GEOCHEMICAL AND PETROGRAPHIC ANALYSIS OF GORE MOUNTAIN GARNETS, ADIRONDACKS NY

By

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Submitted in partial fulfillment
of the requirements of the degree of
Bachelor of Science
Department of Geology

UNION COLLEGE

May, 2011

ABSTRACT

The mine at Gore Mountain is famous for its giant garnets and long history of garnet abrasive production. This location, Warrensburg (Wall St.), and others were examined to attempt to better understand the petrogenesis of these remarkable rocks. Our studies have emphasized the geochemistry of bulk rocks and rock and mineral separates (122 analyses), thin section petrology, and thermodynamic modeling of mineral assemblages. At Gore Mtn. the ore has the assemblage hornblende-plagioclase-garnet-OPX-biotite, and formed over a ~2 m thick transition zone from a layered olivine corona gabbro, metamorphosed at granulite facies. Petrographically the delicate corona structures and fine-grained garnets were replaced by hornblende and progressively larger garnets across the transition zone, indicating that the small number of large garnets in the ore resulted from growth driven by surface energy reduction rather than low nucleation rate. That chemical components must have rapidly migrated through the rock volume via a fluid phase seems obvious. The transition zone is compositionally the same as the gabbro in most cases, except addition of water to form hornblende. However, in the ore there are highly variable trace element composition differences compared to the gabbro. There is also a subtle, variable, loss of LREE relative to HREE. This suggests strongly channelized fluid flow. The situation at Warrensburg is not so clear because gabbro-garnet amphibolite contacts are not exposed. The big garnet rock and nearby corona gabbro have more evolved magmatic compositions than the Gore Mtn. rocks, and the chemical changes are less extreme and different. This may indicate more homogeneous fluid flow and a somewhat different fluid composition. Regional granulite facies metamorphism has been reported at ~750°C and ~8 kbar. New thermodynamic modeling indicates that Gore Mtn. ore formation took place at ~750°C and 4.5-5 kbar, in the presence of silicate melt and hydrous fluid, indicating isothermal uplift followed by fluid infiltration.

DEDICATION

This thesis, my culmination of all the knowledge that I have acquired through the thoughtful guidance of my professors and mentors, is dedicated to a future geologist, perhaps still unborn. The world we live in should be cherished and taken care of and I believe that students who envelop themselves in the earth sciences are the people who truly understand global processes and the time frame in which those awe inspiring parts interact.

ACKNOWLEDGEMENTS

I would like first and foremost to thank my entire family, especially my parents and sister. Without their love and support, completing my undergraduate studies would have been inconceivable. For their unconditional love, I thank them.

To all the members of the 2010-2011 Geology Department (John Garver, Don Rodbell, Holli Frey, Matt Mannon, Dave Gillikin, Deb Klein, Bill Neubeck, George Shaw, Robert Finks, Robert Fleischer and Anouk Verheyden-Gillikin) you have all taught me lessons that I will surely never forget; A special thanks to Kurt Hollocher, my thesis advisor and project manager – thank you for believing in my ability to be a hard-rock, high-grade metamorphism geologist. You fostered this research with never-ending amounts of insight and support

And last, but certainly not least, a thank-you to Bonnie Barton and the tour operations at the Barton Mines for all their assistance in obtaining samples from the various pits.

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INTRODUCTION

Northern New York State is marked with rugged mountains, the highest being Mt. Marcy at an elevation of 1629 m. Formerly known as the Peruvian Mountains, the area was formally named the Adirondacks in 1838 (Ciurca, 1962), and are located in Upstate New York between the St. Lawrence Valley in the north and the Mohawk valley in the south (Fig. 1). In 1892 the state legislature created the Adirondack State Park, which today has grown to more than 5 million acres of public land, making it the largest U.S. state or national park outside of Alaska (Jaffe, 1986).

The Adirondack Mountains are a regionally elevated exposure of the Grenville age mid-Proterozoic high-grade metamorphic rocks. The area is regarded as one of the great mineralogical regions of the earth, and a variety of both ferrous and non-ferrous ores are found within its region (Ciurca, 1962, Presnell, 1981). The Adirondack rocks consist of a wide variety of plutonic and sedimentary rocks metamorphosed to upper amphibolite and granulite facies. The highest grade rocks comprise the central and eastern portions of the massif (Roden-Tice, 2002). The areas of study in this research focus on the Wall St. outcrop in Warrensburg, at New York State's I-87 exit 23, and the Old Barton Mine, located on the north side of Gore Mountain, North River, NY (Fig. 2). The goal of this study is to conduct a comparative analysis of two examples of transformation of corona gabbro to large garnet-bearing amphibolites.

The summit of Gore Mountain is at 1,090 m, and the garnet mine occurs at elevations of roughly 790 m on the northwest side of the Mountain (Ciurca, 1962). The garnets found at in this location have long been one of the puzzling problems of Adirondack petrology (Levin 1948). There are four well-known deposits of garnets in the area: Gore Mountain, Warrensburg, Hooper Mine, and Ruby Mountain. Ruby Mountain is still an active mine where industrial garnets are processed. The industrial-grade garnet has many uses, such as a sand-blasting, water jet cutting, and glass grinding and polishing. Garnet sand paper is favored by cabinetmakers for finishing bare wood and in some cases garnet sand is used for water filtration (Britannica, 2010). The Barton deposit on Gore Mountain is the most petrologically interesting and best-studied among the several local concentrations of garnets. The deposit is widely known for its impressive, large, red garnet crystals, some of which had diameters up to ~0.9 m, though

