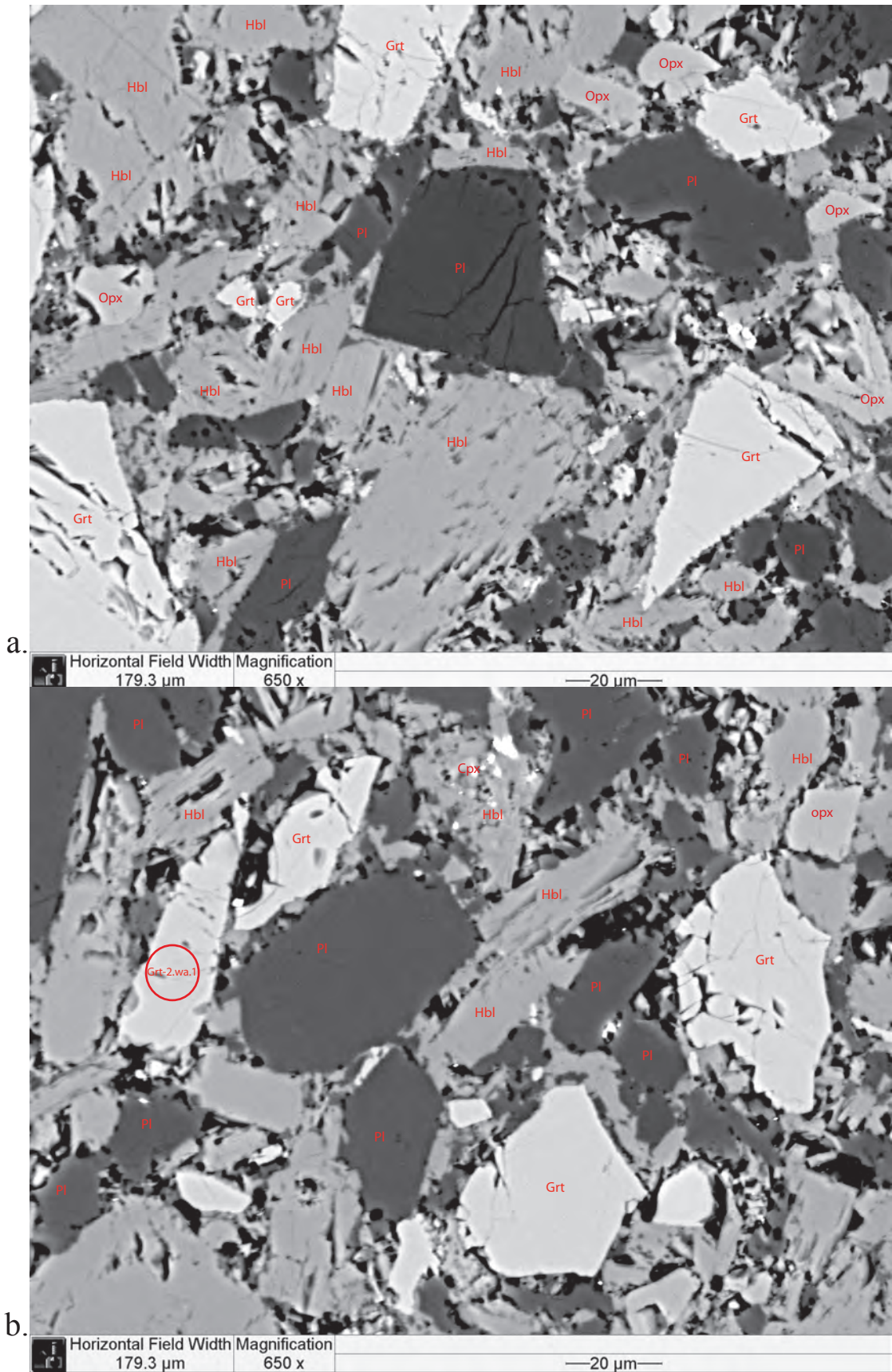


Figure 12. Mineral identifications for the coarse amphibolite samples put at 800°C and 8kbars at 650X magnification as BEI's. (a) The dry coarse amphibolite sample. (b) The wet coarse amphibolite sample.

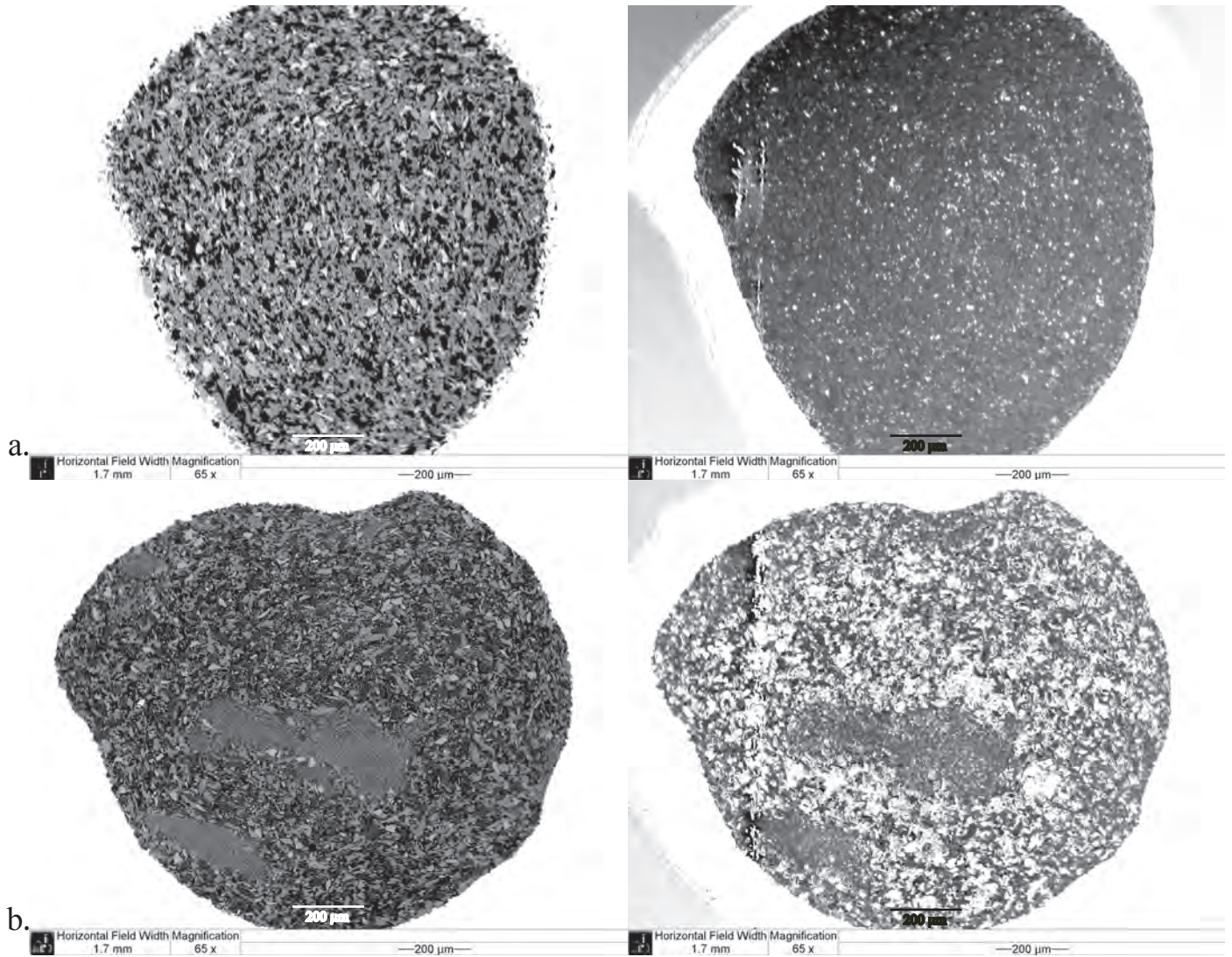


Figure 13. The two fine amphibolite samples from experiment two held under 800°C and 8kbars 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine amphibolite. (b) The wet sample of the fine amphibolite with 5.07 weight percent water added.

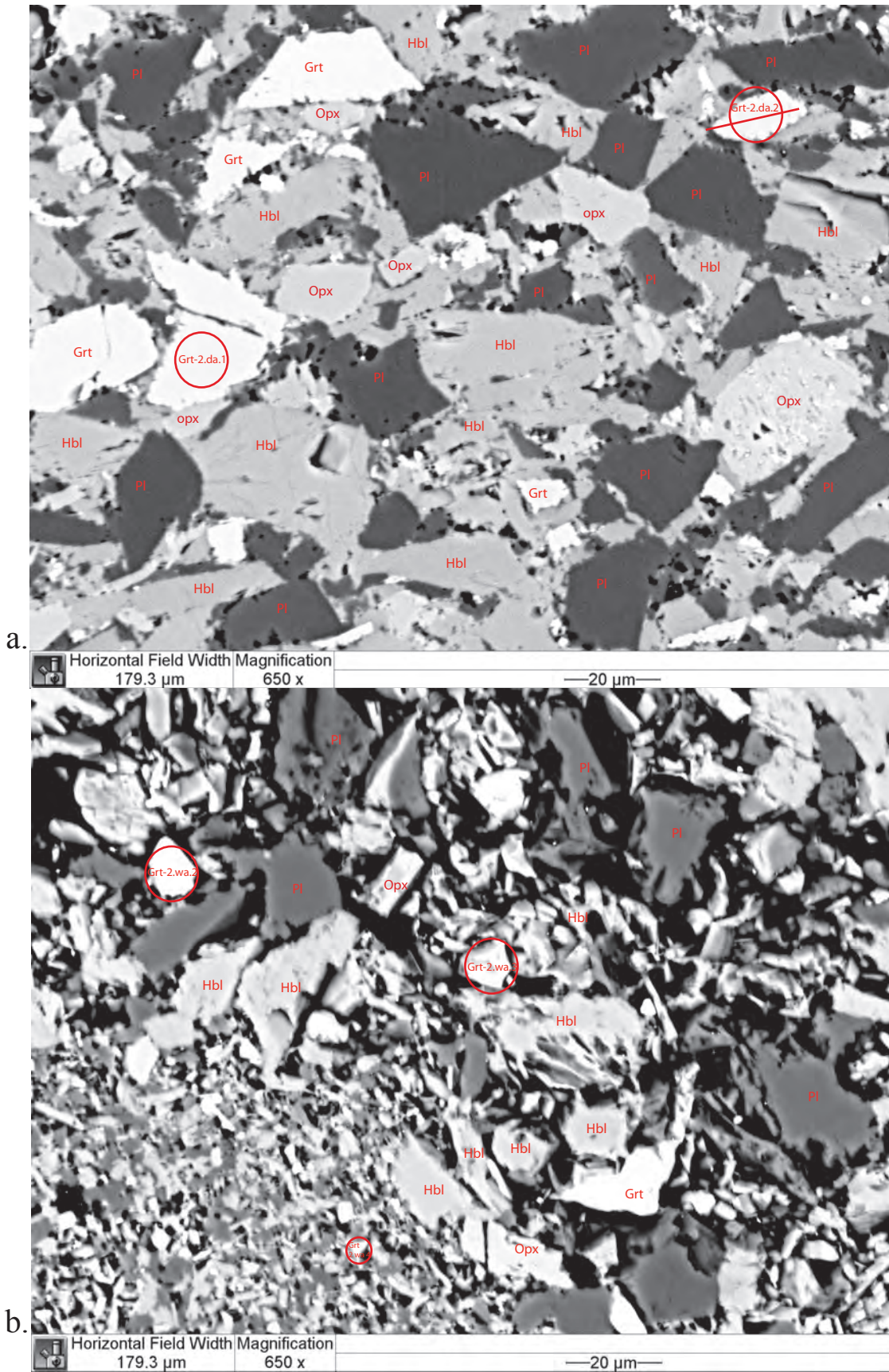


Figure 14. Mineral identifications for the fine amphibolite samples put at 800°C and 8kbars at 650X magnification as BEI's. (a) The dry fine amphibolite sample. (b) The wet fine amphibolite sample.

### **Experiment 3: 900°C, 8kb, 6 days 3.5 hours**

The third experiment was a run with the amphibolite and the meta-gabbro. A wet and dry sample of each was placed within the sample holder and put under 8 kbars of pressure and 900°C of temperature. The samples were held at those conditions for 6 days and a few hours. All of the sample powders were milled to a finer size for this experiment (Fig.7). The powders were milled to create more surface area within the powder promoting crystal interaction during the experiment.

#### ***Dry Amphibolite***

The dry amphibolite contains angular to sub-angular crystals around 18µm wide (Fig. 15a). Hornblende is the most abundant mineral, followed by plagioclase. Garnet comprises about 10% of the sample. Orthopyroxene is also present, but is less abundant than the four minerals mentioned above. Very small vesicles can be seen within the SEI image of the sample (Fig 15a).

Looking closer at the dry amphibolite, the texture of the sample is clear (Fig. 16a). The edges of crystals are jagged. Holes occur primarily within the plagioclase crystals. The orthopyroxene present tends to occur in smaller crystals around 10µm wide. There is no obvious chemical zoning in the BEI image of the sample.

The two garnets analyzed (Grt-3.da.1 and Grt-3.da.2) in Figure 14a have almost identical compositions. Their average chemical formula is:  $\text{Ca}_{0.41}\text{Fe}_{1.34}\text{Mg}_{1.18}\text{Mn}_{0.04}\text{Al}_{2.02}(\text{Si}_{2.98}\text{O}_{12})$ . The two hornblendes chemically analyzed (Hbl-3.da.1 and Hbl-3.da.2) also have similar compositions. Their average chemical composition is  $\text{K}_{0.16}\text{Na}_{0.64}(\text{Na}_{0.24}\text{Ca}_{1.76})(\text{Fe}_{1.31}\text{Mg}_{2.71}\text{Ti}_{0.16}\text{Al}_{0.85})(\text{Al}_{1.82}\text{Si}_{6.18})\text{O}_{22}(\text{OH})_2$ . The orthopyroxene analyzed has the composition:  $\text{Na}_{0.03}\text{Ca}_{0.02}\text{Fe}_{0.60}\text{Mg}_{1.31}\text{Al}_{0.05}(\text{Al}_{0.04}\text{Si}_{1.96}\text{O}_6)$ .



### *Wet Amphibolite*

The wet-amphibolite sample has been altered greatly during the run. The crystals have grown considerably compared to the size of the starting material. The vesicles within the wet sample are larger than those of the dry sample (Fig. 15b). The edges of crystals are smooth and rounded. Plagioclase appears to be interstitial and surrounded many of the smaller crystals (Fig. 16b). Many crystals show zonation, in particular, hornblende has the most visible zonation.

Chemical analysis was completed on a number of crystals. The average composition of garnet was found to be:  $\text{Ca}_{0.30}\text{Fe}_{1.45}\text{Mg}_{1.22}\text{Mn}_{0.04}\text{Al}_{1.99}(\text{Si}_{2.99}\text{O}_{12})$ . This is a different composition than the garnets of the dry amphibolite. Two chemical cross-sections of garnets were made to see if the garnets were zoned or homogenous throughout (Grt-L3.wa and Grt-L3.wa.2 in Fig 16b). Figure 17 shows the counts for the major elements of garnet of line Grt-L3.wg. There is no zoning within the garnet, it is completely homogenous. The same result was found for the other garnet cross-section. A plagioclase crystal was also analyzed (Pl-3.wa.1) and found to have the following composition:  $\text{Na}_{0.45}\text{Ca}_{0.55}\text{Al}_{1.59}\text{Si}_{2.41}\text{O}_8$ .

A chemical cross-section of a hornblende crystal revealed different results. Figure 18 shows the profiles of elements in which zoning is apparent. In particular, potassium has the greatest change throughout the crystal. The hornblende has a greater amount of potassium within its center than on the edges or the newly grown material. There is slightly less magnesium and aluminum, but more calcium within the center of the hornblende. A smaller hornblende surrounded by plagioclase (Hbl-3.wa.2) has the following composition:

$\text{K}_{0.15}\text{Na}_{0.43}(\text{Na}_{0.33}\text{Ca}_{1.67})(\text{Fe}_{1.40}\text{Mg}_{2.77}\text{Ti}_{0.16}\text{Al}_{1.08})(\text{Al}_{1.68}\text{Si}_{6.32})\text{O}_{22}(\text{OH})_2$ .

### ***Dry Meta-Gabbro***

The dry meta-gabbro has two distinct crystal sizes. The larger crystals are around 10 $\mu$ m in diameter and comprise more than half of the sample. The smaller crystals average around 1 $\mu$ m and occur in pockets within the sample (Fig. 19a). Vesicles within the sample are larger and more abundant in the areas with larger crystals (Fig. 19a).

A magnified view of the both the coarse and fine areas can be seen in Figure 20a. The major minerals of the sample were analyzed within each area. The garnets (Grt-3.dg.1 and Grt-3.dg.2) were chemically similar and have an average composition of  $\text{Ca}_{0.51}\text{Fe}_{1.35}\text{Mg}_{1.08}\text{Mn}_{0.04}\text{Al}_{1.98}(\text{Si}_{3.00}\text{O}_{12})$ . The hornblende crystals, however, show a variation in chemistry. Figure 21 shows the difference in weight percent between the oxides that compose the hornblendes. The smaller hornblende (Hbl-3.dg.2) has more iron, silica and magnesium. The larger hornblende (Hbl-3.dg.1) has more alumina, calcium, potassium, and titanium. The plagioclase crystals (Pl-3.dg.1 and Pl-3.dg.2) had little difference in composition. The average composition of the two plagioclase crystals is:  $\text{K}_{0.03}\text{Na}_{0.58}\text{Ca}_{0.41}\text{Al}_{0.43}(\text{Al}_{0.96}\text{Si}_{2.57}\text{O}_8)$ . The orthopyroxene crystals (Opx-3.dg.1 and Opx-3.dg.2) show differences in composition. Figure 22 compares the chemical composition for each of the orthopyroxenes. The smaller orthopyroxene (Opx-3.dg.2) has less magnesium and silica, but more calcium and alumina than the larger orthopyroxene (Opx-3.dg.1).

### ***Wet Meta-Gabbro***

The wet amphibolite looks very different compared to the dry amphibolite (Fig. 19b). The vesicles are much larger and cover a greater amount of space within the sample. The vesicles can be seen in black in the BEI image of Figure 15b. The crystals are rounded to sub-

rounded. Overall the crystals within the wet amphibolite are about the same size as those of the dry amphibolite.

A closer look at the sample shows that the crystals are less defined in some places (Fig. 20b). Many plagioclase crystals still have their original inclusions. Zoning occurs within some hornblende crystals. The garnets analyzed (circled in Fig. 20b) have little variation in composition. The average composition for the garnets of the wet amphibolite sample is:  $\text{Ca}_{0.47}\text{Fe}_{1.34}\text{Mg}_{1.15}\text{Mn}_{0.03}\text{Al}_{2.02}(\text{Si}_{2.97}\text{O}_{12})$ . The hornblende crystals of the sample also have very similar compositions (Fig. 23). The biggest difference between the two crystals is the amount of silica. The smaller hornblende crystal (Hbl-3.wa.2) has 1.92% more silica than the larger hornblende (Hbl-3.wa.1). The plagioclase crystal analyzed (Pl-3.wa.1) has the composition:  $\text{K}_{0.01}\text{Na}_{0.58}\text{Ca}_{0.43}\text{Al}_{1.44}\text{Si}_{2.55}\text{O}_8$ . An orthopyroxene was also chemically analyzed (Opx-3.wa.1) and has the composition:  $\text{Na}_{0.03}\text{Ca}_{0.02}\text{Fe}_{0.54}\text{Mg}_{1.34}\text{Al}_{0.06}(\text{Al}_{0.05}\text{Si}_{1.95}\text{O}_6)$ .

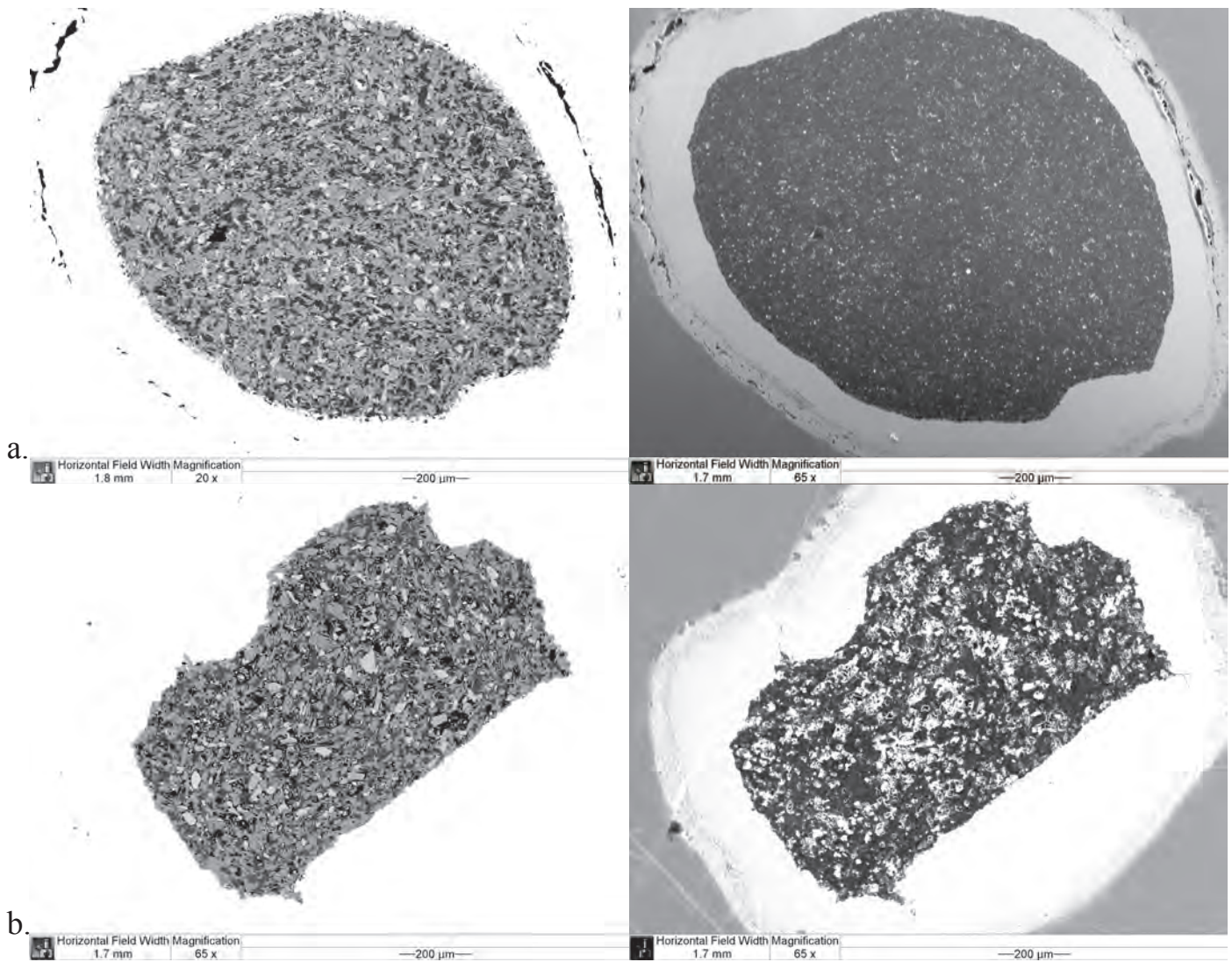


Figure 15. The two fine amphibolite samples from Experiment 3 held under 900°C and 8kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine amphibolite. (b) The wet sample of the fine amphibolite with 12 weight percent water added.