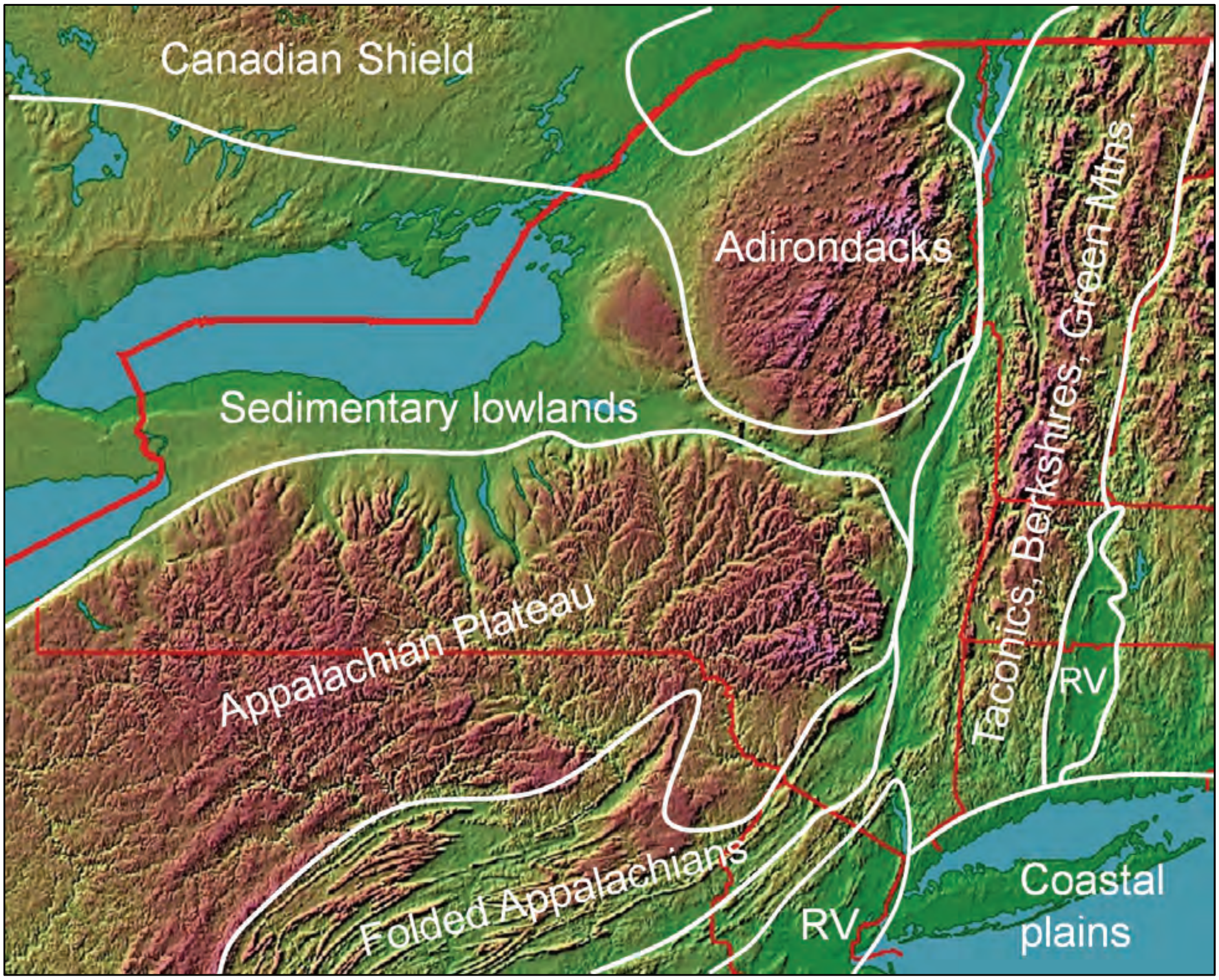

Figure 1. Location of the Adirondack Mountains in relation to other notable geologic provinces. RV stands for the sedimentary and volcanic rocks Mesozoic rift basins. Yellow Star indicates general location for study site. Taken from Hollocher, 2007.

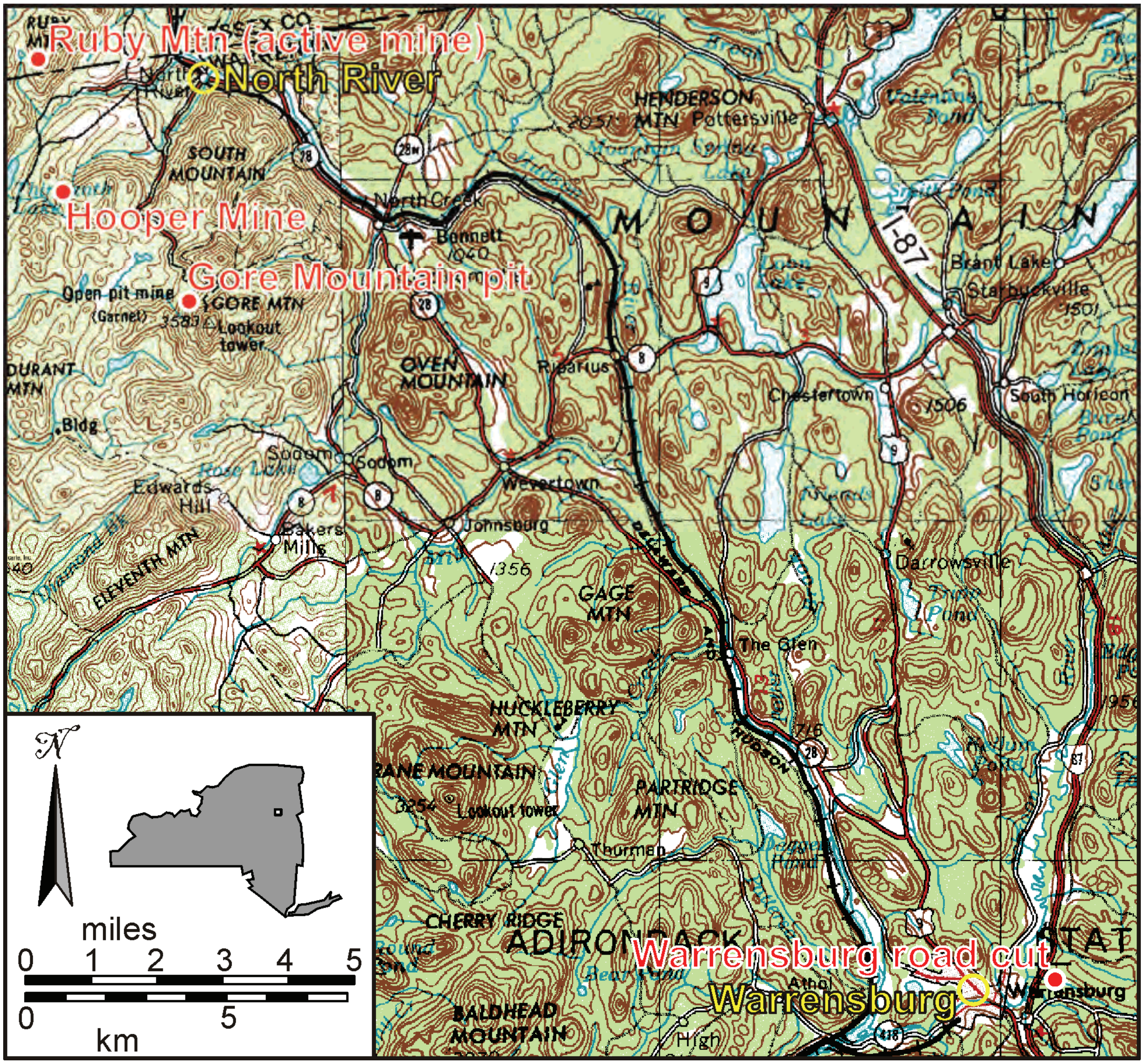

Figure 2., Map of the field areas in the Adirondack Mountains in Upstate N.Y. The small white square on grey state of N.Y. is the location of this map. Adapted from Hollocher et al. (2008).

the largest diameters now exposed are up to about 0.2 m. This mine was once home to the world's largest source of abrasive garnet (Levin, 1950). The garnets located at the mine were first used in the sandpaper industry by Mr. Henry Hudson Barton in the mid 1850's (DiFilippo, 1998). The Barton's history and development, and fabulous exposures made by mining operations, played a crucial role in fueling the interests of researchers to uncover the origin of the garnets (Fig. 3).

GEOLOGIC SETTING

The Adirondacks are a peninsula of the great Canadian or Laurentian Shield, surrounded by flat-lying sedimentary rocks of New York State and southern Canada (Fig. 4). While the Adirondacks contain Precambrian (Grenvillian) rocks that are exposed more widely in Canada, they also are exposed in the Green and Berkshire Mountains of western New England, extend along the Appalachians in the Blue Ridge, reappear in the Llano uplift in Texas, and are even found in northern Mexico (Davis, 1970).

The Adirondack region is approximately 200 km in diameter, and was elevated most recently as highlands as a result of the ~2 km uplift that affected the whole North American eastern seaboard as recently as 30-40 million years ago (Beavan, 1994). As far as it is known, all of the rocks within the Adirondacks are meso-Proterozoic and all were metamorphosed during that period as well. The nature and time sequence of intrusions and deformation in the Adirondack area are pertinent to the understanding of the metamorphism of the rocks in that region (Buddington, 1952). Figure 5 shows a time line of tectonic activity, deformation, metamorphism, and igneous activity that influenced and ultimately produced the study areas. The Grenville Province was assembled in a complex series of events summarized in Figure 5 during arc accretion (ca. 1.39-1.21 Ga) and continental collision (ca. 1.09-1.03 Ga) histories of the southeastern Laurentian margin (Bickford et al, 2008). The geologic times of most importance are as follows: in the Elzevirian (1.3 Ga) arc tonalities (oldest known rocks in the Adirondacks) were formed, followed by arc collision and deformation. Heating and melts from the mantle, and unroofing of the Shawinigan orogenic belt resulted in formation of magmas of the AMCG suite (Anorthosite, Mangerite, Charnocktie, Granite), which includes mantle-derived gabbroic magmas and anorthosite and ferro-gabbro differentiation products, and crustal melts including granites and

Figure 3: (above) Image of the Barton Mine in operation--Circa 1920, (below) Image of workers from the Barton Mine--Circa 1900. All images courtesy of the Adirondack Museum at Blue Mountain Lake, New York.

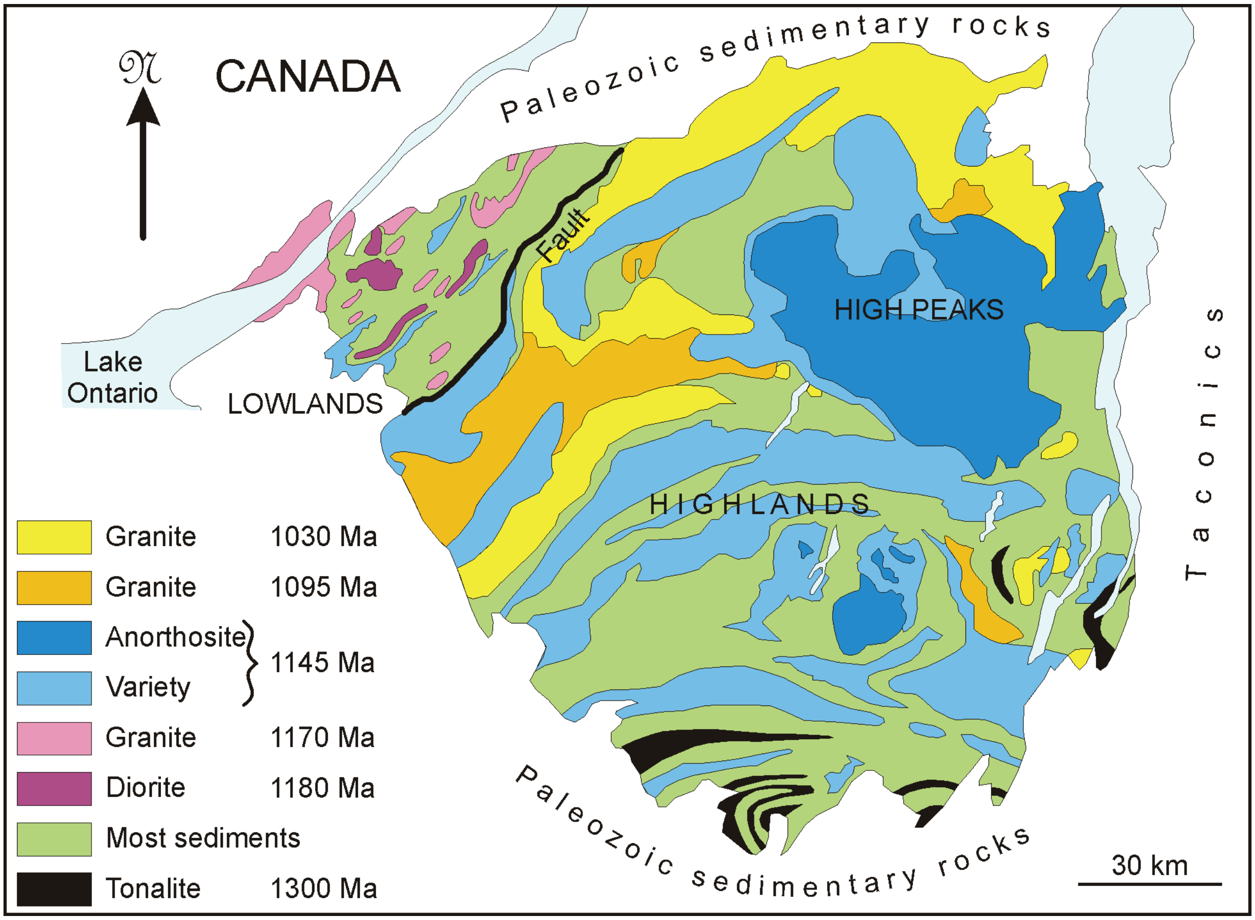

Figure 4., Locations within the Adirondacks of major plutonic rock units in New York. Blue star indicates general location for study site. A from Jaffe et al. (1986).