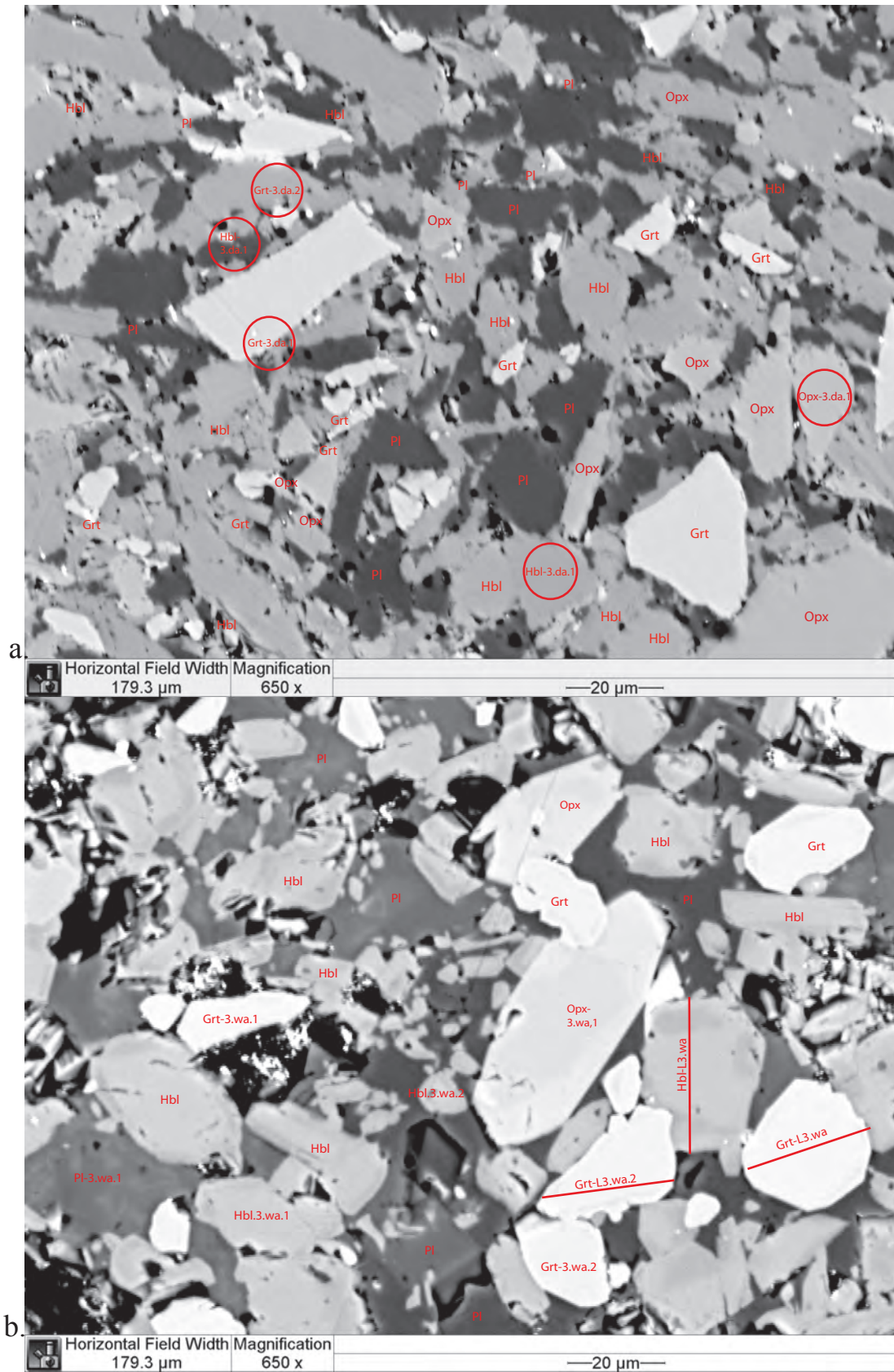


Figure 16. Mineral identifications for the fine amphibolite samples put at 900°C and 8kbars at 650X magnification as BEI's. (a) The dry fine amphibolite sample. (b) The wet fine amphibolite sample.

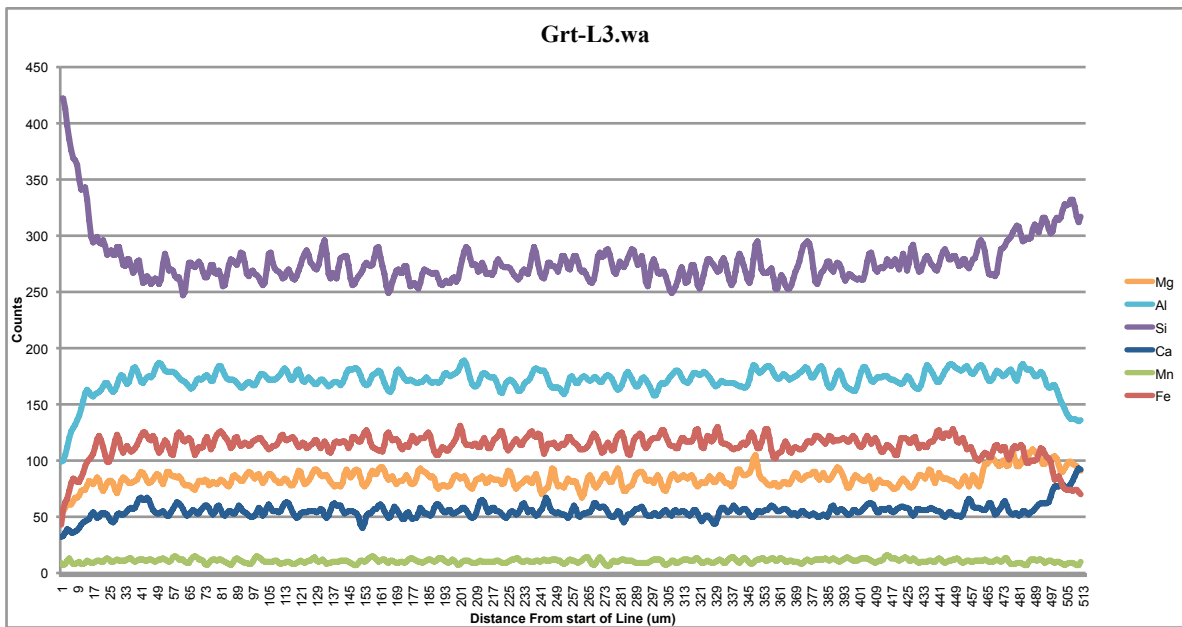


Figure 17. Chemical Profile of Grt-L3.wa. A cross section of a garnet from the wet meta-gabbro is chemically analyzed. The counts for each element is on the y-axis and the distance in  $\mu\text{m}$  from the starting point of the line is on the x-axis.

## Chemical Profile of Hbl-L3.wa

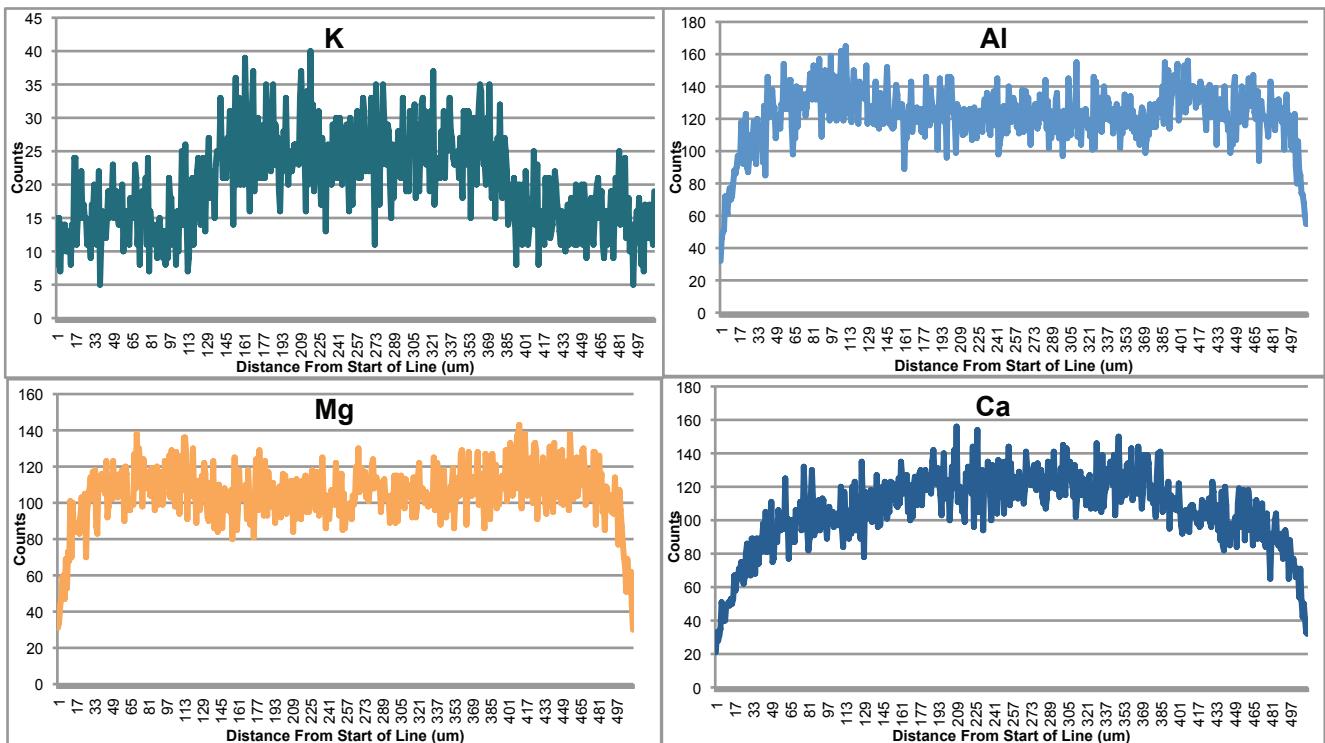


Figure 18. Chemical Profile of Hbl-L3.wa. The variation of potassium, aluminum, magnesium, and calcium across the hornblende crystal can be seen in the 4 graphs. The counts for each element is on the y-axis and the distance in  $\mu\text{m}$  from the starting point of the line is on the x-axis.

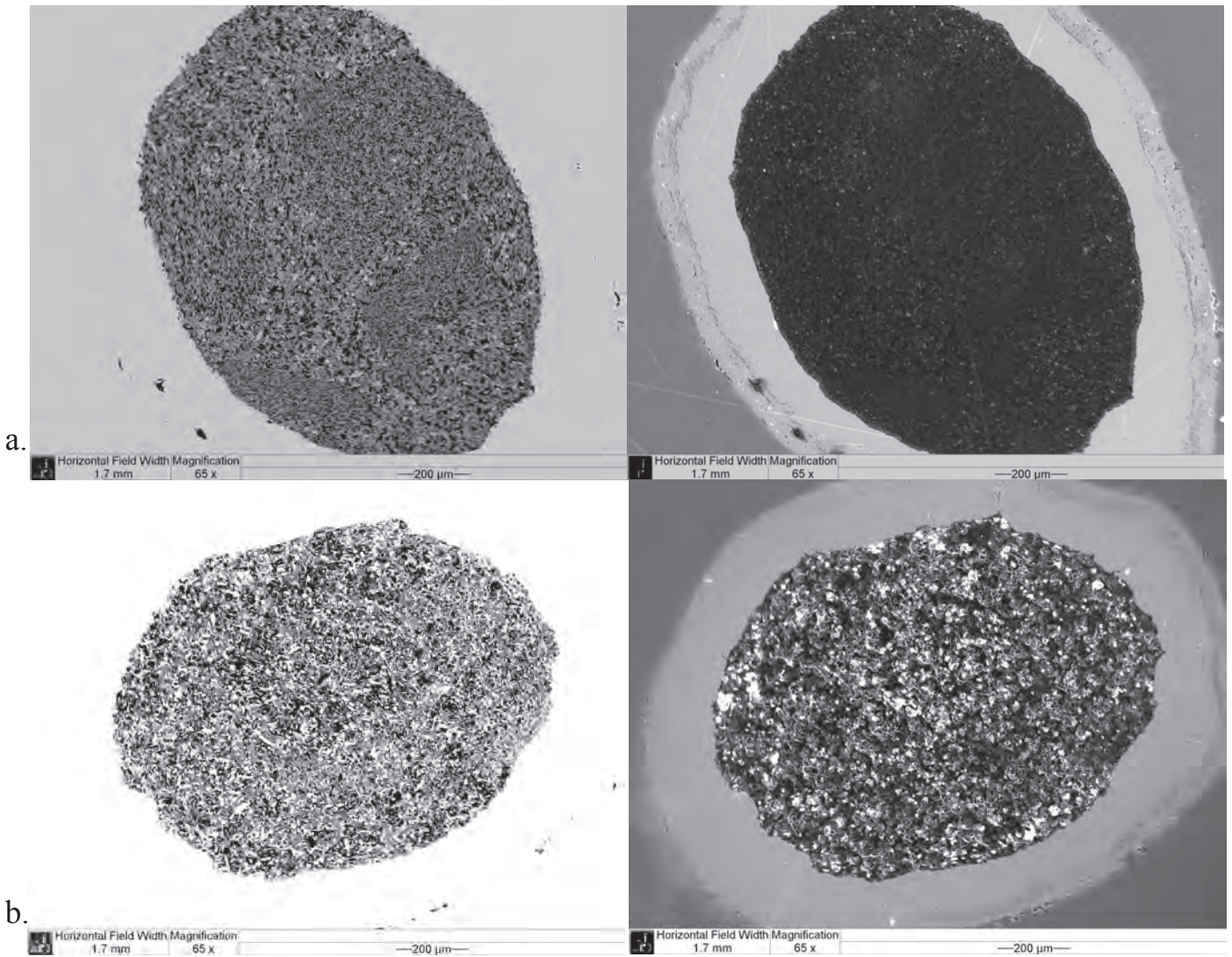


Figure 19. The two fine meta-gabbro samples from Experiment 3 held under 900°C and 8kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine meta-gabbro. (b) The wet sample of the fine meta-gabbro with 15 weight percent water added.

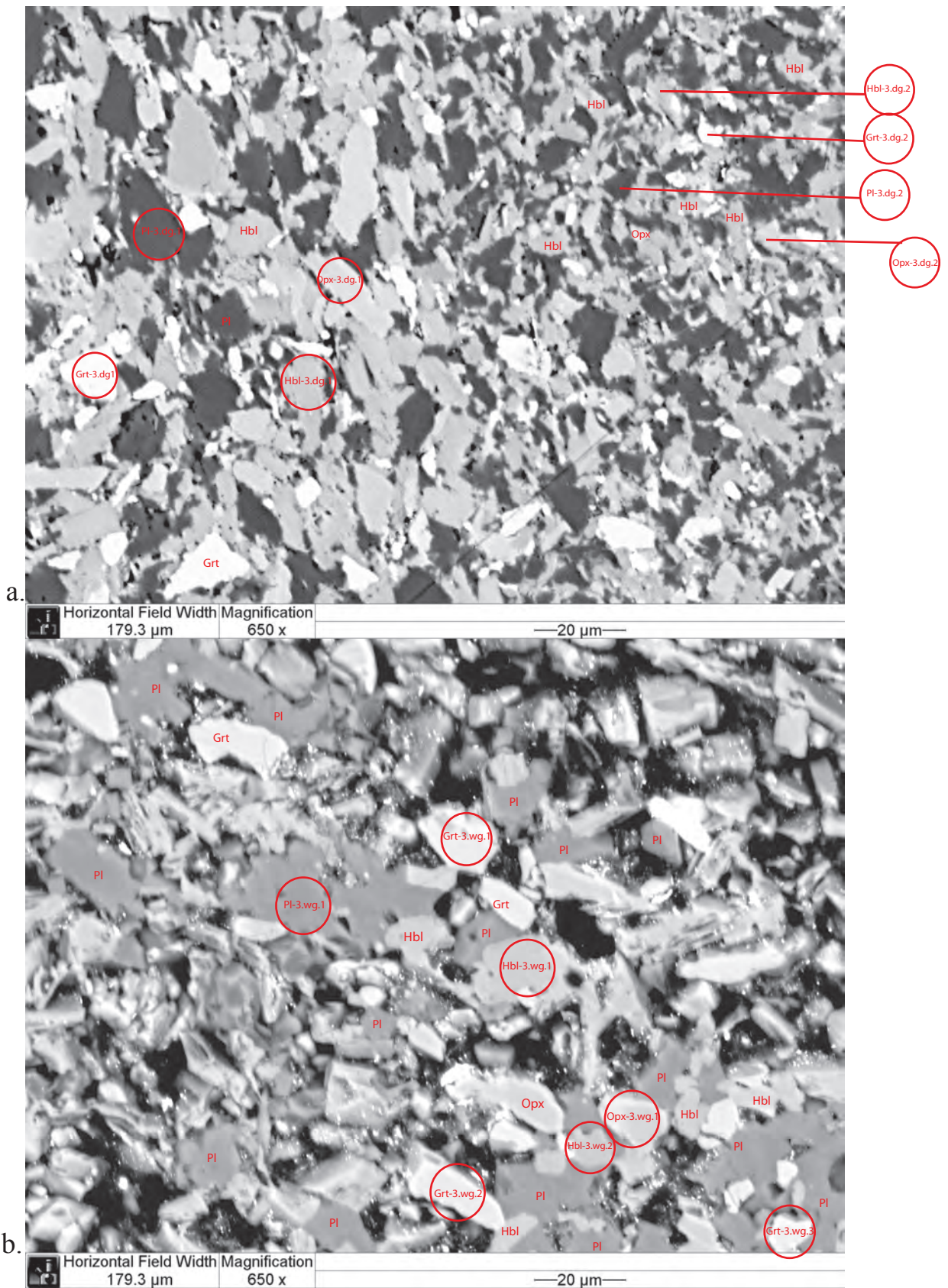


Figure 20. Mineral identifications for the fine meta-gabbro samples put at 900°C and 8kbars at 650X magnification as BEI's. (a) The dry fine meta-gabbro sample. (b) The wet fine meta-gabbro sample.



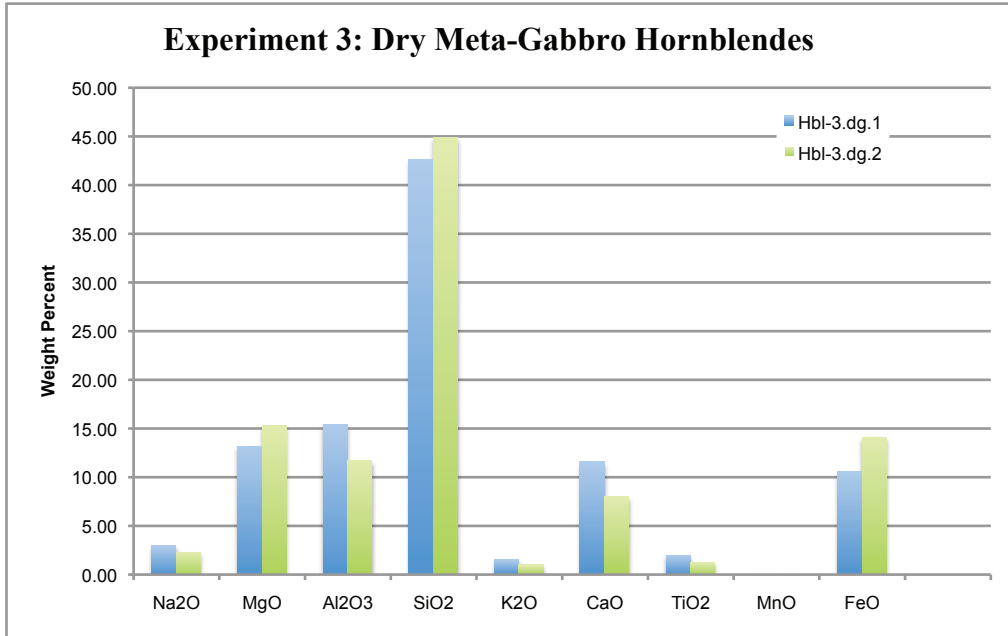


Figure 21. Bar chart of the chemical analysis of hornblendes from the dry meta-gabbro of Experiment 3. The weight percent oxide is the y-axis and the different oxides are on the x-axis.

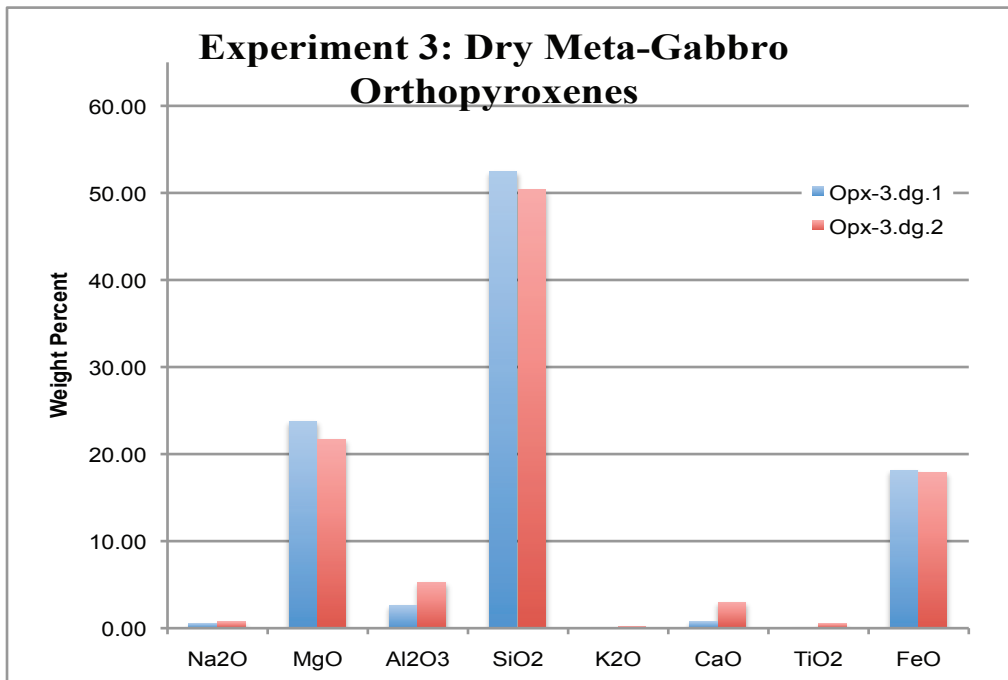


Figure 22. Bar chart of the chemical analysis of orthopyroxenes from the wet meta-gabbro of Experiment 3. The weight percent oxide is the y-axis and the different oxides are on the x-axis.

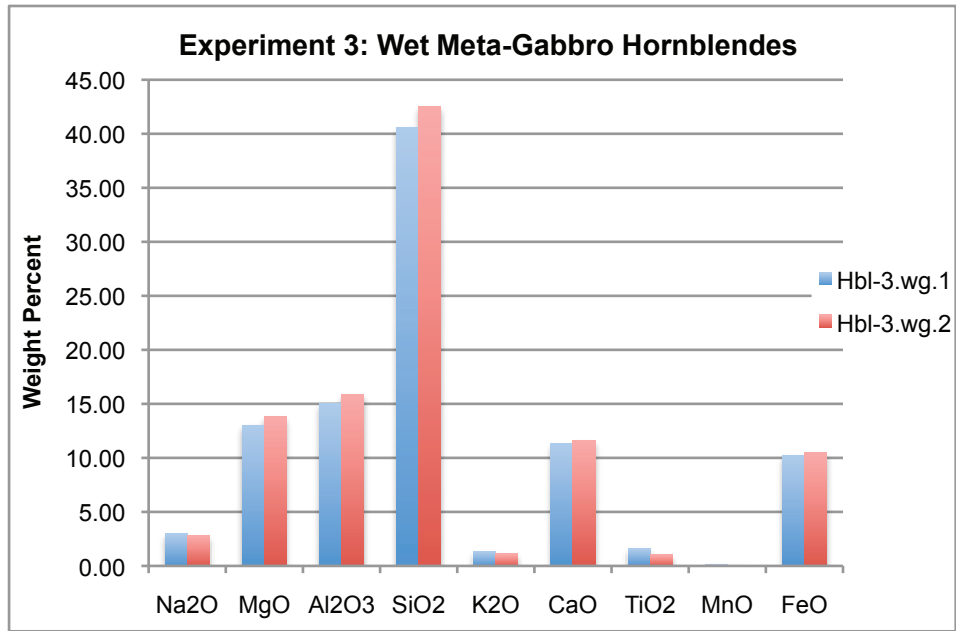


Figure 23. Bar chart of the chemical analysis of hornblendes from the wet meta-gabbro of Experiment 3. The weight percent oxide is the y-axis and the different oxides are on the x-axis.

### **Experiment 5: 800°C, 7kbars, 6 hours**

For this run, amphibolite and meta-gabbro powders were heated to 800°C at 7 kbars. A wet and dry sample of each rock type was made. The wet samples contained around 12 weight percent of water added. The run lasted for 6 hours.

#### ***Dry Amphibolite***

The dry amphibolite sample is composed of hornblende, plagioclase, garnet, and orthopyroxene in decreasing order respectively. There are small vesicles dispersed throughout the sample and they tend to occur mostly in plagioclase (Fig. 24a). The crystals are angular and tend to range from 10 to 20µm in diameter.