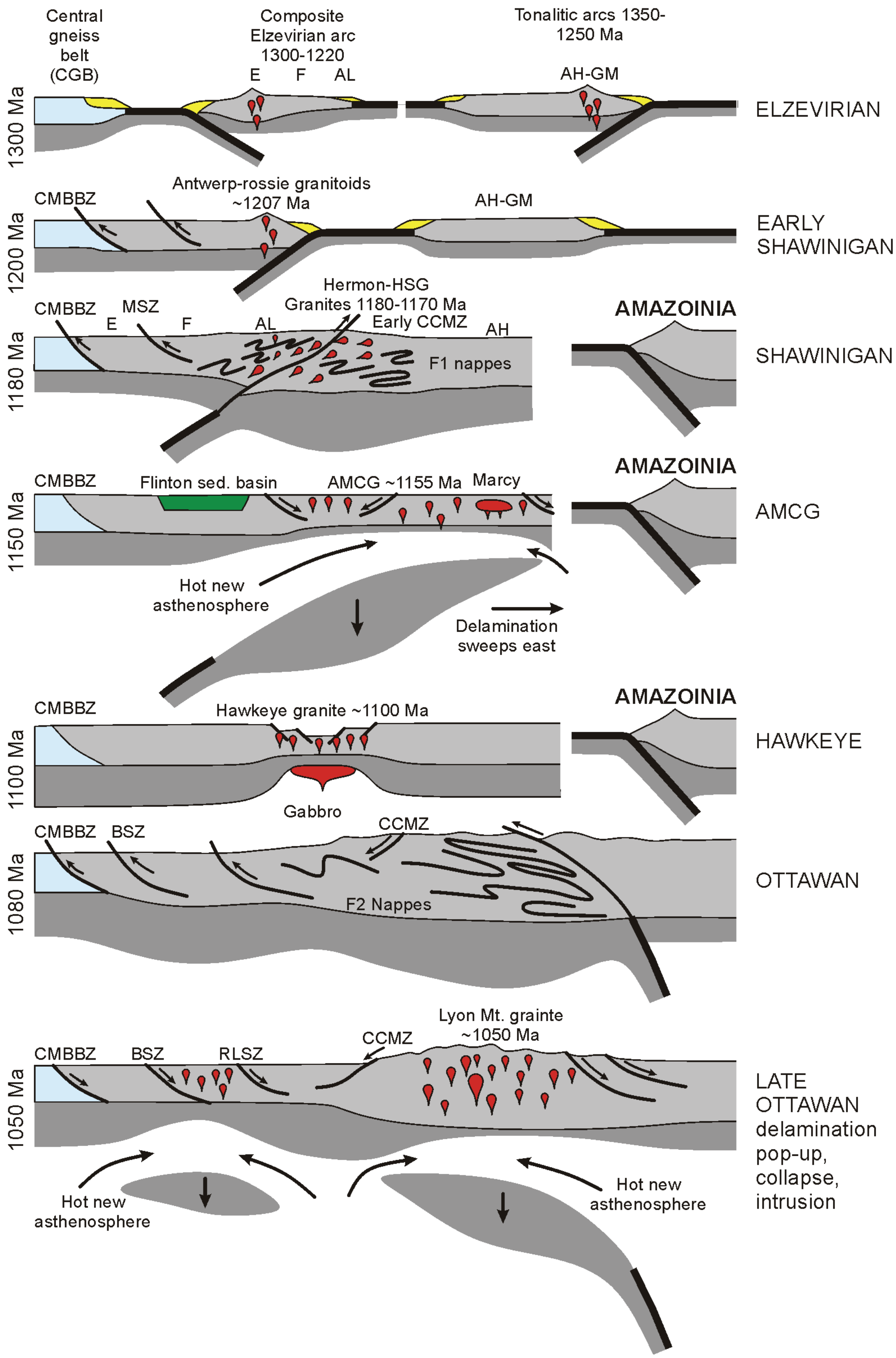

Figure 5. A summary of the tectonic activity that led to assembly of the Adirondack region. Abbreviations as follows: CGB, Central Granulite Belt; E, Elzevir terrane; F, Frontenac terrane; AL, Adirondack Lowlands: AH-GM, Adirondack Highlands-Green Mountains; CMBBZ, Central Meta-sedimentary Belt boundary zone; MSZ, Maberly shear zone; CGMZ, Carthage-Colton mylonite zone; HSG, Hyde School Gneiss, AMCG, (gabbro)-anorthosite-mangerite-charnockite-granite magmatic suite; BSZ, Bancroft shear zone; RLSZ, Robertson Lake shear zone. Modified after Heumann et al, 2006.

charnockites. Lastly in the Ottawan, the rocks underwent extreme metamorphism when Amazoinia collided with the granulite facies. This then allowed for the delamination, pop-up, orogenic collapse, melting, and intrusion that occurred in the Late Ottawan, ultimately involved in forming the large-garnet amphibolites.

Olivine gabbro is an abundant rock type in the Adirondack AMCG suite. These plutons have an inferred age of 1155 Ma (age of structurally and magmatically related rocks), and are thought to be examples of the mantle-derived mafic magmas that were the parental magmas for the anorthosite (A) and supplied heat for crustal melting (MCG). The gabbros are now commonly called corona gabbros, as a result of granulite facies metamorphic reaction rim textures on olivine and titanian magnetite (see below). Both single and multigrain U/Pb zircon thermal ionization mass spectrometry (TIMS) as well as sensitive high resolution ion microprobe (SHRIMP II) dating of two suites of the Adirondack granites has yielded ages constraining the principal tectonomagmatic events of the Ottawan Orogeny to the interval circa 1.09-1.035 Ga (McLelland et al 2001; Bickford et al, 2008). It is believed that the coronas are the result of Ottawan (1080-1050 Ma) granulite facies metamorphism that occurred under dry conditions during crustal thickening associated with continent-continent collision (McClelland and Wong, 2008). The estimated conditions of metamorphism are approximately 750° to 800°C and near 8 kbar (McClelland and Wong, 2008).

Gore Mountain

The granulite facies corona gabbro is a massive, layered rock that is contains an oriented plagioclase primary magmatic foliation, but essentially no metamorphic foliation. It is apparent that the garnet amphibolite in this location is derived from the corona gabbro because of the cumulate layering extending from the corona gabbro into the garnet ore. The large garnets are commonly 20 cm in diameter, and in the central and western part of the ore body they are usually surrounded by a thick hornblendite rims and are set in an orthopyroxene-bearing amphibolite matrix (Fig. 6). These garnets are commonly associated with irregularly shaped, comparatively small, coarse-grained zones that have been informally interpreted to be either crystallized partial melts or related to partial melt grain boundary films (Hollocher, 2008). The mineralogy of the coarse zones is identical to the rest of the rock. Most garnets


Figure 6. Large garnet crystals with thin hornblendite rimming structure. Barton Mine Pit #4.

are surrounded by subtle to obvious 0.5-3 mm thick plagioclase-orthopyroxene-hornblende±biotite symplectite rims. In the garnet amphibolite, the red garnets, each surrounded by the black hornblendite rim, are embedded in the grey amphibolite matrix gives a striking display on the walls of the extensive mine pits (Figs. 7, 8). The transition zone thicknesses are only a few meters, and involve change from corona gabbro to the large-garnett amphibolite ore. There have been petrologic studies (Buddington, 1939, 1952; Bartholome, 1956, 1960; Luther 1976; Bickford et al, 2008) that promote and support the concept that the growth of the large garnets is related to a localized influx of water at the margin of the corona gabbro body during amphibolite facies metamorphism (Kelly and Peterson, 1993). In continuing the research of the Gore Mountain and surrounding area garnets, it is important to state that, still to this day, the formation of the garnets is not completely understood.

Warrensburg

Corona gabbro is well exposed on the northbound 1-87 exit Ramp in Warrensburg. The fresh metagabbro there consists of green, blocky, interlocking plagioclase crystals that preserve the primary igneous texture. The visible black patches are coronas around magnetite and the pink patches are coronas around olivine (Figure 9). Clinopyroxene-bearing pegmatites cut the corona gabbro in this outcrop. These pegmatites have in fact caused some hydration to the corona gabbro in their proximity, however, this is only within 0.5-1 m of the dikes. Also, this process produced amphibolites with garnets only ~1 mm in size

Work on the big-garnet outcrop on Wall St. in Warrensburg (Fig. 10) has been performed by many researchers over the past years. Unofficially known as the “Poor Man’s Gore Mountain” (Selleck, 2008; McLelland and Wong 2008), the dark rock found at this outcrop is thought to be derived from the corona gabbro on the exit ramp on the basis of almost identical chemical composition (Morgan, 2011; Hollocher, 2011). In the garnet amphibolite, like at Gore Mtn., dominant minerals include hornblende, plagioclase, quartz, biotite, orthopyroxene, and garnet. It can be ascertained that the garnet amphibolite at this location was derived from the corona gabbro under upper amphibolite facies conditions during an influx of aqueous fluids, like the garnet amphibolite at Gore Mtn. (Hollocher, 2008).

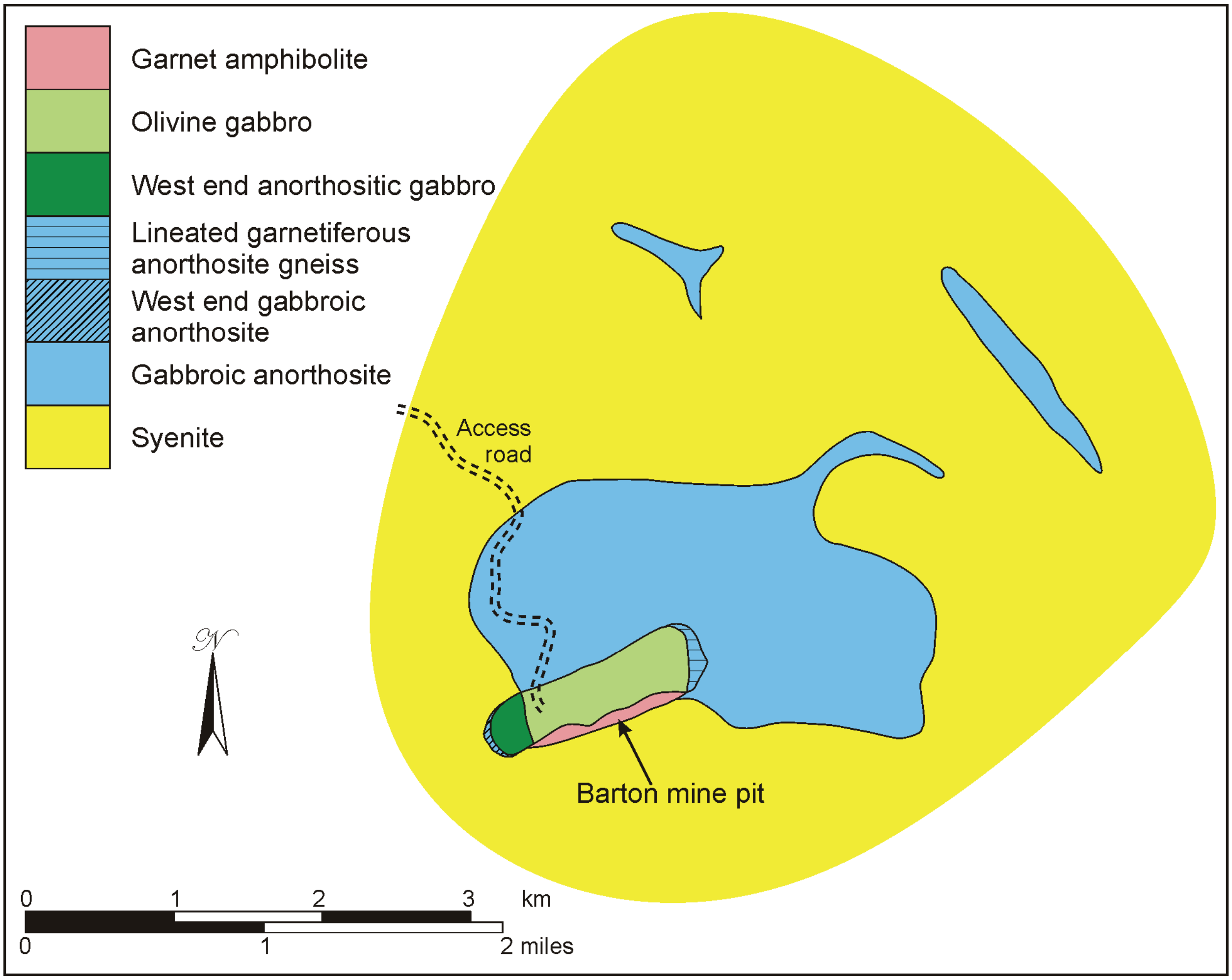

Figure 7. Geologic map of the Barton mine area on Gore Mountain, modified after the map of Luther (1976) and discussion of the structure by Sharga (1986).