Chemical analyses were completed for the crystals circled in Figure 25a. The average garnet composition is:  $\text{Ca}_{0.31}\text{Fe}_{1.45}\text{Mg}_{1.19}\text{Mn}_{0.04}\text{Al}_{2.01}(\text{Si}_{2.99}\text{O}_{12})$ . The two plagioclase crystals analyzed have very similar compositions with less than 2 weight percent oxide difference for each oxide. The size of the plagioclase crystals does not appear to be a factor in composition. The average composition for plagioclase is:  $\text{Na}_{0.53}\text{Ca}_{0.47}\text{Al}_{1.49}\text{Si}_{2.48}\text{O}_8$ . The composition for the hornblende crystal analyzed can be seen in Table 4.

	Hbl-5.da.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	3.29	0.92
MgO	12.96	2.77
Al <sub>2</sub> O <sub>3</sub>	15.47	2.62
SiO <sub>2</sub>	42.44	6.09
K <sub>2</sub> O	1.19	0.22
CaO	11.80	1.81
TiO <sub>2</sub>	1.60	0.17
FeO	11.65	1.40
O		23.00

Table 5. The composition of a hornblende from the dry amphibolite sample of Experiment 5.

#### ***Wet Amphibolite***

At first look in BEI, the wet amphibolite sample may not appear to be very texturally different from the dry amphibolite (Fig. 24b). The wet amphibolite has much larger vesicles than the dry amphibolite (Fig. 24). The vesicles are rounded and dispersed throughout the sample.

The wet amphibolite contains hornblende, plagioclase, and garnet in decreasing order respectively. No orthopyroxene was found. The crystals are angular to sub-angular. Looking at Figure the textural differences between the amphibolite samples can be seen clearly. The wet amphibolite has larger, less angular crystals. The vesicles are distinct black holes (Fig. 25b).

Chemical analysis was completed on a number of crystals. A zoned hornblende was analyzed in the center (Hbl-5.wa.1) and on the edge (Hbl-5.wa.1a). The compositions of all the amphiboles analyzed within the wet amphibolite can be seen in Figure 26. The zoned amphibole shows some slight difference between the edge and the center. The center of the amphibole has a greater percentage of the oxides except for the amount of MgO. The greatest difference in weight percent between the edge of the crystal and the center is 1.53% more calcium in the center. Two other amphiboles were analyzed as well (Hbl-5.wa.3 and Hbl-5.wa.4). The largest hornblende (Hbl-5.wa.1) has a greater weight percent of calcium, titanium, and potassium than any of the other hornblendes analyzed. The hornblende crystal, Hbl-5.wa.4, appears to vary the most from the other hornblende crystals as there are only two oxides for which it is not the minimum or maximum.

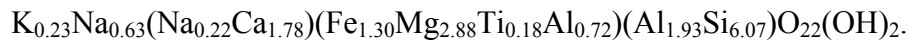
Two garnet crystals were chemically analyzed (Grt-5.wa.1 and Grt-5.wa.2, Fig. 27). The results can be seen in Figure. The two garnet crystals were chosen because of their differences in shape. The narrow or thin garnet (Grt-5.wa.2) has a greater weight percent of every oxide except for iron and manganese. The garnet, Grt-5.wa.1, has 1.31 weight percent more of iron and 0.62% less magnesium than the narrow garnet. The garnets have some differences in composition, but they are less than 2 weight percent differences in oxides. A good analysis of plagioclase was unable to be obtained.

### ***Dry Meta-Gabbro***

The major minerals of the dry meta-gabbro sample are: hornblende, plagioclase, garnet, and orthopyroxene in decreasing order respectively. A few crystals of apatite were found within the sample. The samples had some vesicles all of which are less than 5 microns in diameter (Fig. 28a). The crystals are angular. Many crystals have rough, jagged edges.

A closer look at the sample in Figure 29a reveals the messy looking texture of the crystals. The rough jagged edges can clearly be seen. No chemical zoning of crystals is apparent.

Garnets of the dry meta-gabbro sample were analyzed. The garnets were almost chemically identical. The average garnet composition is:  $\text{Ca}_{0.48}\text{Fe}_{1.38}\text{Mg}_{1.09}\text{Mn}_{0.04}\text{Al}_{2.01}(\text{Si}_{2.99}\text{O}_{12})$ . The garnets in particular have jagged edges. One hornblende (Hbl-5.dg.1) was analyzed and found to have the following composition:



### ***Wet Meta-Gabbro***

The wet meta-gabbro sample is very texturally different from the dry meta-gabbro sample. The wet meta-gabbro sample has larger vesicles than the dry one as well as crystals with sharper edges (Figs. 28 and 29). The sample generally has crystals around 20 $\mu\text{m}$  in diameter, however there are some pockets of crystals around 5 to 10 $\mu\text{m}$  in diameter. Additionally no orthopyroxene was found within the sample, there is an abundance of hornblende however.

A higher magnified view of the sample reveals the texture (Fig. 29b). Many crystals are very well defined with smooth edges. Some edges are angular. No glass was found however perfect form of some crystals could indicate the previous presence of a liquid.

Two garnet crystals were analyzed (Grt-5.wg.1 and Grt-5.wg.2). The smaller garnet (Grt-5.wg.2) has almost 3% less iron than the larger garnet (Grt-5.wg.1). Their compositions are similar overall. Two hornblende crystals were chemically analyzed. The smaller hornblende (Hbl-5.wg.2) has 3% less calcium, 0.7% less iron, 1.1% less magnesium, and 0.6% less titanium than the larger hornblende (Hbl-5.wg.1). The smaller hornblende does have 7.5% more silica and 2.0% more alumina than the larger garnet. The hornblendes of different sizes have different compositions. This is likely because the hydration of orthopyroxene crystals would create a crystal of a different composition.

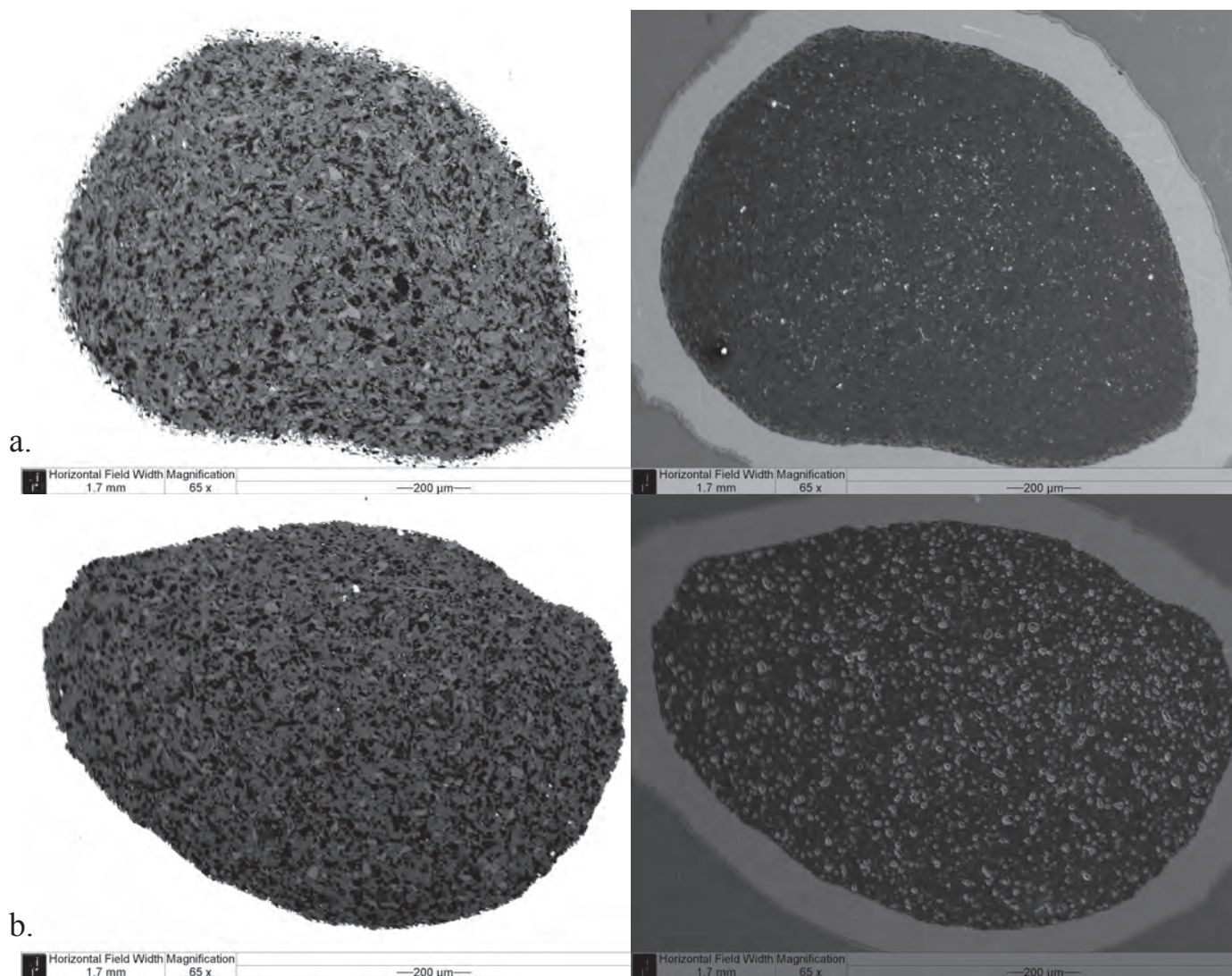


Figure 24. The two fine amphibolite samples from Experiment 5 held under 800°C and 7kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine amphibolite. (b) The wet sample of the fine amphibolite with 12.4 weight percent water added.

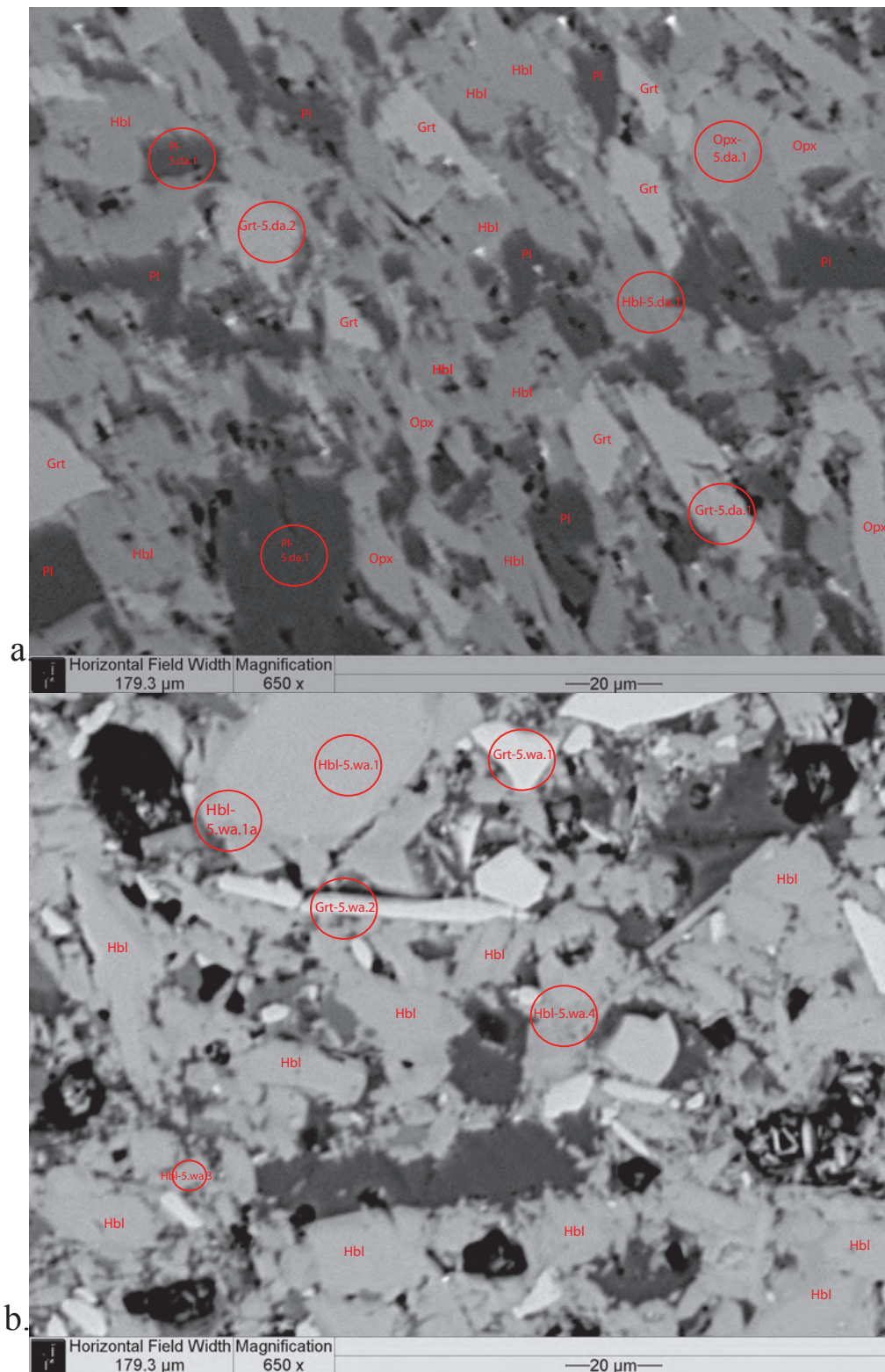


Figure 25. Mineral identifications for the fine amphibolite samples put at 800°C and 7kbars at 650X magnification as BEI's. (a) The dry fine amphibolite sample. (b) The wet fine amphibolite sample.



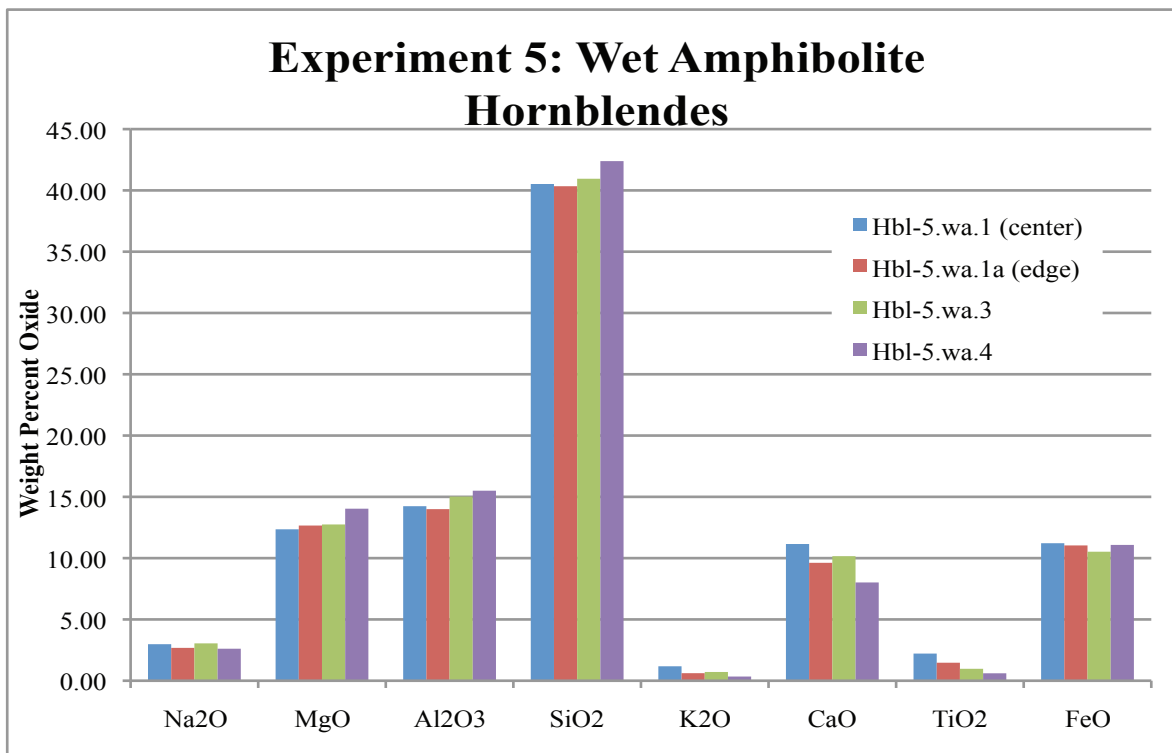


Figure 26. A chart of the compositions of hornblendes within the wet amphibolite sample of Experiment 5 (800°C and 7kbars).

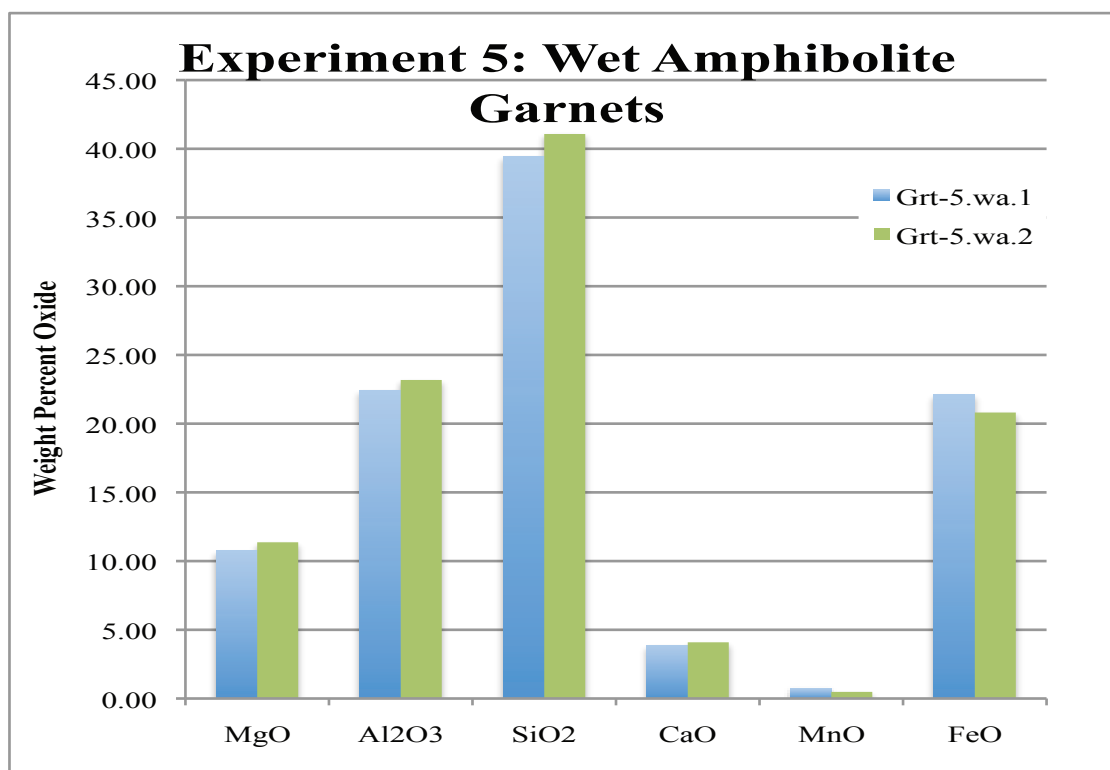


Figure 27. A chart of the compositions of garnets within the wet amphibolite sample of Experiment 5 (800°C and 7kbars).

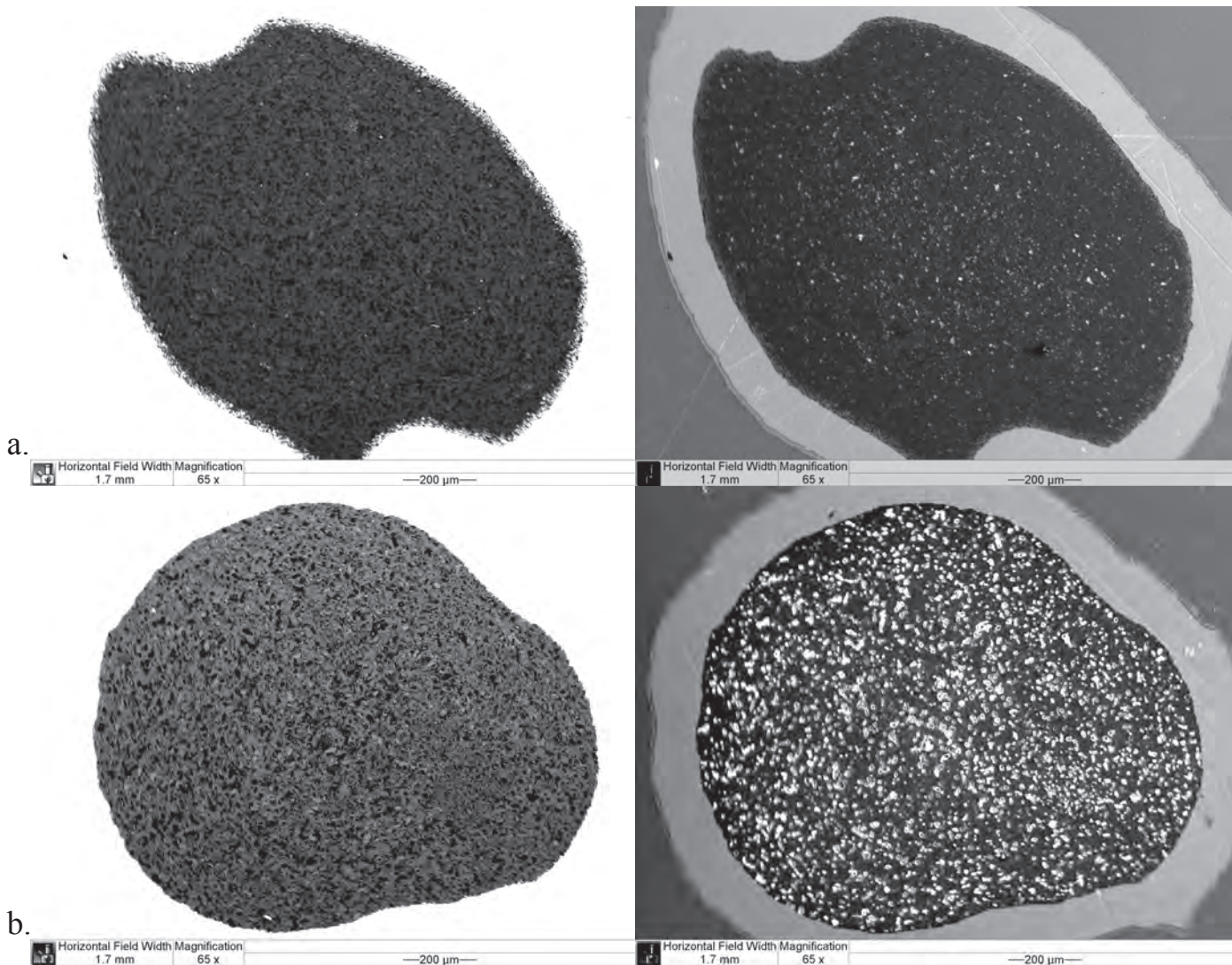


Figure 28. The two fine meta-gabbro samples from Experiment 5 held under 800°C and 7kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine meta-gabbro. (b) The wet sample of the fine meta-gabbro with 15 weight percent water added.