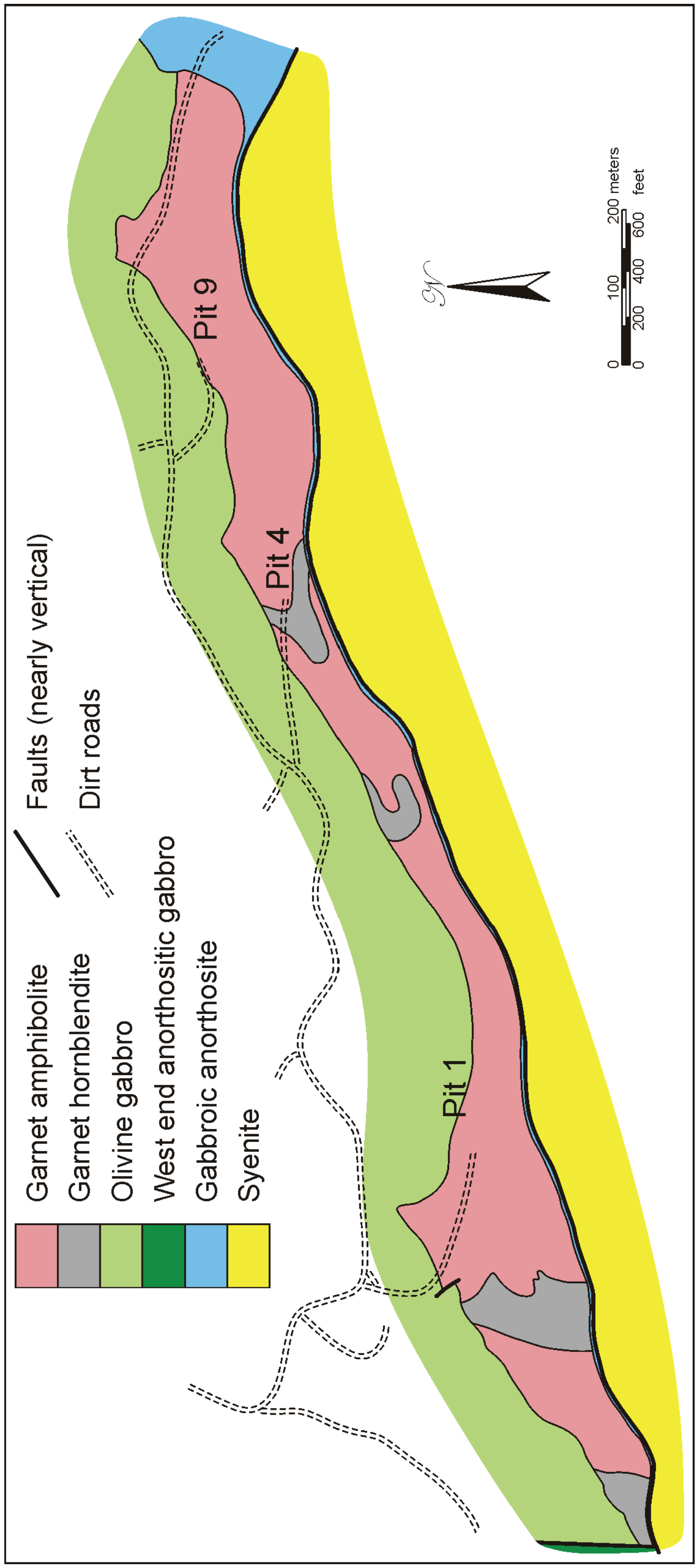

Figure 8. Geologic map of the region around the Barton Mine pit, modified after Luther (1976b).

Figure 9. Example of corona gabbro at an outcrop on the northbound Warrensburg exit ramp of I-87. Finger for scale.

Figure 10. Big garnet amphibolite, Warrensburg, Wall St. outcrop. Dark hornblendite rims are by-products of the garnet-forming reaction. Coarse zones of plagioclase, orthopyroxene, hornblende, and biotite (highlighted by irregular patches of plagioclase) may be the locations of former partial melt.

This Wall St. outcrop (Fig. 11) is a coarse-grained hornblende-plagioclase-biotite-orthopyroxene-ilmenite amphibolite with large garnets occurring mostly in coarse patches that also contain extra-large versions of other minerals (i.e. plagioclase). The garnets have diameters of up to ~0.1 m and are found throughout the outcrop but are most visible on the glacially polished low outcrop surface on the west side of Wall St. (Fig. 11). Looking at the big garnet amphibolite, the garnets are almost entirely in elongated coarse zones also containing coarse plagioclase, OPX, hornblende and biotite.

A section on the northern part of the outcrop, on the east side of the Warrensburg, Wall St. outcrop consists of tonalite gneiss, which is separated from the amphibolite by two pegmatite dikes (Fig. 11).

OBJECTIVES

The large-garnet bearing rocks at Gore Mountain and Warrensburg were derived from their olivine (corona) gabbro parent rocks. In addition to the water necessary to convert dry corona gabbro to garnet amphibolite, there may have been other chemical changes. We collected samples in a series of traverses in hopes of seeing a clear progression of geochemical change from corona gabbro into the garnet ore (Gore Mtn.) and along the garnet amphibolite outcrop toward possible fluid sources (pegmatites and a fault; Warrensburg). This research therefore focuses on the transition from corona gabbro to large-garnet bearing amphibolite as observed three traverses at the Gore Mountain, Barton Mine (Figs 12, 13, 14) location. At the Warrensburg site the research is be focused on two traverses: one is a corona gabbro to the amphibolite matrix, and the other is from the amphibolite matrix to the northern fault contact with white pegmatite and migmatitic tonalitc and granitic gneiss. Looking at the petrology and geochemistry of rocks along these transects will shed light on the century-long question of deciphering how the magnificent garnets formed. Although the petrology of the garnet amphibolite on Gore Mountain has been studied by many previous investigators, a reexamination was carried out for the purposes of: (1) to better understand the conditions present at the time of garnet growth, (2) to evaluate differences between the two locations that seemingly underwent a similar metamorphic process, and (3) to better understand fluid flow and the nature of chemical alteration using major and trace elements.

Figure 11. Composite photograph of the Wall St. outcrop. The larger bolded numbers (1, 2, 3, 4, and 5) represent samples collected in 2008, smaller numbers represent samples collected for this study.

Figure 12. Composite photograph of the Gore Mountain, Pit 4, traverse. Sample locations are labeled.

Figure 13. Composite photograph of a traverse at the Gore Mountain, Pit 4. Sample locations are labeled (Liz Morgan for scale).

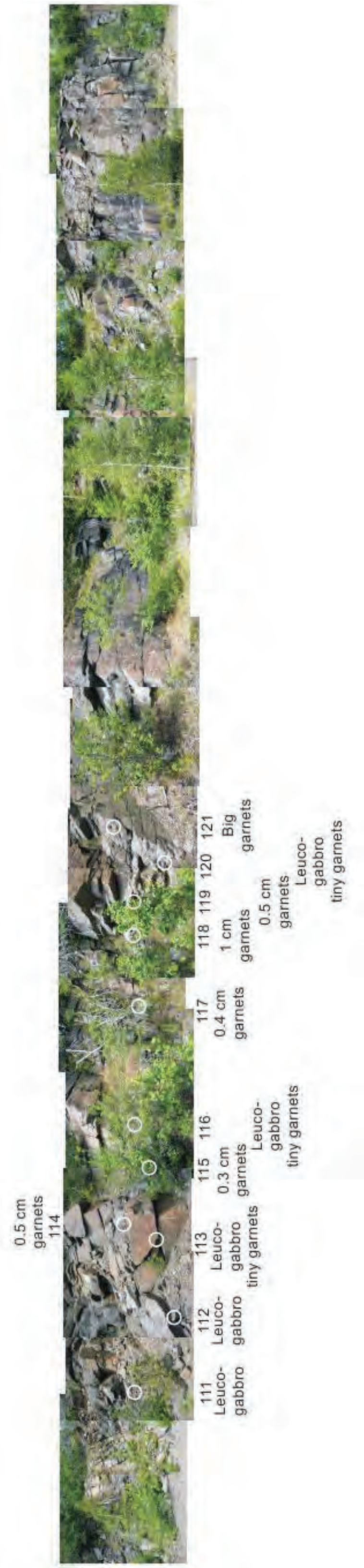

Figure 14. Composite photograph of a traverse at the Gore Mountain, Pit 9. Sample locations are labeled. Omit caption on the image itself.

METHODS

Field Methods – Sample Collection

Two days in early August were set aside for travelling up N.Y. State I-87 to collect rock specimens. All were numbered in order of collection with prefixes indicating collecting locality. In total, there were 57 individual rock samples collected total for both localities, which were processed for mineral separates and bulk chemical analyses.