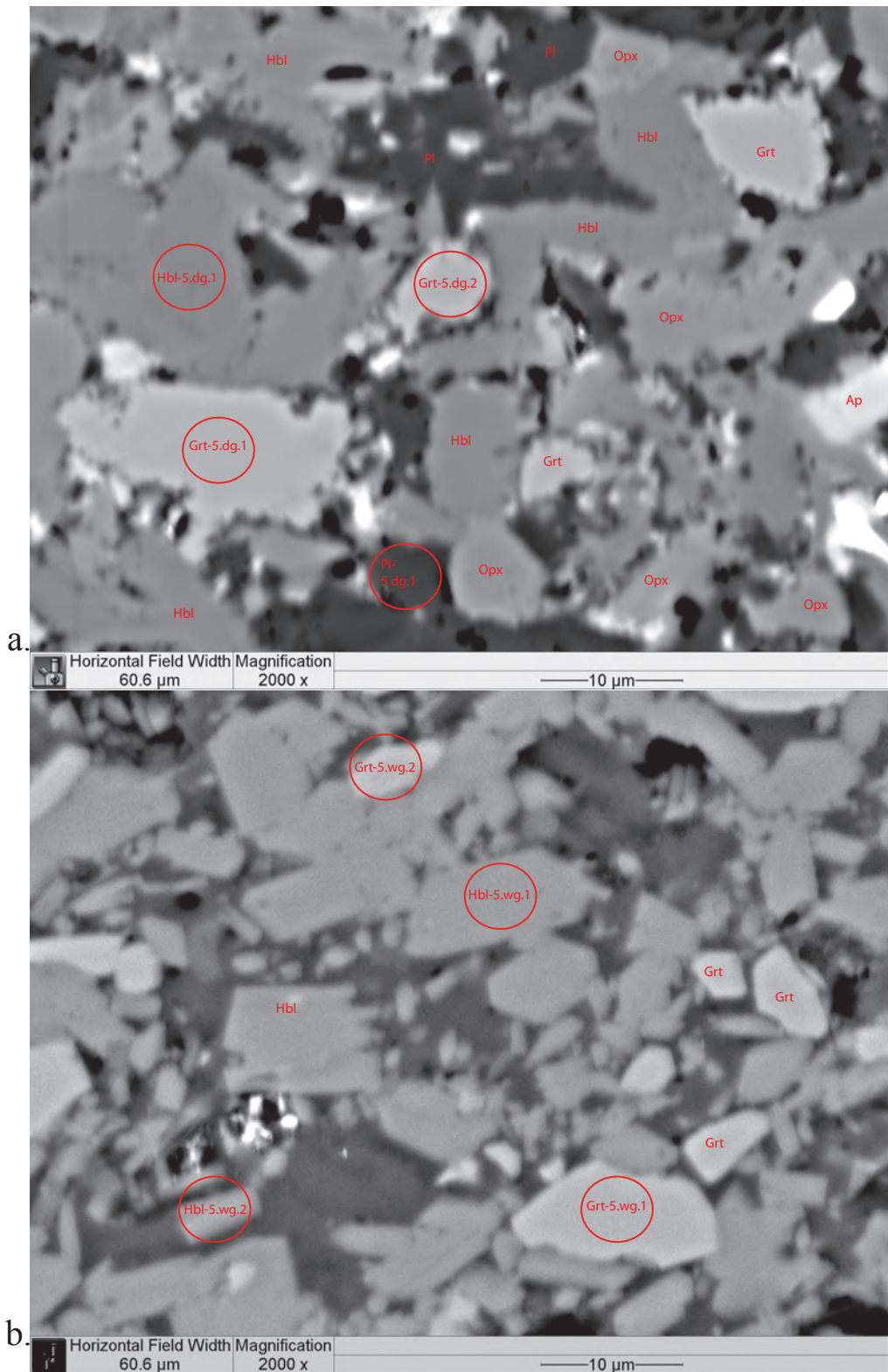


Figure 29. Mineral identifications for the fine meta-gabbro samples put at 800°C and 7kbars at 650X magnification as BEI's. (a) The dry fine meta-gabbro sample. (b) The wet fine meta-gabbro sample.

### **Experiment 6: 800°C, 5kb, 2 days 21 hours**

This experiment consisted of two samples of amphibolite (GM-407) and two samples of meta-gabbro (GM-307). One sample of amphibolite was dry and the other had 6% water added. The meta-gabbro samples consisted of a dry sample and a sample with 7.2% water added. The run lasted for about 45 hours and had a stable temperature and pressure throughout.

#### ***Dry Amphibolite:***

The dry amphibolite sample has small vesicles that appear to prefer occurring around and within plagioclase crystals; however there are vesicles within other minerals (Fig. 30a). The crystals range in size from less than 2  $\mu\text{m}$  to greater than 50  $\mu\text{m}$ . Hornblende is the most abundant mineral. Plagioclase, garnet, and orthopyroxene are also present and listed in order of abundance respectively. Fractures occur within every mineral type. In general, the crystals are angular to sub-angular (Fig. 30a).

Figure 31a is an image of the dry amphibolite sample with a large garnet crystal (Grt-6.da.1). The garnet crystal edges appear to have been affected by the experiment. The edges are rough and wavy. The crystal is not as angular as many of the crystals around it. Figure 32 shows the counts of various elements over the line labeled in Figure 31a. The garnet is homogenous, there is variation but that occurs after 480 $\mu\text{m}$ , which is no longer on the garnet crystal. A chemical analysis of the same garnet was obtained formula for the garnet labeled Grt-6.da.1 in Figure 31a is:  $\text{Ca}_{0.39}\text{Fe}_{1.36}\text{Mg}_{1.20}\text{Mn}_{0.04}\text{Al}_{2.00}(\text{Si}_{2.98}\text{O}_{12})$ .

Two different plagioclase crystals were chemically analyzed, shown in Figure 31a as Pl-6.da.1 and Pl-6.da.2. It is clear that there are two distinct plagioclase types within the altered dry amphibolite. Pl-6.da.2 has 2% more sodium and more than 4% less calcium than Pl-6.da.1. Also,

the aluminum to silica ratio is 1:1.37 in Pl-6.da.1 and 1:1.77 in Pl-6.da.2. Both plagioclases are close to anorthite in composition.

### ***Wet Amphibolite:***

The wet amphibolite contains many more vesicles than the dry amphibolite (Fig. 30b). The vesicles are also larger within the wet amphibolite. There are pockets of small crystals (~5  $\mu\text{m}$ ) within the majority of larger crystals (~30  $\mu\text{m}$ ). The crystals are angular and sub-angular. The edges of crystals have a rough zigzagging pattern (Fig. 30b). Hornblende was most abundant with plagioclase, garnet and orthopyroxene following respectively.

Figure 31b shows the wet amphibolite with mineral identification labels. The wide range of crystal size can be seen even clearer in Figure 31b along with the zigzagging crystal edges. A chemical analysis was done for the plagioclase crystals Pl-6.wa.1 and Pl-6.wa.2 (Table 5). They are very similar to each other. The plagioclase crystals are less than 1% different in the compound percent of sodium. The aluminum to silica ratio is 1:1.83 in Pl-6.wa.1 and 1:1.78 in Pl-6.wa.2. The plagioclase crystals are both anorthitic.

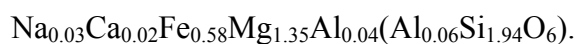
### ***Dry Meta-Gabbro***

The dry meta-gabbro has small rounded vesicles (Fig. 33a). They are dispersed randomly throughout the sample. The crystals are angular and sub angular and range in size from 3 $\mu\text{m}$  to 60 $\mu\text{m}$ . Plagioclase and orthopyroxene are the dominant minerals followed by hornblende and then garnet.

A strange texture occurs within the dry meta-gabbro sample. The crystals look altered on their edges as they have very irregular boundaries. Also the smaller crystals are not sharply defined.

The chemistry of the two different garnets circled in Figure 34a, Grt-6.dg.1 and Grt-6.dg.2, was obtained. The larger garnet, Grt-6.dg.1, has 1.177 weight percent more of  $\text{Al}_2\text{O}_3$ , 1.143 weight percent more of  $\text{FeO}$ , and 2.303 weight percent less of  $\text{SiO}_2$  than Grt-6.dg.2. The differences between the two garnets are not large.

The two hornblende crystals circled in Figure 34a, Hbl-6.dg.1 and Hbl-6.dg.2, were also chemically analyzed (Table 6). Each crystal has a distinct texture. Hbl-6.dg.1 has 6.7% more weight percent of  $\text{SiO}_2$  than Hbl- 7.dg.2. Additionally, Hbl-6.dg.1 has more aluminum, calcium, manganese, and sodium than the other hornblende. Hbl-6.dg.2 has a greater amount of iron, magnesium, titanium, and potassium than Hbl-6.dg.1. The orthopyroxene crystal, Opx-6.dg.1, is richer in magnesium than in iron. Its chemical formula is



### ***Wet meta-gabbro***

Comparing the dry meta-gabbro to the wet-meta-gabbro it is clear that the vesicles are much larger in the wet meta-gabbro (Fig. 33b). Hornblende is the most abundant mineral followed by plagioclase and then orthopyroxene, which occurs only in minor amounts. No garnet was found within the random areas analyzed. It appears that the meta-gabbro has converted into an amphibolite. The crystal edges are smooth and not very angular.

A close up of the wet-gabbro sample can be seen in Figure 34b. The holes occur primarily around crystal boundaries and within plagioclase. The largest crystals are hornblende.

A small crystal of orthopyroxene can be seen with the majority of its edges in contact with hornblende (Opx-6.wg.1). There is little if any defined zoning within crystals of the wet meta-gabbro. A chemical analysis profile of a hornblende crystal (Hbl-6.wg.1) was completed and is indicated in Figure 34b. The results of the analysis can be seen in Figure 35. The beginning of the line does not begin on the hornblende crystal, but rather on a hole adjacent to it. The analysis goes from left to right. The hornblende crystal shows a change in chemistry at the upper right corner. At the end of the line there is an increase in silica and aluminum. Additionally, there is a decrease in calcium and magnesium. At the beginning of the profile, calcium and iron are roughly equal in amount. Then calcium increases while iron decreases, then both come back to close to where they started in the middle of the crystal. This pattern occurs once more in the second half of the crystal.

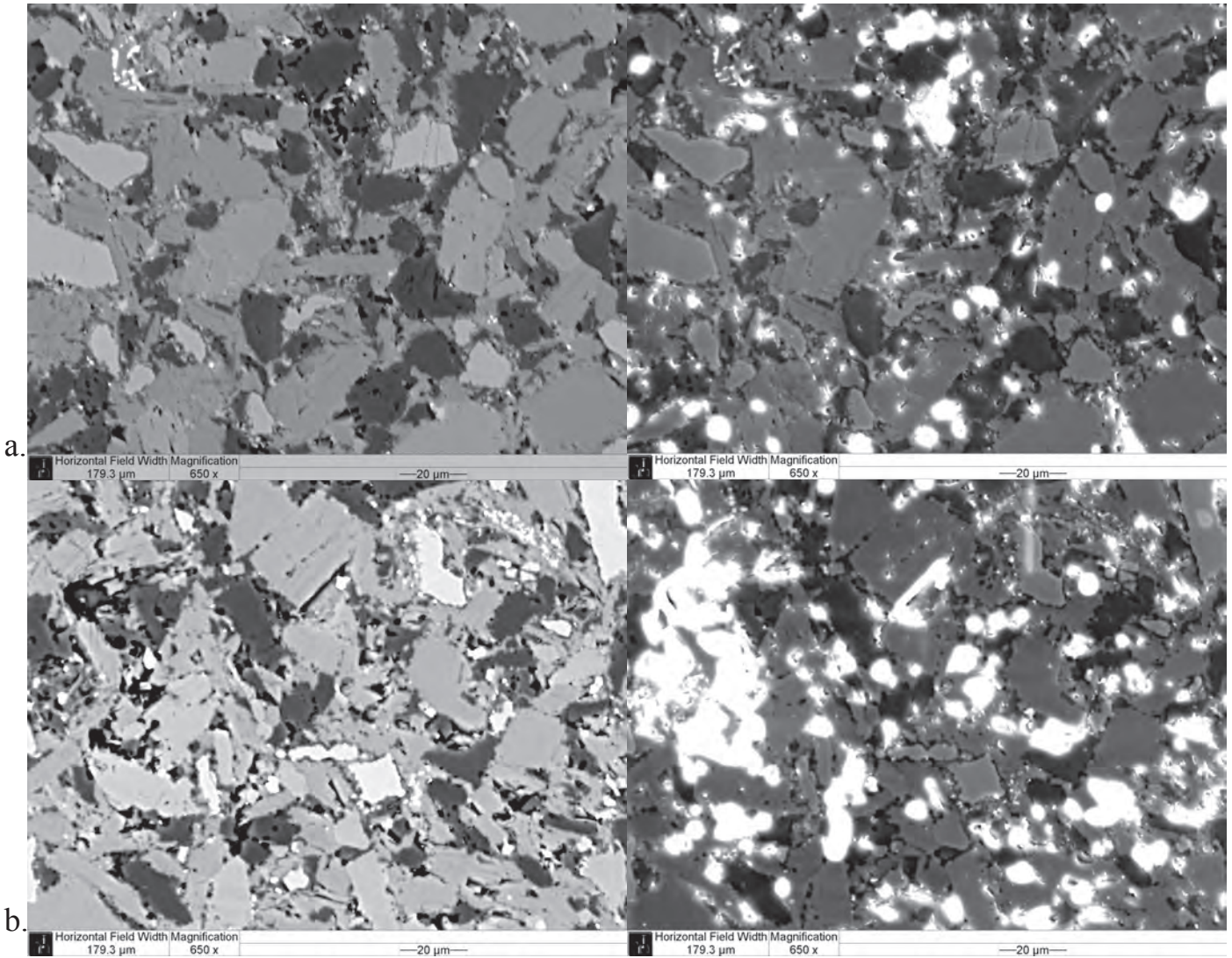


Figure 30. The two fine amphibolite samples from Experiment 6 held under 800°C and 5kbars at 650X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine amphibolite. (b) The wet sample of the fine amphibolite with 6 weight percent water added.



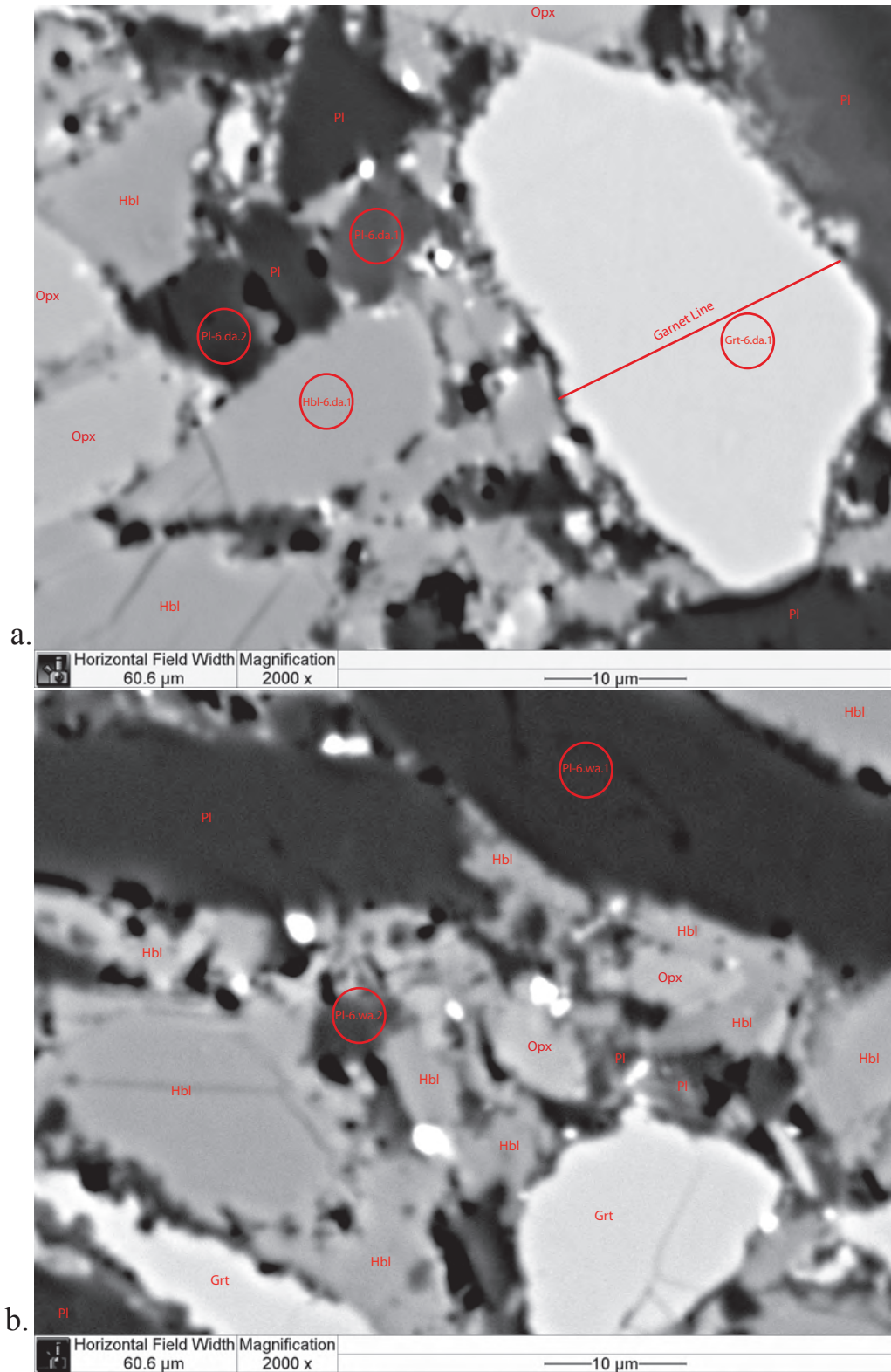


Figure 31. Mineral identifications for the fine amphibolite samples put at 800°C and 5kbars at 2000X magnification as BEI's. (a) The dry fine amphibolite sample. (b) The wet fine amphibolite sample.



Figure 32. A chemical profile of a large garnet from the dry amphibolite sample of Experiment 6. The garnet is homogenous.

	PI-6.wa.1		PI-6.wa.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	6.88	0.61	6.17	0.55
MgO	0.12	0.01	1.06	0.07
Al <sub>2</sub> O <sub>3</sub>	26.29	1.41	25.97	1.41
SiO <sub>2</sub>	56.66	2.58	54.39	2.51
K <sub>2</sub> O	0.28	0.02	0.12	0.01
CaO	8.03	0.39	9.07	0.45
TiO <sub>2</sub>	-0.03	0.00	0.06	0.00
MnO	0.08	0.00	-0.02	0.00
FeO	0.26	0.01	1.37	0.05
		8.00		8.00
	98.57	5.03	98.20	5.06

Table 6. Two plagioclase compositions from the wet amphibolite sample of Experiment 6.

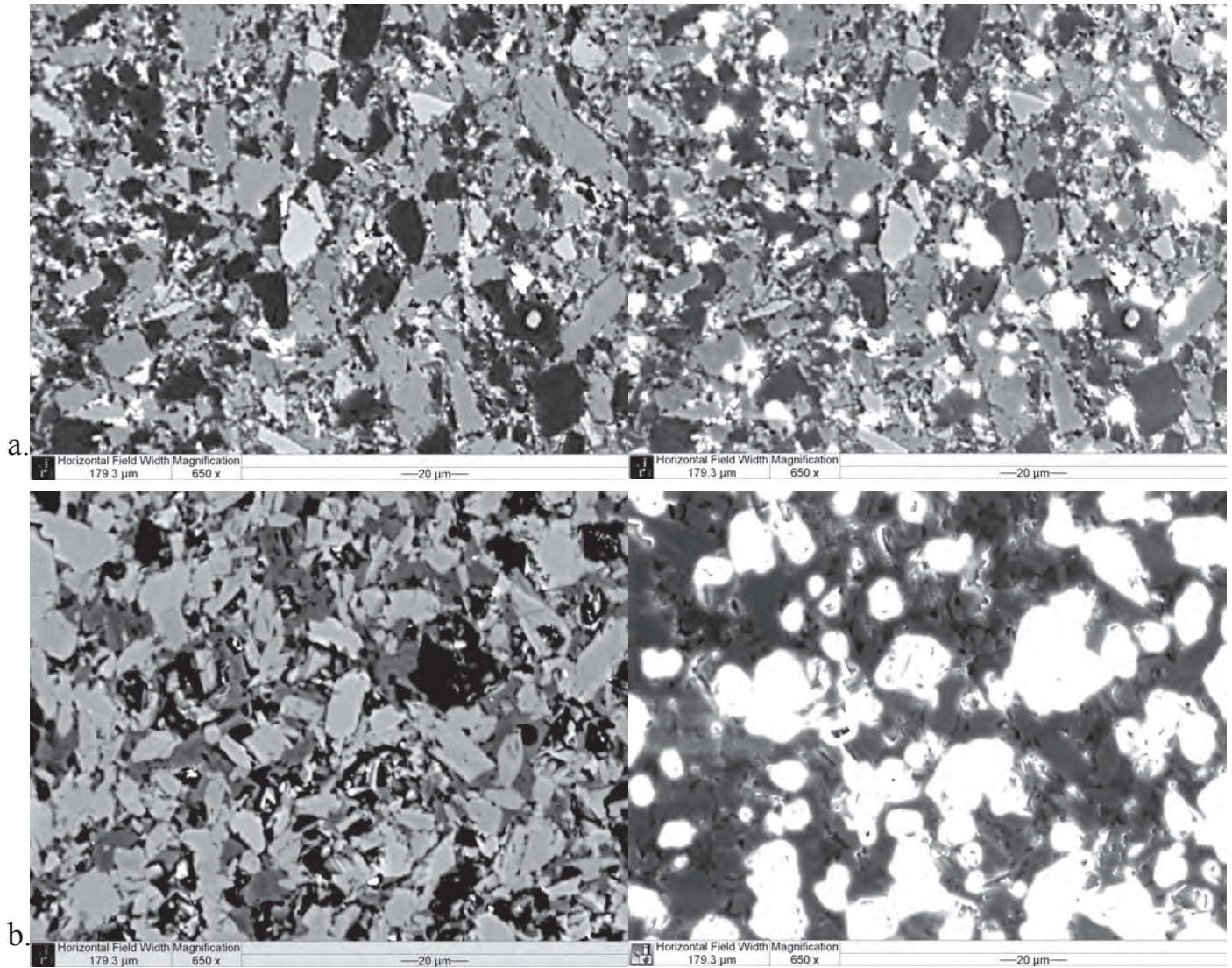


Figure 33. The two fine meta-gabbro samples from Experiment 6 held under 800°C and 5kbars at 650X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine meta-gabbro. (b) The wet sample of the fine meta-gabbro with 15 weight percent water added.

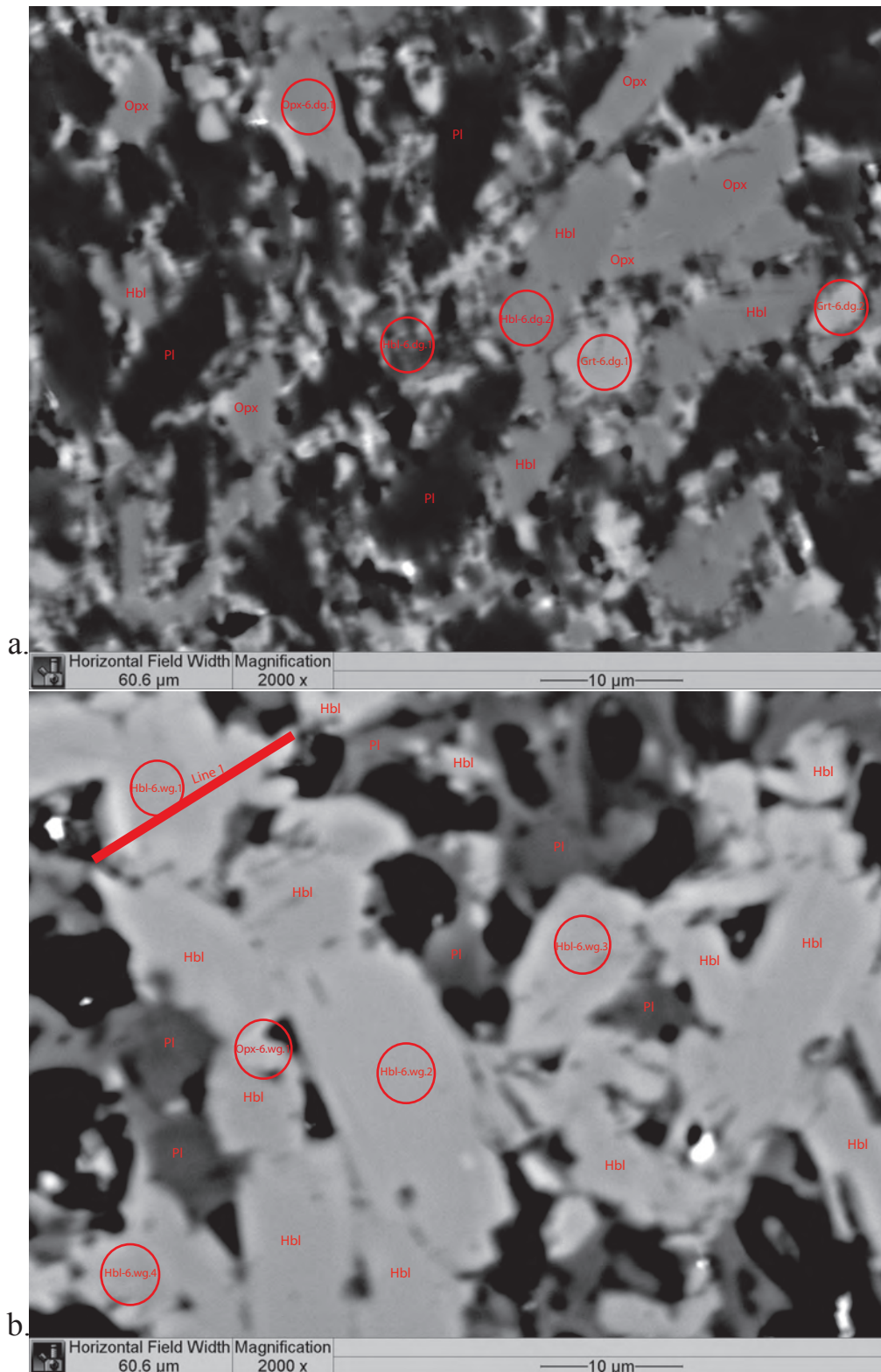


Figure 34. Mineral identifications for the fine meta-gabbro samples put at 800°C and 5kbar at 2000X magnification as BEI's. (a) The dry fine meta-gabbro sample. (b) The wet fine meta-gabbro sample.

	Hbl-6.dg.1		Hbl-6.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.28	0.86	2.67	0.74
MgO	9.46	1.90	12.97	2.76
Al <sub>2</sub> O <sub>3</sub>	21.00	3.34	15.85	2.67
SiO <sub>2</sub>	48.47	6.54	41.78	5.97
K <sub>2</sub> O	0.35	0.06	3.14	0.57
CaO	9.62	1.39	9.04	1.38
TiO <sub>2</sub>	0.17	0.02	3.68	0.39
MnO	0.23	0.03	0.05	0.01
FeO	9.71	1.10	12.32	1.47
		23.00		23.00
	102.28	15.23	101.51	15.96

Table 7. Hornblende compositions of the dry meta-gabbro sample of Experiment 6.

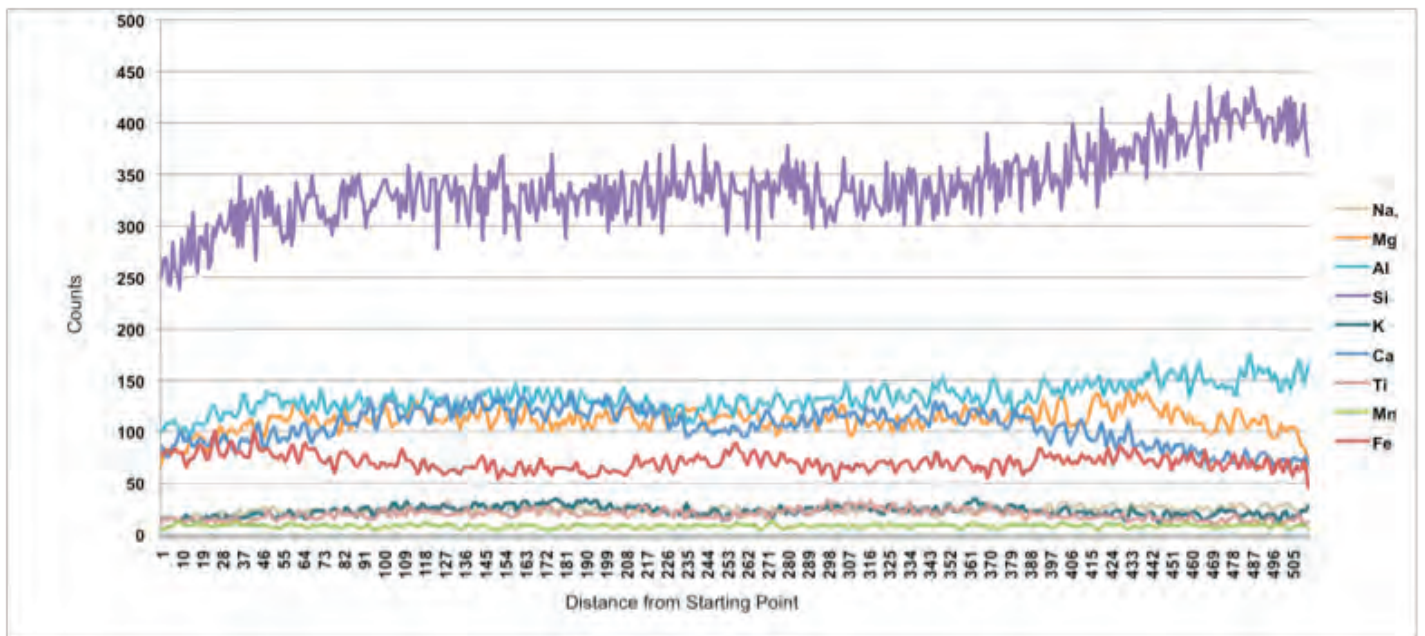


Figure 35. A chemical profile of a hornblende crystal from the wet meta-gabbro sample of Experiment 6.

### **Experiment 7: 800°C, 6kb, 4 days**

Two different rock types were used in this experiment: amphibolite and meta-gabbro. For each type, a dry sample was used along with one with water added to it. Around 18-19% weight percent water was added to increase the amount of melt formed in the run. The samples were held at 800°C and 6kb for 4 days.

#### ***Dry Amphibolite***

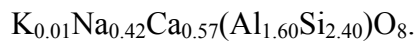
The amphibolite remained predominately composed of hornblende after the run. Plagioclase and garnet are the next most abundant, followed by orthopyroxene. The crystals are fairly uniform in size (~20µm) and are angular to sub-angular (Fig. 36a). In SEI, there do appear to be some vesicles within the sample, but they are very small (<5µm).

A closer look at the dry amphibolite shows the rough crystal edges that are not present within the starting material (Fig. 37a). It appears as if the minerals are being dissolved or broken down during the run. The plagioclase crystals have holes within them. Holes also appear around crystal edges. There may be zonation in plagioclase crystals, but the majority of crystals have no zonation. When looking at Figure 37a the edges of some crystals appear lighter but it is likely due to edge effects in backscatter electron imaging and not due to growth because of the texture of the edges. The two garnets analyzed in Figure 37a (Grt-7.da.2 and Grt-7.da.3) have similar compositions with differences in elements of only 3 weight percent (Bartolome) maximum. Thus, despite the size difference between the two garnets, they have the same composition. The two hornblende crystals circled (Hbl-7.da.2 and Hbl-7.da.3) also have similar compositions with the largest difference in weight percent of an element being only 1.14%.

### ***Wet Amphibolite***

The wet amphibolite looks very different from the dry amphibolite. The most noticeable difference is the amount of garnet is less within the wet amphibolite. Only a small number of rounded garnets remain (Fig. 36b). The texture of the wet amphibolite is also very different. Larger round vesicles are spread throughout the sample. The crystals within the wet amphibolite typically have rounded edges. In some places it appears as if new crystals have formed within a melt, as the crystals show perfect forms. No orthopyroxene was found, leading to the conclusion that the original orthopyroxene was hydrated and formed amphibole. Hornblende is the most abundant mineral, followed by plagioclase. Once again, garnet is present, but in small amounts.

The three garnets analyzed in Figure 37b all had similar compositions. The average composition for the garnets within the wet amphibolite can be found in Table 7. Three hornblende crystals were also analyzed (Fig. 37b and Table 8). There is some significant variation within the composition of the hornblende crystals. The smallest hornblende analyzed, Hbl-7.wa.3, has 7.49 less weight percent CaO than the larger Hbl-7.wa.1 and 4.71 less weight percent CaO than Hbl-7.wa.2. While Hbl-7.wa.3 has less calcium than the larger hornblende crystals, it has a greater amount of magnesium and iron. Hbl-7.wa.3 has 3.44 weight percent more FeO than Hbl-7.wa.1 and 1.88 weight percent more FeO than Hbl-7.wa.2. Additionally, it has 2.44 and 1.05 weight percent more MgO than Hbl-7.wa.1 and Hbl-7.wa.2 respectively. The plagioclase crystal, Pl-7.wa.1, shown in Figure B2b, has the composition;



One hornblende crystal (Hbl-7.wa.1) was analyzed across a section of itself, to see if it contained any chemical zoning (Fig. 37b). The results show a decrease in calcium and magnesium in the rims of the hornblende crystal. Potassium has the opposite trend, with higher

counts within the rims and lower counts within the center. A garnet (Grt-7.wa.1) was also analyzed along a cross section (Fig. 37b and Fig. 38). The garnet did have a decrease in iron and an increase in silica along its edges. There is also a decrease in magnesium along the edge, however it is a smaller change compared to those stated above.

### ***Dry Meta-Gabbro***

The dry meta-gabbro contains a larger amount of hornblende than originally. It still contains orthopyroxene in significant amounts. Plagioclase is the second most common mineral. Garnet occurs in small amounts. A single crystal of olivine was found. There are two distinct crystal sizes. The majority is a larger size around 10  $\mu\text{m}$ , but there are pockets of smaller crystals within the sample (Fig. 39a and Fig. 40b). Small vesicles are scattered throughout the meta-gabbro, they do appear to occur less abundantly within the smaller crystal size areas, however this could be due to a smaller size of vesicle (Fig. 39a).

The compositions of all the hornblendes analyzed within the dry meta-gabbro can be seen in Figure 41. There are only a few percent differences between the hornblendes. There does not appear to be a difference in composition between the larger crystals and the smaller crystals. The garnets analyzed within the dry meta-gabbro had very similar compositions with an average composition of:  $\text{Ca}_{0.49}\text{Fe}_{1.27}\text{Mg}_{1.08}\text{Mn}_{0.03}\text{Al}_{2.00}(\text{Al}_{0.01}\text{Si}_{2.99}\text{O}_{12})$ .

A hornblende crystal (Hbl-7.dg.5) was analyzed to determine if chemical zonation occurred within it. There is a slight increase in the amount of potassium and calcium in the center of the crystal. Magnesium increases by greater amounts towards the center of the crystal. A second line scan was done across a garnet crystal (Grt-L7-dg). The garnet was found to have slight zoning, specifically the amount of magnesium and iron increased toward the center of the crystal.



### ***Wet Meta-Gabbro***

The wet meta-gabbro looks texturally similar to the dry meta-gabbro (Fig. 39b). Like the dry version, it has a majority of crystals around 10 $\mu$ m with pockets of smaller crystals. It does however have a greater number of vesicles. The crystals are slight more rounded within the wet meta-gabbro. The wet meta-gabbro contains hornblende, plagioclase, orthopyroxene, and garnet in decreasing amounts respectively. The orthopyroxene tends to be smaller than the hornblende.

Chemical analysis of the garnets within the fine pockets and the coarser areas were completed. The smaller garnets have 1.99% less weight percent FeO than the larger garnets (Table 9). Overall the garnets are very similar in composition, thus crystal size does not appear to be a factor in composition of garnet within this sample. The hornblende crystals of the wet meta-gabbro have very similar compositions to each other as well as similar compositions to the hornblende crystals of the dry meta-gabbro (Fig. 42).

A chemical analysis was done across a hornblende crystal (Hbl-7.wg.1) showing some differences between the center of the crystal and the edges. Specifically, potassium, titanium, and calcium increase towards the center of the crystal. Iron decreases slightly in the interior of the crystal. A chemical analysis cross-section of a garnet (Grt-7.wg.2) has some patterns within it. Iron increases towards the center of the garnet. Also, at the start of the line magnesium was at its lowest concentration and calcium was at its highest concentration. At the end of the line the opposite is true, magnesium had increased and calcium has decreased.

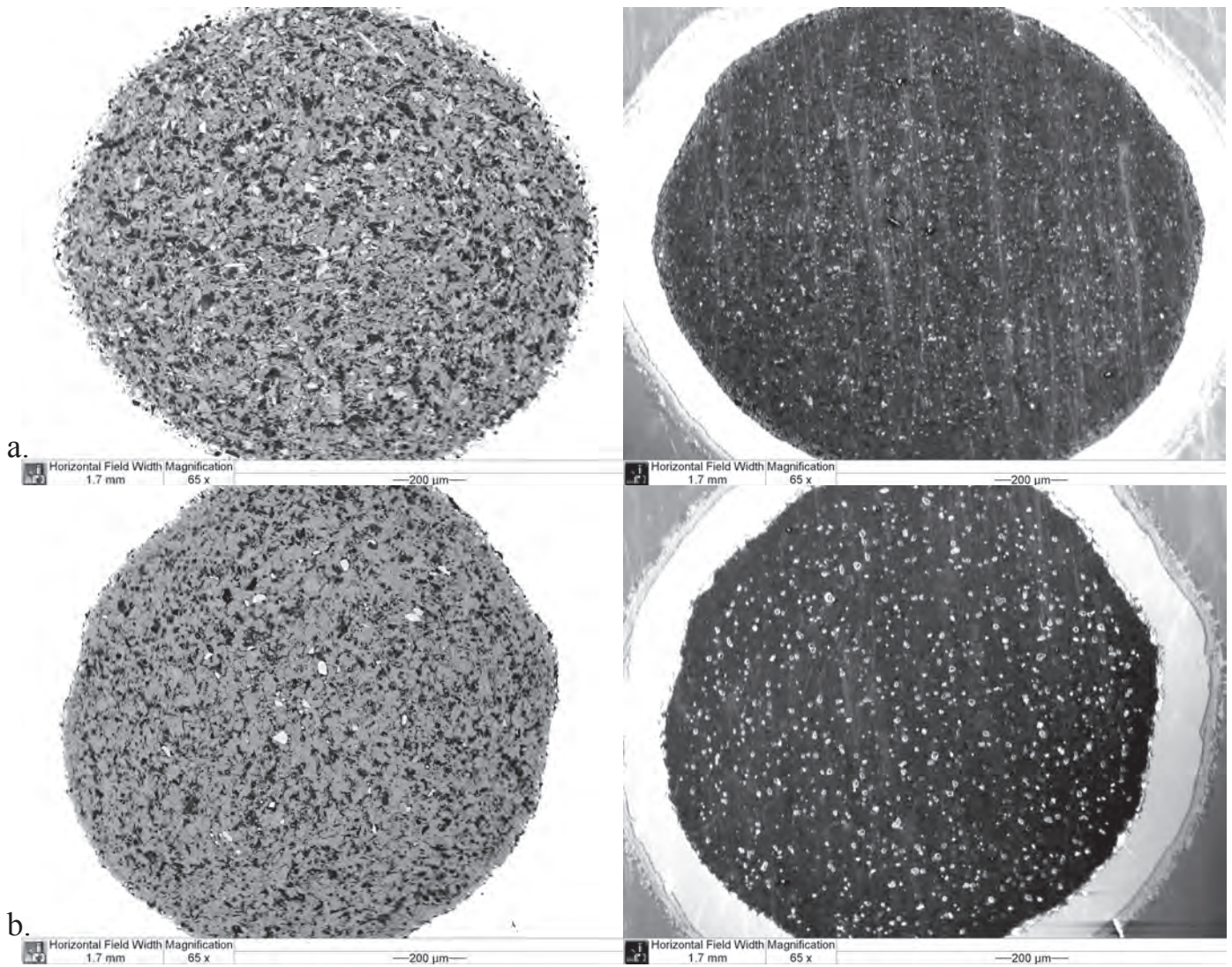


Figure 36. The two fine amphibolite samples from Experiment 7 held under 800°C and 6kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine amphibolite. (b) The wet sample of the fine amphibolite with 19 weight percent water added.

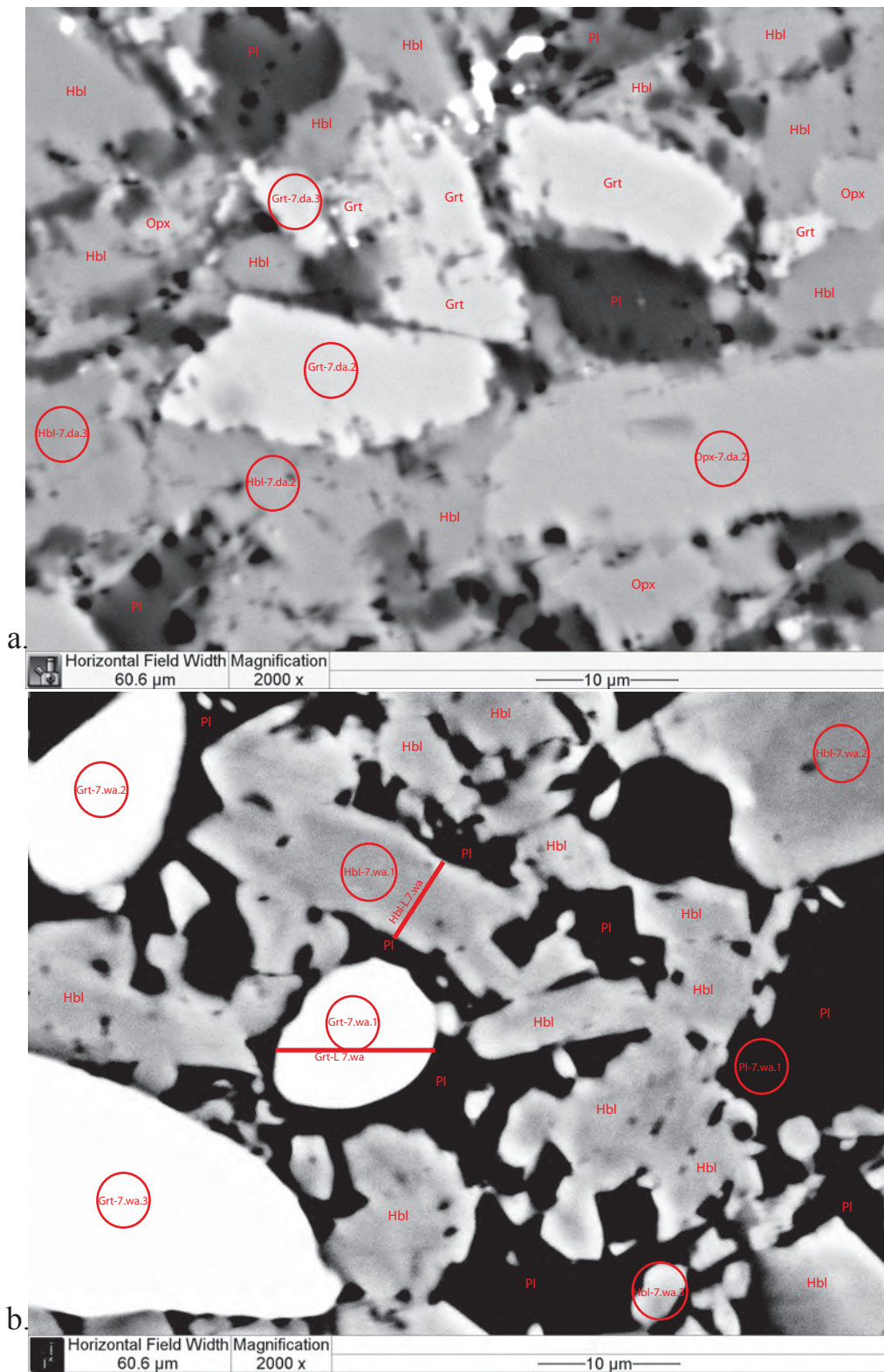


Figure 37. Mineral identifications for the fine amphibolite samples put at 800°C and 7kbars at 2000X magnification as BEI's. (a) The dry fine amphibolite sample. (b) The wet fine amphibolite sample.

Grt-7.wa	Average Compound Percent	Average Nos. of Ions
MgO	11.25	1.25
Al <sub>2</sub> O <sub>3</sub>	22.85	2.00
SiO <sub>2</sub>	40.38	3.00
CaO	3.99	0.32
TiO <sub>2</sub>	0.05	0.00
MnO	0.58	0.04
FeO	22.17	1.38
O		12
Total	101.27	7.99

Table 8. The average composition of garnets from the wet amphibolite of Experiment 7.

	Hbl-7.wa.1		Hbl-7.wa.2		Hbl-7.wa.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.24	0.90	2.84	0.79	2.66	0.72
MgO	13.13	2.80	14.51	3.09	15.56	3.26
Al <sub>2</sub> O <sub>3</sub>	15.91	2.68	15.91	2.68	17.30	2.87
SiO <sub>2</sub>	42.74	6.12	43.82	6.26	45.08	6.34
K <sub>2</sub> O	0.95	0.17	0.38	0.07	0.09	0.02
CaO	11.23	1.72	8.44	1.29	3.74	0.56
TiO <sub>2</sub>	1.49	0.16	0.58	0.06	0.33	0.03
MnO	0.06	0.01	0.07	0.01	0.13	0.02
FeO	11.23	1.34	12.79	1.53	14.67	1.73
		23.00		23.00		23.00

Table 9. Three hornblende compositions from the wet amphibolite of Experiment 7.

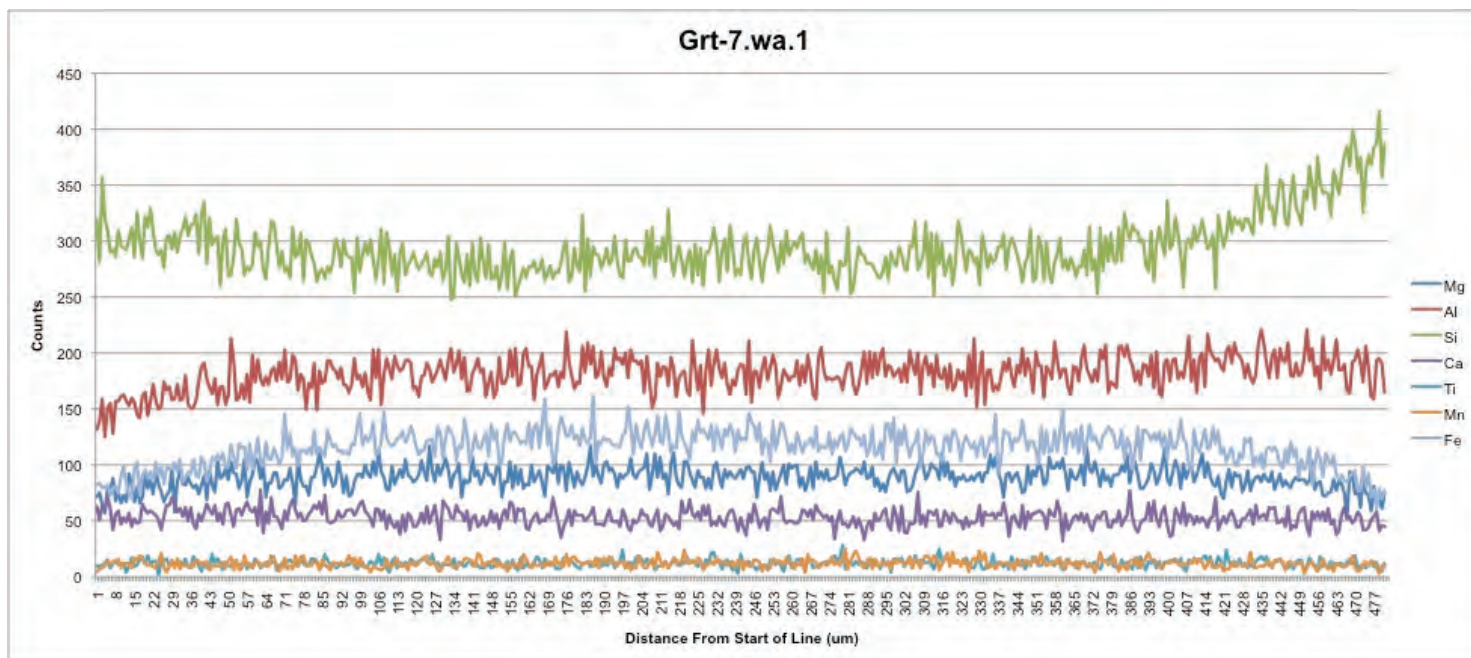


Figure 38. A chemical profile of a garnet from the wet amphibolite sample of Experiment 7. See Figure 37b for an image of the line profiled.