On the first day, samples were taken from two outcrops in Warrensburg, N.Y. The rocks were taken from a road cut in corona gabbro just south of northbound Exit 23 (Warrensburg) on I-87 and from an outcrop on Wall St. in Warrensburg. Thirty-two samples were collected in total from this site. Samples W-100 through W-107 were taken from Exit 23 and consisted of whole rock samples. W-100 is a fine-grained tiny garnet amphibolite from the north end of the outcrop, it is finer grained and more deformed than other samples from this outcrop, indicating it may be a deformed dike. W-101 is a medium-grained tiny garnet amphibolite taken ~2-2.5 m from 2 pegmatite dikes (quartz-feldspar). W-102 consists of green plagioclase-tiny garnet corona gabbro ~50 m from north end of the outcrop. W-103 is relatively undeformed corona gabbro with green plagioclase, just past a hollow in the road cut wall. W-104 is deformed white plagioclase amphibolitized gabbro from between pegmatite dikes. W-105 is corona gabbro with green plagioclase ~80 m from north end of the outcrop. W-106 is amphibolitized and deformed sample of white plagioclase gabbro from near a pyroxene-bearing pegmatite. W-107 is a not so pristine gabbro with partially whitened plagioclase, from ~100 m from the north end of the outcrop and 0.5 m from a pegmatite dike.

W-108 through W-126 (excluding W-122) were taken from Wall St. and consisted of amphibolite matrix to garnet samples (Fig. 11). Samples W-127 through W-131 consisted of whole rocks that were white to pink migmatitic granitoid gneiss. Lastly, W-122 was the thin pegmatite dike shown in Figure 11. The rationale behind the sampling method, taking samples in a traverse (Figure 11), was to see if there are meter-scale chemical changes in the composition of the amphibolite matrix to the garnets, and to see if there is an orderly progression of change related to the pegmatites and fault at the north end of the outcrop. McLelland and Wong (2008) think that the fluids responsible for transformation of corona gabbro to big garnet amphibolite come along faults, present at Wall St. and the Gore Mtn. ore pit. The

Warrensburg traverse was to test if there were substantial chemical changes with distance from the fault. This research hopes to determine if the two Warrensburg outcrops underwent metamorphic processes similar to those at Gore Mountain.

On the second day, a group of rocks was sampled from the Old Barton Mine, North River, N.Y. At this location one sample, GM-100, was taken from Pit 1 (well sampled from previous trips, but in Pit 1 there is no ability to know where on outcrops samples came from due to the nature of the commercial “museum” site; no outcrop sampling is possible in Pit 1). Twenty-four samples were collected from Pits 4 (GM 101-110; Figure 12, 13, 14) and 9 (GM 111-123), mostly along traverses across the transition zone from corona gabbro to big garnet amphibolite. The sampled rocks in the traverses include fresh corona gabbro with green plagioclase (full of spinel inclusions), transition zone rock with small garnets, to big garnet amphibolite.

Bulk Rock Geochemical Analysis

After the all the samples were collected, they were brought back to Union College’s Geology Department and washed. Parts of the rocks were crushed with a hydraulic press (tungsten carbide faces) to pass a 6 mm stainless steel sieve. After crushing to <6 mm, a 50 g split of each sample was taken and powdered using the Spex aluminum oxide puck mill. Very coarse samples GM-100, GM-105, GM-110 and GM-121 were divided into three components, garnets (G suffix), hornblendite (H), and the matrix (M), from which whole rock compositions could ultimately be calculated. Sample W-121 was separated into A, B, C based on how close the portions were to a thin tonalite pegmatite dike in the rock sample (W-121C was closest to the dike, 0.5-5 cm; W121-B was ~7cm from the dike; W-121A was ~15 cm from the dike). Also, small chips were broken off in a traverse across a large garnet in GM-105 (GM-105-G1 to 5), as mineral separates for garnet zoning analysis. Another rock sample, GM-99, which was collected in 2008, was used to obtain a biotite sample from within a large garnet crystal. Some parts of all samples were saved from which chips for thin sections were cut.

The powdered rock samples were dried in an oven at 105° C and 0.2000 ±0.0005 g of each sample dissolved using a Picotrace digestion system, and analyzed for trace elements by ICP-MS at Union College (full procedure can be found at:

http://minerva.union.edu/hollochk/picotrace/standard_procedure.htm). Portions of the powdered samples were then sent out for major elemental compositions at Acme Labs, Vancouver, Canada.

Thin Sections

30μm thick thin sections were made from the 57 samples collected. All sections were examined using an Olympus petrographic microscope for textural relationships and mineralogy. Photomicrographs were taken from samples in the four traverses and compared.

Photomicrographs

In the Gore Mountain outcrop traverses, photos were taken of the thin sections in sequence across three different corona gabbro-big garnet amphibolite transition zones (Figs. 15, 16, 17). All three traverses through the transition zone show essentially the same thing. Through the transition zone plagioclase re-crystallizes and turns white as the green, spinel-rich cores are lost. Hornblende replaces pyroxenes, and garnet progressively re-crystallizes and grain size increases. Garnet is present throughout the entirety of all three traverses.

In the Warrensburg outcrop traverse, the first three thin section photomicrographs show changes in the amphibolite matrix with approach to the thin pegmatite (Figs. 18, 19). The sample W-126 is normal matrix amphibolite, W-121A is ~10cm from the pegmatite and W-121C is at the pegmatite margin. Moving closer to the pegmatite, grain size decreases and the proportion of biotite increases, in keeping with the approximate doubling of the potassium content of the rock. W-127 and W-128 are from the migmatitic tonalite gneiss north of the garnet amphibolite, and W-129 is from the migmatitic granitic gneiss at the far north end of the outcrop. The traverse dealing with the transition from the corona gabbro to the amphibolite matrix is similar to the traverses from Gore Mountain. We see plagioclase re-crystallizing and garnet is present throughout the entirety of the traverse, though the garnets do not get larger than 1 mm, from ~0.1 mm in the corona gabbro.