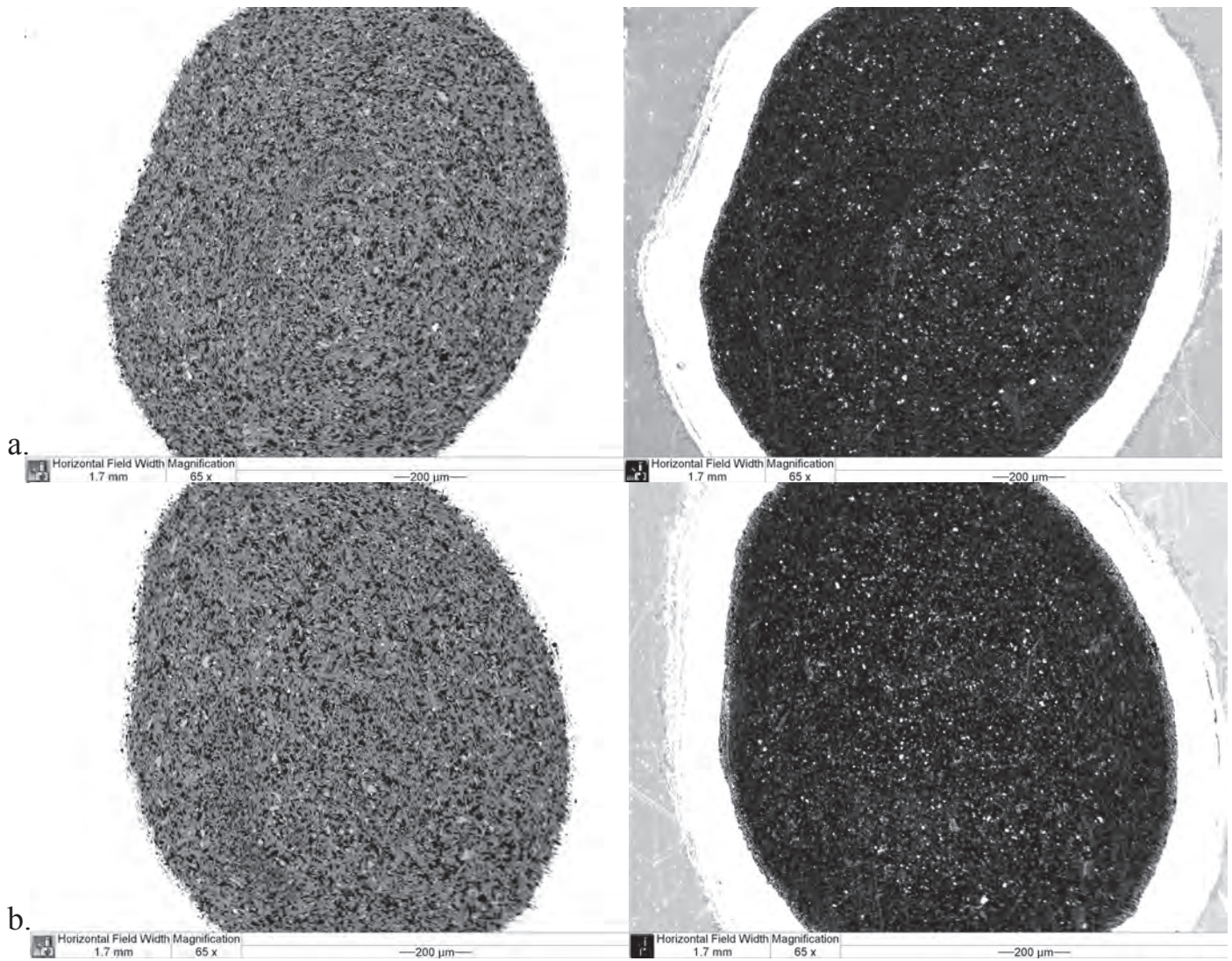


Figure 39. The two fine meta-gabbro samples from Experiment 7 held under 800°C and 6kbars at 65X magnification. For each, the images on the left are BEI's and the images on the right are SEI's. (a) The dry sample of the fine meta-gabbro. (b) The wet sample of the fine meta-gabbro with 18 weight percent water added.



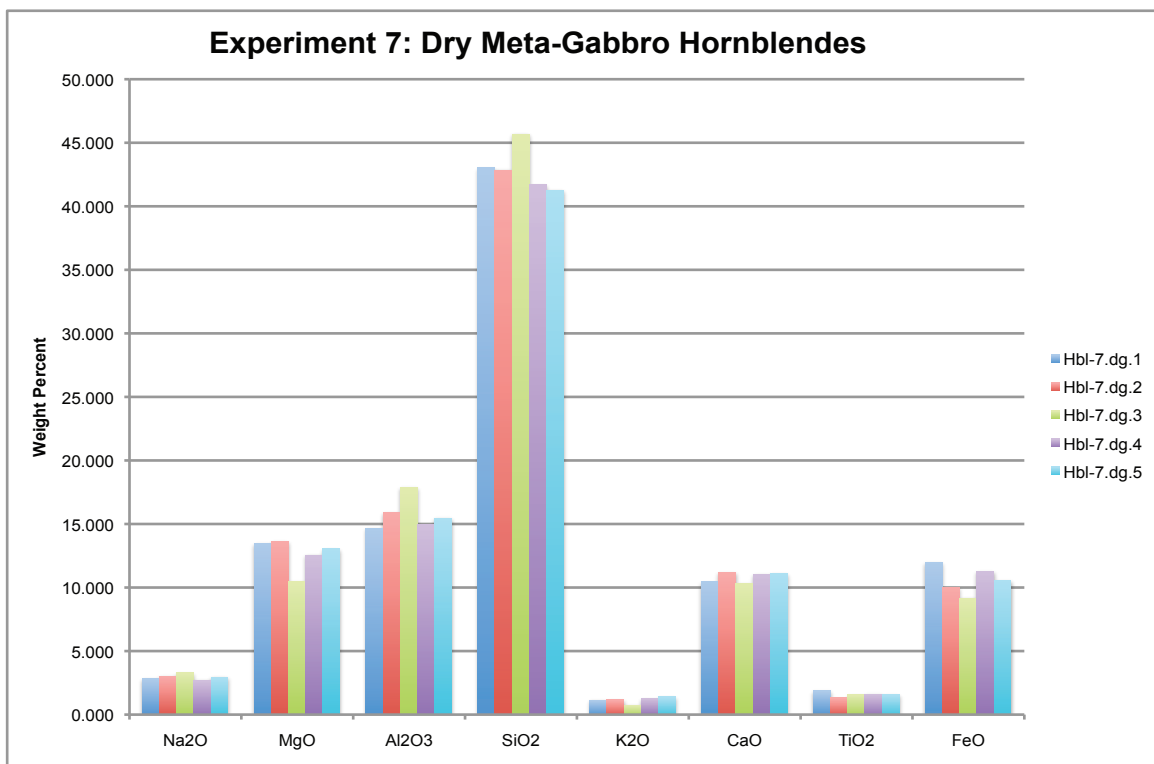


Figure 41. Compositions of hornblendes in weight percent oxide from the dry meta-gabbro of Experiment 7.

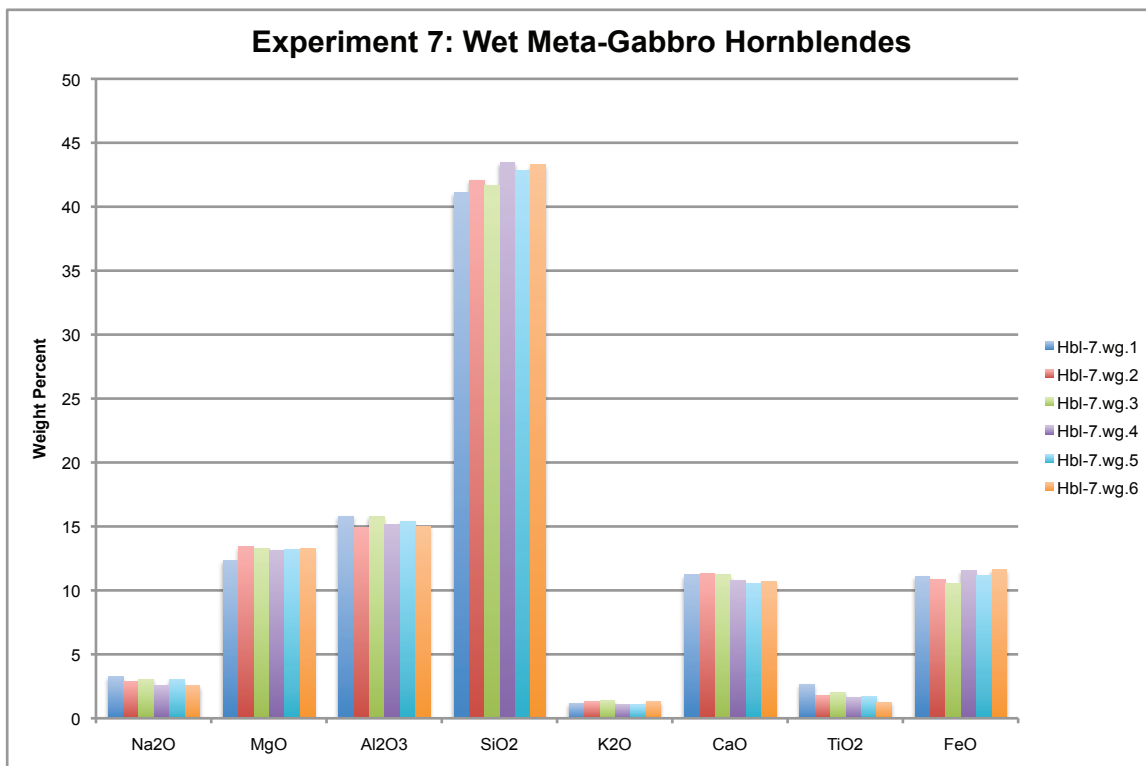


Figure 42. Compositions of hornblendes in weight percent oxide from the wet meta-gabbro of Experiment 7.

	Small Garnet Crystals (~2um)		Large Garnet Crystals (~10um)	
	Average Compound %	Average Nos. of ions	Average Compound %	Average Nos. of ions
Na <sub>2</sub> O	1.09	0.15	0.40	0.06
MgO	9.90	1.07	9.74	1.10
Al <sub>2</sub> O <sub>3</sub>	22.68	1.94	22.27	2.00
SiO <sub>2</sub>	43.20	3.14	39.62	3.02
CaO	6.14	0.48	5.82	0.47
MnO	0.50	0.03	0.62	0.04
FeO	18.80	1.14	20.78	1.32
O		12		12
	102.31	7.96	99.26	8.01

Table 10. Garnet compositions of different size crystals within the wet meta-gabbro of Experiment 7.



## Discussion

The garnets of the meta-gabbro samples and the amphibolite samples plot in two different groups on a ternary diagram (Fig. 43). This shows that the meta-gabbros did not equilibrate to the amphibolite under the temperature and pressure conditions applied. While the wet meta-gabbros hydrated and became amphibolites, their garnets did not have the same composition as the garnets from the amphibolite samples. Thus, the simple addition of water to the meta-gabbro did not create the same amphibolite seen at Gore Mountain. No melt was found within the samples also indicating that partial melting is unlikely to be involved in the formation of the garnet ore. The large vesicles in the wet samples indicate some vapor phase present. A water vapor is likely to form due to oversaturation of water within the powder.

When the garnets of the experiment samples are compared to garnets of previous studied, specifically Luther (1976) and Levin (1950), there is little compositional difference (Fig. 43). The garnets from the meta-gabbros of Levin (1950) plot with the garnets of the experimental samples. The same occurs with the garnets from the amphibolite samples. The cores of Luther's (1976) amphibolite garnets plot with the garnets of the experimental amphibolite samples. This implies that the conditions of the experiments did not alter the composition of the garnets (the original material).

There are two garnets that appear to be outliers. Both are from Experiment 2 (800°C and 8kb). The outliers are from the fine wet amphibolite sample. The garnet that plots with the meta-gabbros is likely a rim of a larger garnet, as the rims of the natural amphibolite plot closer to the meta-gabbro (Luther, 1976). No explanation is known for the outlier that is very magnesium rich.

The hornblende of both the meta-gabbros and the amphibolites do not show any pattern (Fig. 44). The hornblendes of the original powder plot within the small cloud of points. One hornblende from Luther (1976) was plotted and also graphs near the experimental hornblende samples. While zoning and growth appeared in many hornblende crystals, the centers of the hornblende crystals appear not to have changed much or at all in composition.

Two pairs of hornblende centers and edges are shown in Figure with an arrow pointing to the edge of the crystals. The hornblende pair of the wet meta-gabbro from Experiment 1, appears to have changed very much in composition, yet the edge still plots among all of the hornblendes graphed. The edge of the hornblende crystal in Experiment 5 has not changed very much at all. Thus, the hornblendes do not appear to have changed in composition because of the experiments. This is significant because it supports the results of the garnet compositions, specifically that the powders did not appear to reorganize chemically during the experiments.

The wet amphibolite sample from Experiment 3 showed the greatest amount of growth. This could be due to the greater temperature than other runs. Wolf and Wyllie (1993) reported that garnets grew up to 100 $\mu$ m after 4 days at 925°C and 10 kbars. Experiment 3 also lasted the longest, 6 days and 3 hours. It is possible that the experiments needed longer durations, however the lower pressure of the experiments completed in this study should have allowed faster diffusion. Wolf and Wyllie (1993) also state that garnets began to nucleate at 850°C. They did start out with a garnet free powder. With garnet crystals already in the powder able to act as seed in addition to lower pressures, it would seem likely that melting and garnet growth would have occurred in greater amounts in the experiments of this study. Another factor is the addition of water. This in itself could have aided the growth of crystals. Additionally, the grinding of the rock into a powder takes the crystals out of textural equilibrium. Growth could have occurred

because of changes in surface energy. Many factors aided the growth of the minerals, yet the two unique ones for this sample appear to be the higher temperature and the longer duration of the experiment.

Melt was not texturally observed in the BEI images. There were no chemical analyses that did not match reasonable mineral compositions. Additionally, using EBSD at Amherst College, amorphous areas were looked for within samples, yet none were identified. It is possible that the melt could have move to a different part of the sample that was not analyzed. Minerals were consumed in some experiments and grown in others, however, no glass was apparent in any of the samples. Using the program MELTS, a liquid was predicated to form at similar conditions. MELTS did not predict the formation of hornblende in most of the cases, but rather clinopyroxene. This difference could have changed the predicted outcomes. Additionally, vesicles indicate a fluid or vapor phase did exist within the sample. The amount of water added to the experiments should have been enough to saturate the sample, allowing for a separate water phase. The presence of vesicles also indicates that the gold capsule was sealed during the experiment and that melt could not have escaped.

This study did not replicate the results of a previous experiment done with the same Gore Mountain samples. Howard (2004) ran an experiment using the same setup. She put the same meta-gabbro and amphibolite, one wet and one dry, at 800°C and 8kb. The wet samples had 20 weight percent water added to them. Although garnets did not grow, the wet amphibolite sample had a significant, visible amount of glass after the run. It is not clear why the results varied so greatly. This study put a maximum of 18 weight percent water and no glass was evident. Howard (2004) calculated the weight percent water using the volume of the cylinder. This is not the best approach because the cylinders vary in volume. This study used the actual weight of the water

compared to the weight of the powder added to determine the weight percent of water added. The results of this study were consistent, as no melt appears to have formed in any of the experiments. It is also not an ideal to compare the results with only one example.

This study shows what conditions were unfavorable for garnet growth. Specifically, The addition of 18 weight percent water to the amphibolite at 800°C and 6kb dissolved the majority of the garnet within the sample. The addition of water to the meta-gabbro at 800°C and 5kb (Exp. 6) also dissolved the garnet within the sample. Low pressures were used because they favored the formation of a partial melt, but this did not support the growth of garnet in the above-mentioned conditions. The fact that it appears that no melt has formed under conditions similar those thought to have occurred at Gore Mountain, does not support the idea that a partial melt aided the growth of the garnets

## Garnets from the Wet and Amphibolites

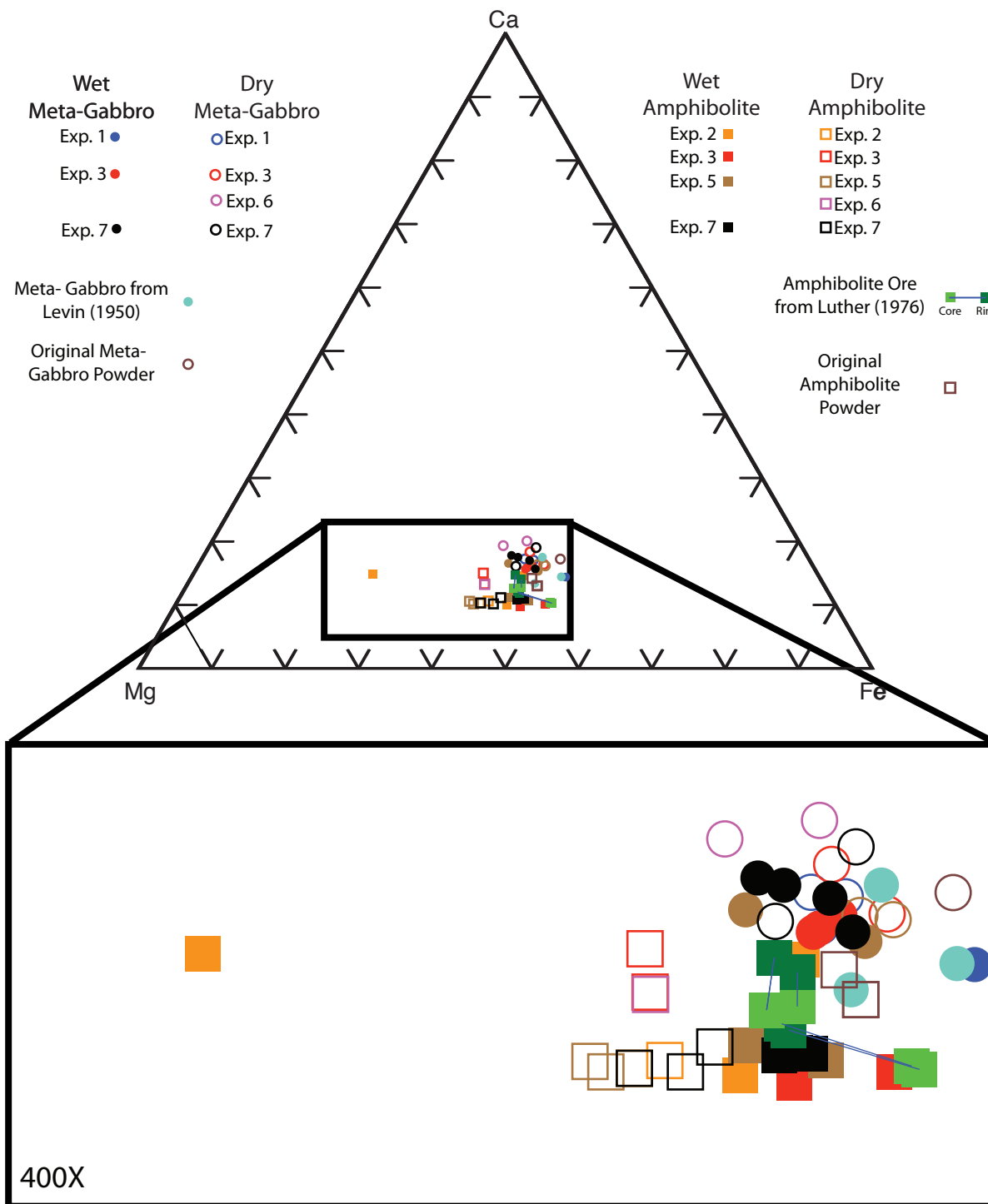


Figure 43. A ternary plot of the composition of garnets from different experiments done with meta-gabbro and amphibolite powders from Gore Mountain. The samples with water added are shown as solid circles (meta-gabbro) or as solid squares (amphibolite). The dry samples are shown as hollow circles (meta-gabbro) or as hollow squares (amphibolite). The same color denotes the same temperature and pressure conditions. Notice how the two different rock types plot as two separate groups overall. Also note how the garnet compositions did not change from the original material.

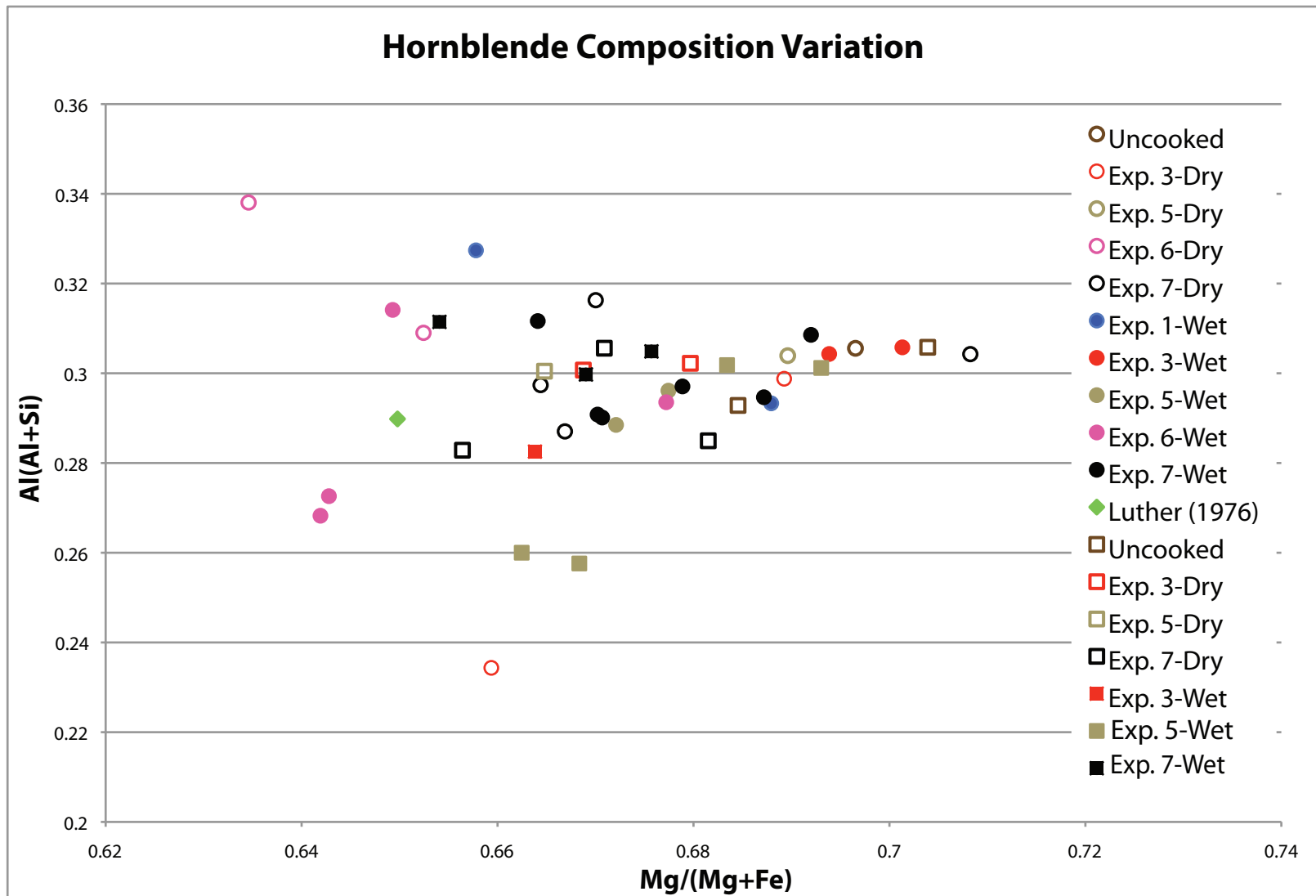


Figure 44. Graph of the molar ratio of elements within hornblende crystals. This graph shows the variation of composition of hornblendes within wet and dry meta-gabbro and amphibolite samples. Hornblendes from the original dry unaltered powders are plotted. An analysis of a hornblende found in Luther (1976) is also compared. The samples with water added are shown as solid circles (meta-gabbro) or as solid squares (amphibolite). The dry samples are shown as hollow circles (meta-gabbro) or as hollow squares (amphibolite). The same color denotes the same temperature and pressure conditions. The hornblende compositions are very similar in both meta-gabbro and amphibolite samples.

## **Conclusions**

The goal of this study was to determine if the presence of a partial melt was a factor in the formation of the large garnets at Gore Mountain. The results do not support the hypothesis that the garnets grew in the presence of a partial melt. Additionally, the simple addition of water did not change the meta-gabbro into the garnet amphibolite. Conditions were found which disfavored the growth of garnets (low pressure, high water content). One particular condition was found which favored the growth of crystals, specifically, adding water to the amphibolite and placing it at 900°C and 8kbars, however, the growth was not in the presence of a melt and could have been due to surface energy changes causing the large crystals to grow and the smaller crystals to disappear. The conditions for the formation of the large garnets are yet to be determined.

## References

- Asimow, P., Ghiorso, M. Algorithmic Modifications Extending MELTS to Calculate Subsolidus Phase Relations. *American Mineralogist* 83 (1998): 1127-1131
- Ayers, J., J. Brenan, B. Watson, D. Wark, and W. Minarik. "A new capsule technique for hydrothermal experiments using the piston-cylinder apparatus." *American Mineralogist* 77 (1992): 1080-1086.
- Bartolome, P. "Genesis of the Gorw Mountain Garnet Deposit, New York." *Economic Geology and the Bulletin of the Society of Economic Geologists* (The Economic Geology Publishing Company), 1960: 255-277.
- Ghiorso, M., Sack, R. Chemical Mass Transfer in Magmatic Processes. IV. A Revised and Internally Consistent Thermodynamic Model for the Interpolation and Extrapolation of Liquid-Solid Equilibria in Magmatic Systems at Elevated Temperatures and Pressures. *Contributions to Mineralogy and Petrology* 119 (1995):197-212 (MELTS)
- Goldblum, D., and M. Hill. "Enhanced Fluid Flow Resulting from Competency Contrast Within a Shear Zone; the Garnet Ore Zone at Gore Mountain, NY." *Journal of Geology* (The University of Chicago Press) 100, no. 1 (1992): 776-782.
- Howard, H. Effect of Partial Melt on the Growth of Gore Mountain Garnets. *Special Studies, Geosciences, Smith College*, unpublished, 2004.
- Levin, S. "Genesis of Some Adirondack Garnet Deposits." *Bulletin of the Geological Society of America* 61 (1950): 519-565.
- Luther, F. A chemical reaction for the formation of the Gore Mountain garnet deposit, Warren County, New York. Ph.D. Dissertation, Lehigh University, unpublished, 1976.
- McLelland, J. "Geochronology and petrogenesis of Adirondack igneous and metamorphic rocks." *Field Trip Guide for the 76th Annual Meeting of the New York State Geological Association*, 1995: 205-226.
- Morse, S., J. Brady, and B. Sporleder. "Experimental Petrology of the Kiglapait Intrusion: Cotectic Trace for the Lower Zone at 5 kbar in Graphite." *Journal of Petrology* 45, no. 11 (2004): 2225-2259.
- Wolf, M., and P. Wyllie. "Dehydration-melting of amphibolite at 10 kbar: the effects of temperature and time." *Contributions to Mineralogy and Petrology*, 1994: 369-383.
- Wolf, M., and P. Wyllie. "Garnet growth during amphibolite anatexis: implications of a garnetiferous restite." *Journal of Geology* 101 (1993): 357-373.



## Appendix I: Additional Run Information

### Experiment 1

	Powder Sample	Powder Wt (g)	Water Wt (g)	Wt% H2O
<b>Sample 1</b>	GM-307	0.025	0.0000	0.0
<b>Sample 2</b>	GM-308	0.022	0.0000	0.0
<b>Sample 3</b>	GM-307	0.022	0.0015	6.3
<b>Sample 4</b>	GM-308	0.019	0.0015	7.4

10/22/10

Time	Temperature	Output Power	Upper Ram	Lower Ram	Comment
5:38:00 PM	18		6230	2600	
5:39:00 PM	100	15.7	6230	2600	
5:39:40 PM	200	24.1	6230	2600	
	300	29.7	6230	2600	
	400	34.6	6230	2600	
	500	38.8			
	600	43			
	700	47.6			
5:47:00 PM	800	52.2	6350	2600	
5:57:00 PM	800	50.9	6500	2700	
6:10:00 PM	800	51.3	6600	2710	
6:37:00 PM	800	51.9	6700	2720	
7:00:00 PM	800	52.1	6710	2730	
8:09:00 PM	800	51.6	6720	2780	
8:38:00 PM	800	52	6720	2780	
10:09:00 PM	800	51.4	6720	2780	
10:30:00 PM	800	51.3	6740	2780	
11:48:00 PM	800	51.5	6750	2760	
9:09:00 AM	800	51.7	6730	2750	
10:07:00 AM	800	51.2	6730	2740	
12:50:00 PM	800	51.7	6700	2720	
5:37:00 PM	800	51.7	6680	2700	
8:17:00 PM	800	51.9	6670	2680	
8:19:00 PM	800	52	6690	2870	
8:24:00 PM	800	51.8	6690	2860	
10:27:00 PM	800	52	6680	2850	
9:00:00 AM	800	51.4	6640	2790	
11:20:00 AM	800	51.6	6630	2780	
12:03:00 PM	800	50.5	6630	2760	
1:42:00 PM	800	51.3	6600	2750	
1:56:00 PM	800				temperature alarm
1:57:00 PM	800	51.2	6600	2800	noticed at this
2:42:00 PM	800				quench

## Experiment 2

	<b>Powder Sample</b>	<b>Powder Weight (g)</b>	<b>Water Weight (g)</b>	<b>Wt% H2O</b>
<b>Sample 1</b>	Coarse GM-407	0.028	0.0000	0.0
<b>Sample 2</b>	Coarse GM-407	0.023	0.0014	5.7
<b>Sample 3</b>	Fine GM-407	0.021	0.0000	0.0
<b>Sample 4</b>	Fine GM-407	0.021	0.0011	5.1

11/22/10

800C 8kb

<b>Time</b>	<b>Temperature (°C)</b>	<b>Output</b>	<b>Upper Ram</b>	<b>Lower</b>	<b>Comment</b>
9:13 PM	200	23.7	6850	2650	
9:15 PM	300	29.1	6870	2630	
	400	33.7	6880	2620	
	500	38	6910	2650	
	600	41.5	6910	2550	
	700	45.7	6950	2580	
9:21 AM	800	48.2	7000	2670	
9:31 AM	800	48.3	7100	2520	
9:51 AM	800	48.2	7290	2650	
10:12 AM	800	48.4	7310	2640	
11:01 AM	800	48.7	7850	2650	7850 could have
11:50 AM	800	47.7	7350	2650	really been 7350
1:51 PM	800	47.9	7390	2750	
1:57 PM	800	48.1	7440	2860	
8:20 AM	800	48.4	7450	2730	
10:21 AM	800	48.5	7440	2750	
1:30 PM	800	48.6	7430	2730	
3:40 PM	800	48.7	7430	2700	
6:10 PM	800	48.5	7430	2700	
9:20 AM	800	48.6	7390	2590 to 2730	
12:00 PM	800	48.6	7350	2550 to 2710	
4:30 PM	800	48.7	7350	2500 to 2710	
5:40 PM	800	48.9	7330	2300	quench

### Experiment 3

	Powder Sample	Powder Weight (g)	Water Weight (g)	Wt% H2O
Sample 1	GM-407	0.02	0	
Sample 2	GM-407	0.0113	0.0015	11.7
Sample 3	GM-307	0.0146	0	0.0
Sample 4	GM-307	0.01	0.0017	14.5

1/8/11

900C 8kb

Date	Time	Temperature	Output Power	Upper Ram	Lower	Comment		
8-Jan	2:10 PM	62	17.3	8200	2450			
		100	21.5					
		200	23.5					
		300	30.2					
		400	35.5					
		500	39					
		600	44					
		700	48					
		800	52.9					
		900	57					
	2:23 PM	900	57.5	8430	2650			
		2:31 PM	900	57.6	8550	2500		
		2:32 PM	900	57.9	8570	2650	adjusted pressure	
		3:28 PM	900	58.4	8800	2740		
		3:39 PM	900	58.1	8800	2730		
		7:55 PM	900	56	8820	2740	temp alarm noticed	
		10:20 PM	900	55.4	8850	2720		
		10:22 PM	900	55.6	8850	2830	increased pressure	
		9-Jan	9:17 AM	900	54.4	8830	2700	
			12:45 PM	900	53.9	8820	2670	
12:46 PM	900		54.1	8820	2720	adjusted pressure		
2:03 PM				8770	1950			
2:04 PM	900		53.6	8800	2780	adjusted pressure		
2:09 PM	900		53.9	8820	2770	adjusted pressure		
2:45 PM	900		53.6	8820	2720			
3:55 PM	900		53.9	8800	2720			
4:12 PM	900		53.9	8800	2720			
5:15 PM	900		53.5	8800	2720			
5:25 PM	900	53.3	8800	2720				
7:07 PM	900	53.2	8800	2710				
8:51 PM	900	53	8800	2680				
9:28 PM	900	53	8800	2670				
9:33 PM	900	53.1	8800	2810	adjusted pressure			
9:46 PM	900	53.1	8800	2810				
10-Jan	10:27 AM	900	52.4	8770	2720			
	11:15 AM	900	52.3	8770	2700			
	12:45 PM	900	52.6	8760	2690			
	2:21 PM	900	52.4	8760	2680			
	2:47 PM	900	52.5	8760	2670			
	3:07 PM	900	52.6	8770	2760			
	6:08 PM	900	52.4	8770	2760			

	7:13 PM	900	52.5	8760	2760
	7:52 PM	900	52.7	8760	2760
	7:58 PM	900	52.3	8770	2840 adjusted pressure
11-Jan	10:15 AM	900	52.1	8750	2770
	12:43 PM	900	51.9	8740	2750
	1:48 PM	900	51.9	8750	2750
	4:00 PM	900	51.9	8750	2700
	7:45 PM	900	51.9	8760	2700
	10:30 PM	900	51.4	8770	2700
12-Jan	8:45 AM	900	50.7	8750	2650
	11:15 AM	900	48.5	8720	2600-->2750
	12:00 PM	900	48.5	8700	2660
	1:15 PM	900	48.8	8680	2600-->2750
	3:00 PM	900	49.1	8690	2660
	4:30 PM	900	49.5	8700	2650
	6:00 PM	900	49.5	8700	2640-->2780
	7:00 PM	900	49.7	8710	2780
13-Jan	7:45 AM	900	47.4	8660	2600-->2750
	11:30 AM	900	48.4	8680	2730
	3:00 PM	900	49.2	8690	2730
	5:50 PM	900	49.4	8700	2730
14-Jan	12:06 AM	900	48.2	8700	2730
	9:45 AM	900	49.3	8690	2700
	1:55 PM	900	49.6	8680	2700
	5:45 PM	900	50.2	8670	2670

quench

## Experiment 4

Date	Time	Output Power	800C 7kb Temp (°C)	Upper Ram Pressure	Lower Ram Pressure	Comment	
6-Feb	4:40pm	21.2	100				
		28.7	200				
		32.5	300				
		33.6	400				
		38.6	500				
	~42		47.3	700			
			51.1	800			
		4:50	50.9	800	8100	2290	
		5:00	51.4	800	8200	2300	
		5:10	51.6	800	8280	2280	
		5:11	51.5	800	8300	2300	
		5:33	52.3	800	8400	2300	
		7:13	53.8	800	8450	2280	
		8:30	52.8	800	8460	2260-->2300	
		9:57	52.8	800	8460	2150-->2350	
	10:26	53	800	8500	2300-->2390		
7-Feb	9:50 AM	53.7	800	8490	2190-->2300		
	11:23	53.7	800	8450	2160-->2290		
	12:40pm	54	800	8460	2250-->2340		
	12:43	53.8	800	8450	2300-->2380		
	2:17	54	800	8480	2320-->2380		
	4:16	53.8	800	8460	2260-->2380		
	6:11	53.8	800	8460	2360		
	8:17	53.1	800	8480	2360		
	11:43	48.6	800	8430	2140-->2480		
8-Feb	8:39 AM			>8000	1800	Temperature cycles rapidly 600-1200C. Turned power off. Temperature reads 78 even though the pressure vessel is cold. Where is the Junction?	

## Experiment 5

	<b>Powder Sample</b>	<b>Powder Weight (g)</b>	<b>Water Weight (g)</b>	<b>Wt% H2O</b>
<b>Sample 1</b>	GM-407	0.0206	0	0
<b>Sample 2</b>	GM-407	0.0148	0.0021	12.4
<b>Sample 3</b>	GM-307	0.0174	0	0.0
<b>Sample 4</b>	GM-307	0.0167	0.0022	11.6

<b>Date</b>	<b>Time</b>	<b>Temp (°C)</b>	<b>Output Power</b>	<b>Upper Ram Pressure</b>	<b>Lower Ram Pressure</b>	<b>Comment</b>
11-Feb	4:45	115	19.5	8150	2230	
		200	26.7			
		300	33			
		400	34			
		500	37.9			
		600	42			
		700	46.4			
		800	49.1			
	4:56	800	49.1	8220	2260	
	5:02	800	49.2	8280	2240--> 2300	
	5:12	800	49.6	8350	2230-->2350	
	5:22	800	49.7	8400	2300-->2330	
	8:18	800	50.5	8500	2300	
	8:58	800	50.3	8520	2280-->2350	
	10:55	800	50.8	8550	2220	
	11:00					Quenched due to water leak

## Experiment 6

	Powder Sample	Powder Weight (g)	Water Weight (g)	Wt% H2O
Sample 1	407	0.0303	0	0.0
Sample 2	407	0.0281	0.0018	6.0
Sample 3	307	0.0272	0	0.0
Sample 4	307	0.0218	0.0017	7.2

Date	Time	Temp (°C)	Output Power	Upper Ram Pressure	Lower Ram Pressure	Comment	
26-Feb	16:45	100	16.8				
		200	25.5				
		300	31.6				
		400	36.2				
		500	40.2				
		600 ~43					
			700	46.7			
			800	49.6			
		16:52	800	49.5	8120	1620	
		17:03	801	50.1	8230	1700	
		17:08	800	50.5	8250	1650-->1750	
		17:14	800	50.5	8300	1700	
		17:26	800	50.2	8330	1680	
		17:35	800	50.8	8350	1680-->1720	
		19:32	800	51.7	8400	1670	
		21:00	800	51	8400	1650	
		21:28	800	51.3	8440	1620-->1740	
		23:25	800	51.5	8440	1630	
		23:42	800	51.4	8450	1790-->1890	
		23:53	800	51.7	8450	1820-->1900	
27-Feb	8:28	800	51.8	8450	1720-->1800		
	9:37	800	51.8	8450	1750-->1780		
	12:07	800	51.5	8430	1700-->1800		
	14:55	800	51.9	8440	1630-->1820		
	18:04	800	52	8460	1730		
	19:18	800	51.8	8450	1720-->1830		
	22:03	800	51.8	8450	1700-->1860		
	22:21	800		8450	1800-->1930		
28-Feb	8:43	800	52.3	8430	1700-->1780		
	9:55	800	52.1	8430	1620-->1730		
	10:54	800	52	8430	1650-->1800		
	11:04	800	52.1	8430	1550-->1820		
	11:20	800	52.1	8430	1770		
	12:04	800	52	8420	1750		
	13:40	7	100	7820	450	Power outage around 1:20 quenched run	

## Experiment 7

	Powder Sample	Powder Weight (g)	Water Weight (g)	Wt% H2O
Sample 1	407	0.0226	0	0.0
Sample 2	407	0.0223	0.0052	18.9
Sample 3	307	0.0202	0	0.0
Sample 4	307	0.0202	0.0045	18.2

Date	Time	Temp (°C)	Output Power	Upper Ram Pressure	Lower Ram Pressure	Comment
16-Mar	1:47 PM	100	19.2			
		200	28.8			
		300	33.1			
		400	37			
		500	40.2			
		600	43.3			
		700	46.6			
	1:55 PM	800	49	8200	1890-->2010	
	1:58	800	48.9	8250	1930-->2050	
	2:20	800	49.58	8440		2060
	2:36	800	50.2	8500	2050-->2130	
	4:05	800	50.5	8560		2080
	6:00	800	50.6	8580		2050
	7:45	800	50.4	8600	2040-->2140	
	9:47	800	50.6	8600		2050
	11:52	800	50.4	8600		1950
17-Mar	1:00 AM	800	50.5	8600	1920-->2200	
	10:06	800	51.4	8580		1930
	11:15	800	51.5	8600	1900-->2100	
	2:00 PM	800	51.3	8570	1900-->2130	
	2:54	800	51.3	8600	2040-->2120	
	6:06	800	51.3	8600		2000
	7:52	800	51.4	8600		2000
	10:30	800	51.4	8570		1970
18-Mar	12:25 AM	800	51.1	8560		1950
	1:15	800	51.3	8550	1940-->2200	
	10:35	800	51.6	8540		1980
	11:55	800	51.7	8540		1980
	4:25 PM	800	51.9	8530		1950
	7:00 PM	800	52	8520		1940
	9:00	800	51.5	8520		1930
	9:55	800	51.6	8520	1930-->2200	
	19-Mar	10:05	800	51.6	8480	1810-->2100
11:45		800	51.6	8460		2000
1:00 PM		800	52	8450	1930-->2080	
2:30		800	51.9	8450	1850-->2150	
4:00		800	52.1	8460		2080
5:00		800	52.1	8450		2040
5:45		800	51.9	8450		2030
6:50		800	52	8450		1950
7:17		800	51.7	8440	1800-->2190	
8:52		800	51.4	8440	2020-->2190	



	10:45	800	51.6	8430 2000-->2160	
20-Mar	12:08 AM	800	51.5	8430 2010-->2110	
	1:30	800	51.5	8420 1870-->2200	
	2:00	800	51.6	8420	2150
	7:25	800	51.5	8420	2080
	8:17	800	51.7	8410	2070
	10:30	800	51.5	8400 1960-->2100	
	12:00 PM	800	51.5	8400	2010
	1:45	800	51.7	8400 1900-->1950	
	1:48				Quench

## Appendix II: Chemical Analyses

### Experiment 1

#### Dry Coarse Meta-Gabbro GM-307

	Grt-1.dg.1		Grt-1.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	9.88	1.12	9.67	1.10
Al <sub>2</sub> O <sub>3</sub>	22.40	2.00	22.09	1.99
SiO <sub>2</sub>	39.70	3.01	39.24	3.00
CaO	6.15	0.50	6.10	0.50
MnO	0.58	0.04	0.60	0.04
FeO	20.25	1.28	20.80	1.33
O		12.00		12.00
Total	98.95	7.95	98.51	7.96

	Ol-1.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.73	0.04
MgO	26.83	1.19
Al <sub>2</sub> O <sub>3</sub>	-0.03	0.00
SiO <sub>2</sub>	33.89	1.01
FeO	30.51	0.76
O		4.00
Total	91.93	3.00

	Opx-1.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.45	0.03
MgO	29.88	1.64
Al <sub>2</sub> O <sub>3</sub>	-0.18	-0.01
SiO <sub>2</sub>	55.64	2.05
FeO	8.24	0.25
O		6.00
Total	94.04	3.96

	Cpx-1.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	1.27	0.09
MgO	13.88	0.76
Al <sub>2</sub> O <sub>3</sub>	4.32	0.19
SiO <sub>2</sub>	52.04	1.92
K <sub>2</sub> O	0.07	0.00
CaO	21.48	0.85
TiO <sub>2</sub>	0.15	0.00
FeO	7.02	0.22
O		6.00
Total	100.23	4.03

	Pl-1.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	6.82	0.59
MgO	0.11	0.01
Al <sub>2</sub> O <sub>3</sub>	27.23	1.44
SiO <sub>2</sub>	56.99	2.56
K <sub>2</sub> O	0.30	0.02
CaO	8.21	0.39
FeO	0.23	0.01
O		8.00
Total	99.90	5.02

## Experiment 1

### Wet Coarse Meta-Gabbro GM-307

	Grt-1.wg.1		Grt-1.wg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	8.14	0.91	9.85	1.13
Al <sub>2</sub> O <sub>3</sub>	22.15	1.96	22.45	2.03
SiO <sub>2</sub>	42.20	3.16	38.89	2.99
CaO	4.75	0.38	5.59	0.46
MnO	0.62	0.04	0.52	0.03
FeO	21.53	1.35	20.47	1.31
O		12.00		12.00
Total	99.40	7.80	97.77	7.96

	Hbl-1.wg.1		Hbl-1.wg.1a	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.59	0.77	3.23	0.91
MgO	12.79	2.92	13.38	2.91
Al <sub>2</sub> O <sub>3</sub>	13.89	2.51	17.26	2.97
SiO <sub>2</sub>	39.45	6.04	41.79	6.10
K <sub>2</sub> O	1.57	0.31	0.14	0.03
CaO	11.46	1.88	8.23	1.29
TiO <sub>2</sub>	2.16	0.25	0.58	0.06
FeO	10.34	1.32	12.41	1.52
O		23.00		23.00
Total	94.25	15.99	97.01	15.79

**Experiment 2****Wet Coarse Amphibolite GM-407**

	Grt-2.wa.1	
	Compound %	Nos. of ions
MgO	10.99	1.24
Al <sub>2</sub> O <sub>3</sub>	22.65	2.02
SiO <sub>2</sub>	39.78	3.01
CaO	3.70	0.30
MnO	0.59	0.04
FeO	21.37	1.35
O		12.00
Total	99.08	7.95

**Experiment 2****Dry Fine Amphibolite GM-407**

	Grt-2.da.1		Grt-2.da.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.69	1.21	10.93	1.24
Al <sub>2</sub> O <sub>3</sub>	22.73	2.04	22.62	2.03
SiO <sub>2</sub>	39.18	2.98	39.37	2.99
CaO	3.64	0.30	3.86	0.31
MnO	0.73	0.05	0.63	0.04
FeO	21.92	1.40	21.52	1.37
O		12.00		12.00
Total	98.89	7.97	98.93	7.97

**Experiment 2****Wet Fine Amphibolite GM-407**

	Grt-2.wa.2		Grt-2.wa.3		Grt-2.wa.4	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.37	1.16	11.62	1.29	17.57	1.92
Al <sub>2</sub> O <sub>3</sub>	22.76	2.02	22.92	2.01	11.19	0.96
SiO <sub>2</sub>	39.98	3.01	40.45	3.01	48.88	3.57
CaO	5.26	0.42	3.66	0.29	5.89	0.46
MnO	0.53	0.03	0.54	0.03	0.24	0.01
FeO	20.75	1.30	21.01	1.31	12.72	0.78
O		12.00		12.00		12.00
Total	99.64	7.95	100.20	7.94	96.49	7.71

### Experiment 3

#### Dry Fine Amphibolite GM-407

	Grt-3.da.1		Grt-3.da.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.53	1.19	10.27	1.16
Al <sub>2</sub> O <sub>3</sub>	22.72	2.03	22.30	2.00
SiO <sub>2</sub>	39.19	2.97	39.31	2.99
CaO	4.83	0.39	5.35	0.44
MnO	0.51	0.03	0.65	0.04
FeO	21.23	1.35	20.96	1.33
O		12.00		12.00
Total	99.01	7.97	98.84	7.97

	Opx-3.da.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.43	0.03
MgO	23.74	1.31
Al <sub>2</sub> O <sub>3</sub>	2.00	0.09
SiO <sub>2</sub>	52.79	1.96
CaO	0.49	0.02
TiO <sub>2</sub>	0.09	0.00
FeO	19.39	0.60
O		6.00
Total	98.92	4.01

	Hbl-3.da.1		Hbl-3.da.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.18	0.89	3.08	0.87
MgO	13.05	2.83	11.85	2.58
Al <sub>2</sub> O <sub>3</sub>	15.41	2.64	15.64	2.70
SiO <sub>2</sub>	41.94	6.09	42.87	6.27
K <sub>2</sub> O	0.91	0.17	0.83	0.16
CaO	11.63	1.81	10.85	1.70
TiO <sub>2</sub>	1.59	0.17	1.40	0.15
FeO	10.96	1.33	10.46	1.28
O		23.00		23.00
Total	98.69	15.94	96.98	15.72

### Experiment 3

#### Wet Fine Amphibolite GM-407

	Grt-3.wa.1		Grt-3.wa.2		Grt-3.wa.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.60	1.18	10.25	1.16	9.94	1.12
Al <sub>2</sub> O <sub>3</sub>	22.74	2.01	22.56	2.01	22.74	2.03
SiO <sub>2</sub>	39.50	2.96	39.27	2.98	39.35	2.97
CaO	5.85	0.47	5.76	0.47	5.92	0.48
MnO	0.48	0.03	0.56	0.04	0.52	0.03
FeO	21.50	1.35	21.11	1.34	21.24	1.34
O		12.00		12.00		12.00
Total	100.67	8.00	99.50	7.99	99.71	7.98

	Hbl-3.wa.1		Hbl-3.wa.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.00	0.87	2.83	0.79
MgO	13.00	2.89	13.82	2.96
Al <sub>2</sub> O <sub>3</sub>	15.06	2.65	15.88	2.69
SiO <sub>2</sub>	40.57	6.06	42.49	6.11
K <sub>2</sub> O	1.34	0.25	1.11	0.20
CaO	11.29	1.81	11.57	1.78
TiO <sub>2</sub>	1.60	0.18	1.06	0.11
FeO	10.22	1.28	10.49	1.26
O		23.00		23.00
Total	96.09	15.98	99.24	15.92

	Pl-3.wa.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	6.66	0.58
MgO	0.12	0.01
Al <sub>2</sub> O <sub>3</sub>	27.30	1.44
SiO <sub>2</sub>	57.04	2.55
CaO	9.06	0.43
O		8.00
Total	100.18	5.01

	Opx-3.wa.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.42	0.03
MgO	24.31	1.34
Al <sub>2</sub> O <sub>3</sub>	2.54	0.11
SiO <sub>2</sub>	52.65	1.95
CaO	0.60	0.02
FeO	17.32	0.54
O		6.00
Total	97.86	4.00

### Experiment 3

#### Dry Fine Meta-Gabbro: Coarse Area GM-307

Grt-3.dg.1		
	Compound %	Nos. of ions
MgO	9.49	1.09
Al <sub>2</sub> O <sub>3</sub>	22.16	2.01
SiO <sub>2</sub>	38.63	2.97
CaO	5.92	0.49
MnO	0.63	0.04
FeO	21.98	1.41
		12.00
Total	98.82	8.00

Opx-3.dg.1		
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.53	0.04
MgO	23.79	1.32
Al <sub>2</sub> O <sub>3</sub>	2.62	0.11
SiO <sub>2</sub>	52.42	1.95
CaO	0.74	0.03
TiO <sub>2</sub>	0.09	0.00
FeO	18.10	0.56
		6.00
Total	98.29	4.01

Hbl-3.dg.1		
	Compound %	Nos. of ions
Na <sub>2</sub> O	2.92	0.81
MgO	13.16	2.82
Al <sub>2</sub> O <sub>3</sub>	15.39	2.61
SiO <sub>2</sub>	42.57	6.12
K <sub>2</sub> O	1.51	0.28
CaO	11.50	1.77
TiO <sub>2</sub>	1.98	0.21
FeO	10.57	1.27
		23.00
Total	99.60	15.90

Pl-3.dg.1		
	Compound %	Nos. of ions
Na <sub>2</sub> O	6.43	0.56
Al <sub>2</sub> O <sub>3</sub>	27.01	1.43
SiO <sub>2</sub>	56.97	2.55
K <sub>2</sub> O	0.28	0.02
CaO	9.13	0.44
		8.00
Total	99.82	4.99

### Experiment 3

#### Dry Fine Meta-Gabbro Fine Area GM-307

Grt-3.dg.2		
	Compound %	Nos. of ions
MgO	9.66	1.08
Al <sub>2</sub> O <sub>3</sub>	22.11	1.95
SiO <sub>2</sub>	40.56	3.04
CaO	6.65	0.53
MnO	0.53	0.03
FeO	20.41	1.28
		12.00
Total	99.91	7.92

Opx-3.dg.2		
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.72	0.05
MgO	21.67	1.19
Al <sub>2</sub> O <sub>3</sub>	5.27	0.23
SiO <sub>2</sub>	50.39	1.86
CaO	2.97	0.12
TiO <sub>2</sub>	0.51	0.01
FeO	17.87	0.55
		6.00
Total	99.39	4.02

Hbl-3.dg.2		
	Compound %	Nos. of ions
Na <sub>2</sub> O	2.24	0.63
MgO	15.29	3.32
Al <sub>2</sub> O <sub>3</sub>	11.64	2.00
SiO <sub>2</sub>	44.83	6.53
K <sub>2</sub> O	0.94	0.17
CaO	7.96	1.24
TiO <sub>2</sub>	1.21	0.13
FeO	14.08	1.71
		23.00
Total	98.19	15.74

Pl-3.dg.2		
	Compound %	Nos. of ions
Na <sub>2</sub> O	6.86	0.61
MgO	0.82	0.06
Al <sub>2</sub> O <sub>3</sub>	25.29	1.36
SiO <sub>2</sub>	56.78	2.58
K <sub>2</sub> O	0.61	0.04
CaO	7.70	0.38
FeO	1.14	0.04
		8.00
Total	99.19	5.06



### Experiment 3

#### Wet Fine Meta-Gabbro GM-307

	Grt-3.wg.1		Grt-3.wg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.16	1.16	11.24	1.28
Al <sub>2</sub> O <sub>3</sub>	22.03	1.99	22.09	1.99
SiO <sub>2</sub>	39.01	2.99	39.12	2.99
CaO	3.71	0.30	3.58	0.29
MnO	0.59	0.04	0.59	0.04
FeO	23.20	1.49	22.05	1.41
		12.00		12.00
Total	98.69	7.98	98.66	8.00

	Hbl-3.wg.2	
	Compound %	Nos. of ions
Na <sub>2</sub> O	2.70	0.76
MgO	12.72	2.77
Al <sub>2</sub> O <sub>3</sub>	14.47	2.49
SiO <sub>2</sub>	43.31	6.32
K <sub>2</sub> O	0.81	0.15
CaO	10.70	1.67
TiO <sub>2</sub>	1.47	0.16
FeO	11.48	1.40
		23.00
Total	97.66	15.72

	Opx-3.wg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.52	0.04
MgO	23.31	1.29
Al <sub>2</sub> O <sub>3</sub>	2.14	0.09
SiO <sub>2</sub>	52.43	1.95
CaO	0.63	0.03
FeO	19.62	0.61
		6.00
Total	98.68	4.02

	Pl-3.wg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	5.06	0.45
MgO	0.11	0.01
Al <sub>2</sub> O <sub>3</sub>	29.45	1.59
SiO <sub>2</sub>	52.61	2.41
K <sub>2</sub> O	0.07	0.00
CaO	11.28	0.55
FeO	0.40	0.02
		8.00
Total	98.99	5.03

## Experiment 5

### Dry Fine Amphibolite GM-407

	Gr-5.da.1		Gr-5.da.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.85	1.20	10.39	1.17
Al <sub>2</sub> O <sub>3</sub>	23.02	2.01	22.54	2.01
SiO <sub>2</sub>	40.28	2.98	39.46	2.99
CaO	3.80	0.30	3.83	0.31
MnO	0.75	0.05	0.63	0.04
FeO	23.36	1.45	22.87	1.45
O		12.00		12.00
Total	102.06	7.99	99.72	7.97

	Pl-5.da.1		Pl-5.da.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	6.00	0.54	5.72	0.51
MgO	0.94	0.07	0.18	0.01
Al <sub>2</sub> O <sub>3</sub>	26.62	1.47	27.80	1.51
SiO <sub>2</sub>	52.65	2.46	54.19	2.49
K <sub>2</sub> O	0.21	0.01	0.11	0.01
CaO	9.15	0.46	9.61	0.47
FeO	1.97	0.08	0.25	0.01
O		8.00		8.00
Total	97.54	5.08	97.87	5.01

	Hbl-5.da.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	3.29	0.92
MgO	12.96	2.77
Al <sub>2</sub> O <sub>3</sub>	15.47	2.62
SiO <sub>2</sub>	42.44	6.09
K <sub>2</sub> O	1.19	0.22
CaO	11.80	1.81
TiO <sub>2</sub>	1.60	0.17
FeO	11.65	1.40
O		23.00
Total	100.39	15.99

## Experiment 5

### Wet Fine Amphibolite GM-407

Grt-5.wa.1		
	Compound %	Nos. of ions
MgO	10.74	1.21
Al <sub>2</sub> O <sub>3</sub>	22.41	2.00
SiO <sub>2</sub>	39.42	2.99
CaO	3.87	0.31
MnO	0.76	0.05
FeO	22.12	1.40
O		12.00
Total	99.32	7.97

	Hbl-5.wa.1		Hbl-5.wa.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.98	0.87	2.68	0.87
MgO	12.35	2.77	12.66	2.80
Al <sub>2</sub> O <sub>3</sub>	14.24	2.52	14.00	2.49
SiO <sub>2</sub>	40.52	6.09	40.34	6.19
K <sub>2</sub> O	1.18	0.23	0.62	0.18
CaO	11.15	1.80	9.62	1.70
TiO <sub>2</sub>	2.22	0.25	1.47	0.21
FeO	11.22	1.41	11.04	1.39
O		23.00		23.00
Total	95.85	15.93	92.42	15.84

## Experiment 5

### Dry Fine Meta-Gabbro GM-307

	Grt-5.dg.1		Grt-5.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	9.93	1.08	10.00	1.10
Al <sub>2</sub> O <sub>3</sub>	23.34	2.01	23.07	2.01
SiO <sub>2</sub>	40.89	2.99	40.52	3.00
CaO	6.07	0.48	6.04	0.48
MnO	0.56	0.03	0.68	0.04
FeO	22.99	1.41	21.99	1.36
O		12.00		12.00
Total	103.78	8.00	102.30	8.00

	Hbl-5.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	3.14	0.85
MgO	13.82	2.88
Al <sub>2</sub> O <sub>3</sub>	16.10	2.65
SiO <sub>2</sub>	43.46	6.07
K <sub>2</sub> O	1.29	0.23
CaO	11.88	1.78
TiO <sub>2</sub>	1.75	0.18
FeO	11.09	1.30
O		23.00
Total	102.53	15.94

	Pl-5.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	5.50	0.49
MgO	1.92	0.13
Al <sub>2</sub> O <sub>3</sub>	25.69	1.39
SiO <sub>2</sub>	53.95	2.48
K <sub>2</sub> O	0.27	0.02
CaO	9.54	0.47
FeO	2.34	0.09
O		8.00
Total	99.21	5.07

**Experiment 5**

**Wet Fine Meta-Gabbro GM-307**

	Grt-5.wg.1		Grt-5.wg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	10.05	1.11	10.86	1.17
Al <sub>2</sub> O <sub>3</sub>	22.85	1.99	22.75	1.94
SiO <sub>2</sub>	40.79	3.01	42.84	3.11
CaO	5.74	0.45	6.08	0.47
MnO	0.62	0.04	0.50	0.03
FeO	22.40	1.38	19.71	1.19
		12.00		12.00
Total	102.45	7.97	102.75	7.92

	Hbl-5.wg.1		Hbl-5.wg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.98	0.84	3.13	0.82
MgO	12.88	2.78	11.79	2.36
Al <sub>2</sub> O <sub>3</sub>	15.18	2.59	17.19	2.73
SiO <sub>2</sub>	42.52	6.15	49.97	6.72
K <sub>2</sub> O	1.34	0.25	0.80	0.14
CaO	11.33	1.76	8.25	1.19
TiO <sub>2</sub>	1.89	0.21	1.33	0.13
FeO	10.93	1.32	10.25	1.15
		23.00		23.00
Total	99.02	15.88	102.72	15.25

## Experiment 6

### Dry Fine Amphibolite GM-407

Grt-6.da.1		
	Compound %	Nos. of ions
MgO	10.31	1.20
Al <sub>2</sub> O <sub>3</sub>	21.68	2.00
SiO <sub>2</sub>	38.19	2.98
CaO	4.63	0.39
MnO	0.57	0.04
FeO	20.84	1.36
O		12.00
Total	96.84	8.05

Pl-6.da.1		Pl-6.da.2		
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.56	0.33	6.16	0.55
MgO	0.76	0.05	0.64	0.04
Al <sub>2</sub> O <sub>3</sub>	29.49	1.66	26.53	1.43
SiO <sub>2</sub>	47.60	2.27	55.45	2.53
K <sub>2</sub> O	0.27	0.02	0.25	0.01
CaO	12.67	0.65	8.44	0.41
FeO	1.69	0.07	1.19	0.05
O		8.00		8.00
Total	96.03	5.04	98.66	5.03

## Experiment6

### Wet Fine Amphibolite GM-407

Pl-6.wa.1		Pl-6.wa.2		
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	6.88	0.61	6.17	0.55
Al <sub>2</sub> O <sub>3</sub>	26.29	1.41	25.97	1.41
SiO <sub>2</sub>	56.66	2.58	54.39	2.51
K <sub>2</sub> O	0.28	0.02	0.12	0.01
CaO	8.03	0.39	9.07	0.45
O		8.00		8.00
Total	98.14	5.01	95.73	4.93

## Experiment 6

### Dry Fine Meta-Gabbro GM-307

	Grt-6.dg.1		Grt-6.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	9.35	1.03	10.31	1.11
Al <sub>2</sub> O <sub>3</sub>	23.27	2.02	22.09	1.87
SiO <sub>2</sub>	41.18	3.04	43.48	3.13
CaO	7.04	0.56	6.84	0.53
MnO	0.63	0.04	0.48	0.03
FeO	19.46	1.20	18.31	1.10
O		12.00		12.00
Total	100.92	7.89	101.51	7.77

	Opx-6.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.50	0.03
MgO	25.17	1.35
Al <sub>2</sub> O <sub>3</sub>	2.35	0.10
SiO <sub>2</sub>	53.96	1.94
CaO	0.55	0.02
FeO	19.28	0.58
O		6.00
Total	101.81	4.02

	Hbl-6.dg.1		Hbl-6.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.28	0.86	2.67	0.74
MgO	9.46	1.90	12.97	2.76
Al <sub>2</sub> O <sub>3</sub>	21.00	3.34	15.85	2.67
SiO <sub>2</sub>	48.47	6.54	41.78	5.97
K <sub>2</sub> O	0.35	0.06	3.14	0.57
CaO	9.62	1.39	9.04	1.38
TiO <sub>2</sub>	0.17	0.02	3.68	0.39
FeO	9.71	1.10	12.32	1.47
O		23.00		23.00
Total	102.05	15.21	101.46	15.96

## Experiment 6

### Wet Fine Meta-Gabbro GM-307

	Hbl-6.wg.1		Hbl-6.wg.2		Hbl-6.wg.3		Hbl-6.wg.4	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na2O	3.41	0.95	3.22	0.91	2.40	0.67	2.52	0.71
MgO	12.87	2.75	11.92	2.59	13.28	2.87	13.95	3.03
Al2O3	14.97	2.53	15.90	2.73	13.93	2.38	13.79	2.36
SiO2	42.47	6.09	40.91	5.96	43.81	6.35	44.32	6.45
K2O	1.26	0.23	1.25	0.23	0.80	0.15	0.49	0.09
CaO	11.20	1.72	11.21	1.75	9.96	1.55	8.16	1.27
TiO2	3.06	0.33	3.14	0.34	1.30	0.14	0.62	0.07
FeO	10.93	1.31	11.48	1.40	13.15	1.59	13.87	1.69
O		23.00		23.00		23.00		23.00
Total	100.18	15.90	99.02	15.90	98.64	15.71	97.72	15.68

	Opx-6.wg.1		Opx-6.wg.1a		Opx-6.wg.2		Opx-6.wg.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na2O	0.70	0.05	0.94	0.07	1.08	0.08	0.43	0.03
MgO	23.51	1.23	22.07	1.20	19.22	1.05	23.91	1.33
Al2O3	5.08	0.21	5.45	0.23	8.43	0.36	2.31	0.10
SiO2	54.86	1.93	52.08	1.90	51.02	1.87	52.23	1.95
CaO	1.15	0.04	2.06	0.08	3.70	0.15	0.32	0.01
FeO	17.17	0.51	16.65	0.51	14.97	0.46	18.87	0.59
O		6.00		6.00		6.00		6.00
Total	102.48	3.97	99.25	4.00	98.43	3.97	98.06	4.01



## Experiment 7

### Dry Fine Amphibolite GM-407

	Grt-7.da.1		Grt-7.da.2		Grt-7.da.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	11.23	1.28	10.85	1.21	11.45	1.26
Al <sub>2</sub> O <sub>3</sub>	22.33	2.02	23.12	2.04	22.92	1.99
SiO <sub>2</sub>	38.89	2.98	39.88	2.98	41.30	3.05
CaO	3.66	0.30	3.74	0.30	4.04	0.32
MnO	0.51	0.03	0.71	0.05	0.47	0.03
FeO	21.32	1.37	22.35	1.40	20.95	1.29
O		12.00		12.00		12.00
Total	97.94	7.98	100.66	7.97	101.14	7.94

	Ol-7.da.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.66	0.03
MgO	27.81	1.14
Al <sub>2</sub> O <sub>3</sub>	0.57	0.02
SiO <sub>2</sub>	37.85	1.04
FeO	31.09	0.71
O		4.00
Total	97.99	2.95

	Hbl-7.da.1		Hbl-7.da.2		Hbl-7.da.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.24	0.92	2.75	0.78	3.21	0.90
MgO	12.72	2.78	13.22	2.86	13.44	2.89
Al <sub>2</sub> O <sub>3</sub>	15.47	2.68	14.41	2.47	14.63	2.49
SiO <sub>2</sub>	41.44	6.08	43.05	6.26	43.28	6.24
K <sub>2</sub> O	0.92	0.17	0.89	0.17	0.86	0.16
CaO	11.32	1.78	10.06	1.57	11.21	1.73
TiO <sub>2</sub>	1.54	0.17	1.63	0.18	1.42	0.15
FeO	11.12	1.37	12.33	1.50	11.19	1.35
O		23.00		23.00		23.00
Total	97.77	15.95	98.35	15.78	99.23	15.89

	Opx-7.da.2	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.54	0.04
MgO	23.16	1.30
Al <sub>2</sub> O <sub>3</sub>	2.34	0.10
SiO <sub>2</sub>	51.57	1.95
CaO	0.45	0.02
FeO	19.05	0.60
O		6
Total	97.10	4.02

## Experiment 7

### Wet Fine Amphibolite GM-407

	Grt-7.wa.1		Grt-7.wa.2		Grt-7.wa.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	11.168	1.238	11.513	1.269	11.07	1.23
Al <sub>2</sub> O <sub>3</sub>	22.898	2.007	22.763	1.984	22.88	2.02
SiO <sub>2</sub>	40.415	3.006	40.712	3.010	40.03	3.00
CaO	3.976	0.317	4.056	0.321	3.95	0.32
MnO	0.556	0.035	0.633	0.040	0.56	0.04
FeO	22.081	1.373	22.221	1.374	22.21	1.39
O		12		12.000		12.00
Total	101.094	7.976	101.898	7.998	100.69	7.99

	Hbl-7.wa.1		Hbl-7.wa.2		Hbl-7.wa.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.24	0.90	2.84	0.79	2.66	0.72
MgO	13.13	2.80	14.51	3.09	15.56	3.26
Al <sub>2</sub> O <sub>3</sub>	15.91	2.68	15.91	2.68	17.30	2.87
SiO <sub>2</sub>	42.74	6.12	43.82	6.26	45.08	6.34
K <sub>2</sub> O	0.95	0.17	0.38	0.07	0.09	0.02
CaO	11.23	1.72	8.44	1.29	3.74	0.56
TiO <sub>2</sub>	1.49	0.16	0.58	0.06	0.33	0.03
FeO	11.23	1.34	12.79	1.53	14.67	1.73
O		23.00		23.00		23.00
Total	99.92	15.91	99.28	15.76	99.41	15.54

	Pl-7.wa.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	4.84	0.42
Al <sub>2</sub> O <sub>3</sub>	30.40	1.60
SiO <sub>2</sub>	53.48	2.40
CaO	11.98	0.57
O		8.00
Total	100.70	5.00

## Experiment 7

### Dry Fine Meta-Gabbro GM-307

	Grt-7.dg.1		Grt-7.dg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	8.87	0.97	10.69	1.18
Al <sub>2</sub> O <sub>3</sub>	23.45	2.02	23.01	2.01
SiO <sub>2</sub>	42.73	3.13	40.26	2.99
CaO	6.48	0.51	5.90	0.47
MnO	0.51	0.03	0.58	0.04
FeO	19.68	1.20	20.47	1.27
O		12.00		12.00
Total	101.71	19.86	100.91	19.97

	Ol-7.dg.1	
	Compound %	Nos. of ions
Na <sub>2</sub> O	0.93	0.05
MgO	26.83	1.06
Al <sub>2</sub> O <sub>3</sub>	2.86	0.09
SiO <sub>2</sub>	38.56	1.02
CaO	1.81	0.05
FeO	29.65	0.66
O		4.00
Total	100.65	2.93

### Fine Area

	Hbl-7.dg.1		Hbl-7.dg.2		Hbl-7.dg.3	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.85	0.79	3.07	0.85	3.33	0.91
MgO	13.53	2.90	13.67	2.92	10.49	2.20
Al <sub>2</sub> O <sub>3</sub>	14.72	2.49	15.92	2.69	17.95	2.97
SiO <sub>2</sub>	43.08	6.18	42.90	6.15	45.73	6.42
K <sub>2</sub> O	1.19	0.22	1.20	0.22	0.79	0.14
CaO	10.50	1.61	11.21	1.72	10.35	1.56
TiO <sub>2</sub>	1.92	0.21	1.37	0.15	1.60	0.17
FeO	12.05	1.45	10.03	1.20	9.21	1.08
O		23.00		23.00		23.00
Total	99.83	15.85	99.38	15.90	99.44	15.45

### Coarse Area

	Hbl-7.dg.4		Hbl-7.dg.5	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	2.74	0.78	2.99	0.85
MgO	12.59	2.76	13.09	2.86
Al <sub>2</sub> O <sub>3</sub>	14.98	2.60	15.51	2.68
SiO <sub>2</sub>	41.73	6.15	41.31	6.06
K <sub>2</sub> O	1.34	0.25	1.46	0.27
CaO	11.09	1.75	11.14	1.75
TiO <sub>2</sub>	1.66	0.18	1.63	0.18
FeO	11.34	1.40	10.62	1.30
O		23.00		23.00
Total	97.48	15.88	97.75	15.97

## Experiment 7

### Wet Fine Meta-Gabbro GM-307

#### Coarse Area

	Grt-7.wg.1		Grt-7.wg.2	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	9.96	1.12	9.51	1.09
Al <sub>2</sub> O <sub>3</sub>	22.54	2.01	22.01	1.99
SiO <sub>2</sub>	39.72	3.00	39.52	3.03
CaO	6.12	0.50	5.53	0.45
MnO	0.55	0.03	0.70	0.05
FeO	20.87	1.32	20.69	1.33
O		12.00		12.00
Total	99.75	7.98	97.96	7.93

	Hbl-7.wg.1		Hbl-7.wg.2		Hbl-7.wg.3		Hbl-7.wg.4	
	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.28	0.93	2.90	0.82	3.05	0.86	2.54	0.71
MgO	12.32	2.68	13.40	2.91	13.29	2.87	13.13	2.81
Al <sub>2</sub> O <sub>3</sub>	15.79	2.71	14.91	2.56	15.76	2.69	15.12	2.56
SiO <sub>2</sub>	41.11	6.00	42.06	6.12	41.63	6.03	43.45	6.24
K <sub>2</sub> O	1.19	0.22	1.32	0.25	1.43	0.26	1.11	0.20
CaO	11.21	1.75	11.30	1.76	11.26	1.75	10.81	1.66
TiO <sub>2</sub>	2.66	0.29	1.81	0.20	2.03	0.22	1.61	0.17
FeO	11.10	1.35	10.87	1.32	10.55	1.28	11.52	1.38
O		23.00		23.00		23.00		23.00
Total	98.67	15.93	98.58	15.93	98.99	15.97	99.29	15.75

#### Fine Area

	Grt-7.wg.3		Grt-7.wg.4	
	Compound %	Nos. of ions	Compound %	Nos. of ions
MgO	9.92	1.08	9.89	1.06
Al <sub>2</sub> O <sub>3</sub>	22.31	1.93	23.06	1.96
SiO <sub>2</sub>	42.61	3.13	43.78	3.15
CaO	6.16	0.48	6.11	0.47
MnO	0.48	0.03	0.52	0.03
FeO	19.19	1.18	18.40	1.11
O		12.00		12.00
Total	100.67	7.84	101.76	7.78

	Hbl-7.wg.5		Hbl-7.wg.6	
	Compound %	Nos. of ions	Compound %	Nos. of ions
Na <sub>2</sub> O	3.04	0.85	2.56	0.72
MgO	13.21	2.85	13.30	2.86
Al <sub>2</sub> O <sub>3</sub>	15.35	2.61	15.01	2.55
SiO <sub>2</sub>	42.80	6.18	43.29	6.25
K <sub>2</sub> O	1.04	0.19	1.30	0.24
CaO	10.53	1.63	10.69	1.65
TiO <sub>2</sub>	1.68	0.18	1.25	0.14
FeO	11.14	1.35	11.64	1.40
O		23.00		23.00
Total	98.78	15.84	99.03	15.81