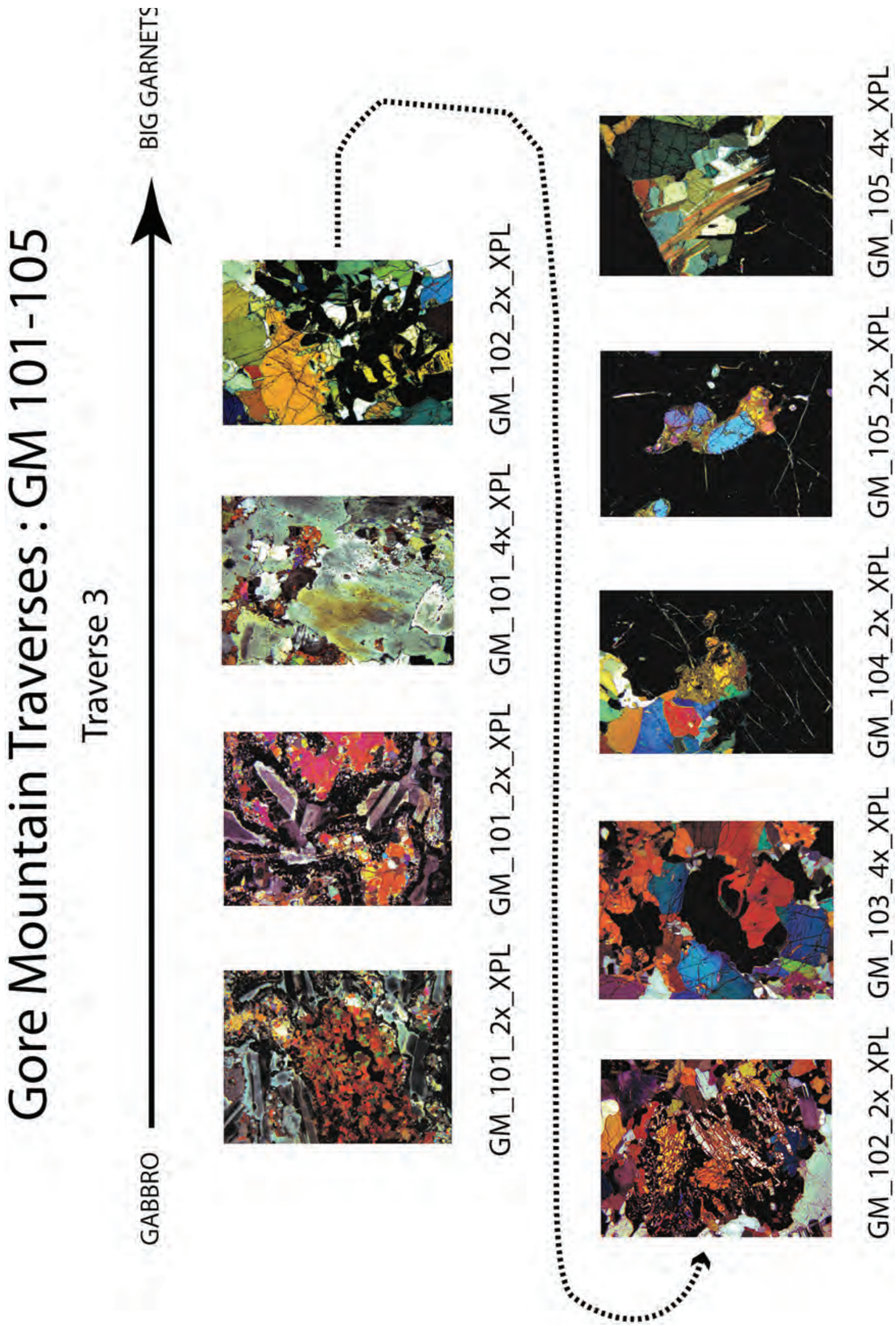

Figure 15. Gore Mountain traverse 3, the traverses show the transition of the mineralogy and textures from the corona gabbro to the garnet bearing ore.

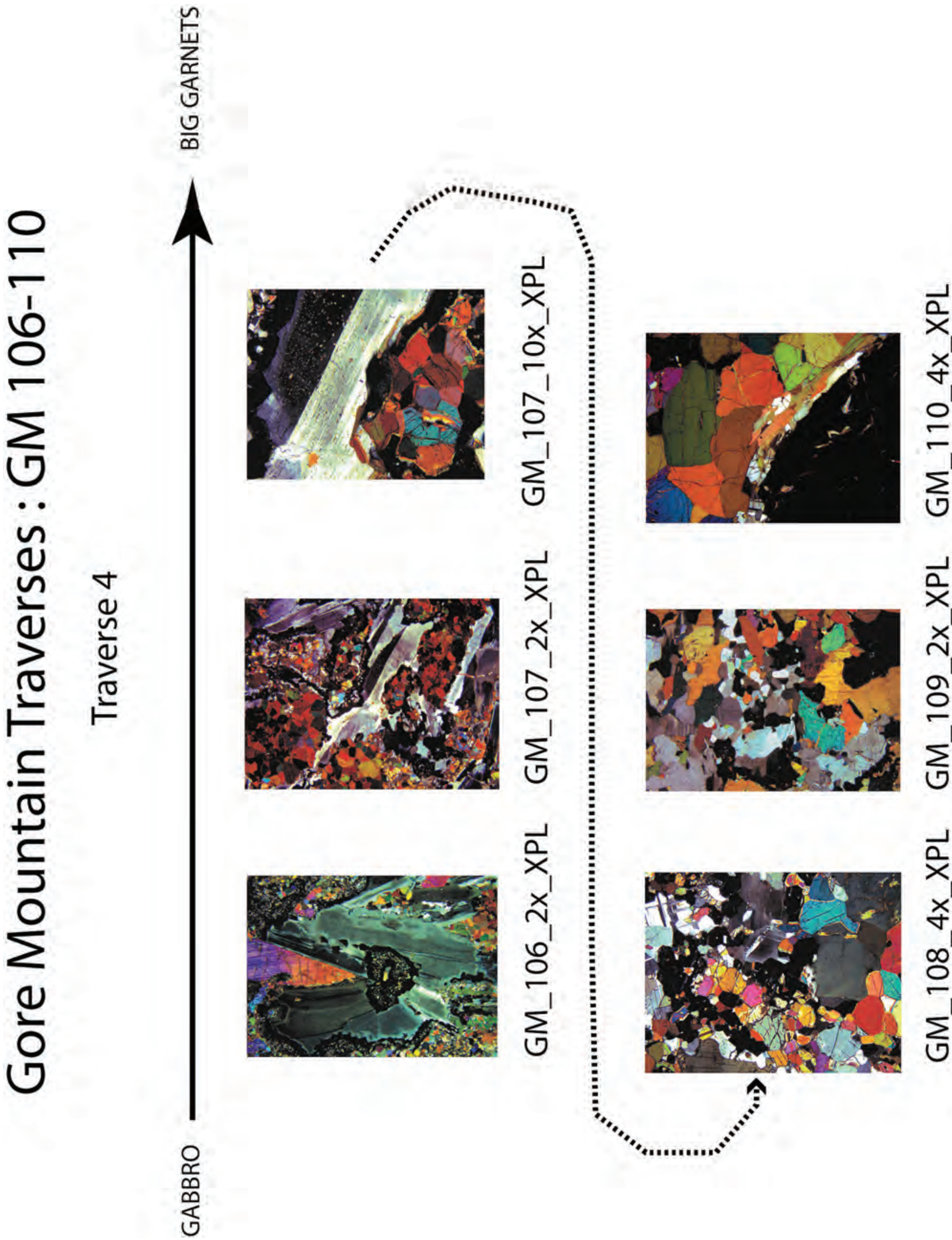

Figure 16. Gore Mountain traverse 4, showing the transition from the corona gabbro to the garnet bearing ore.

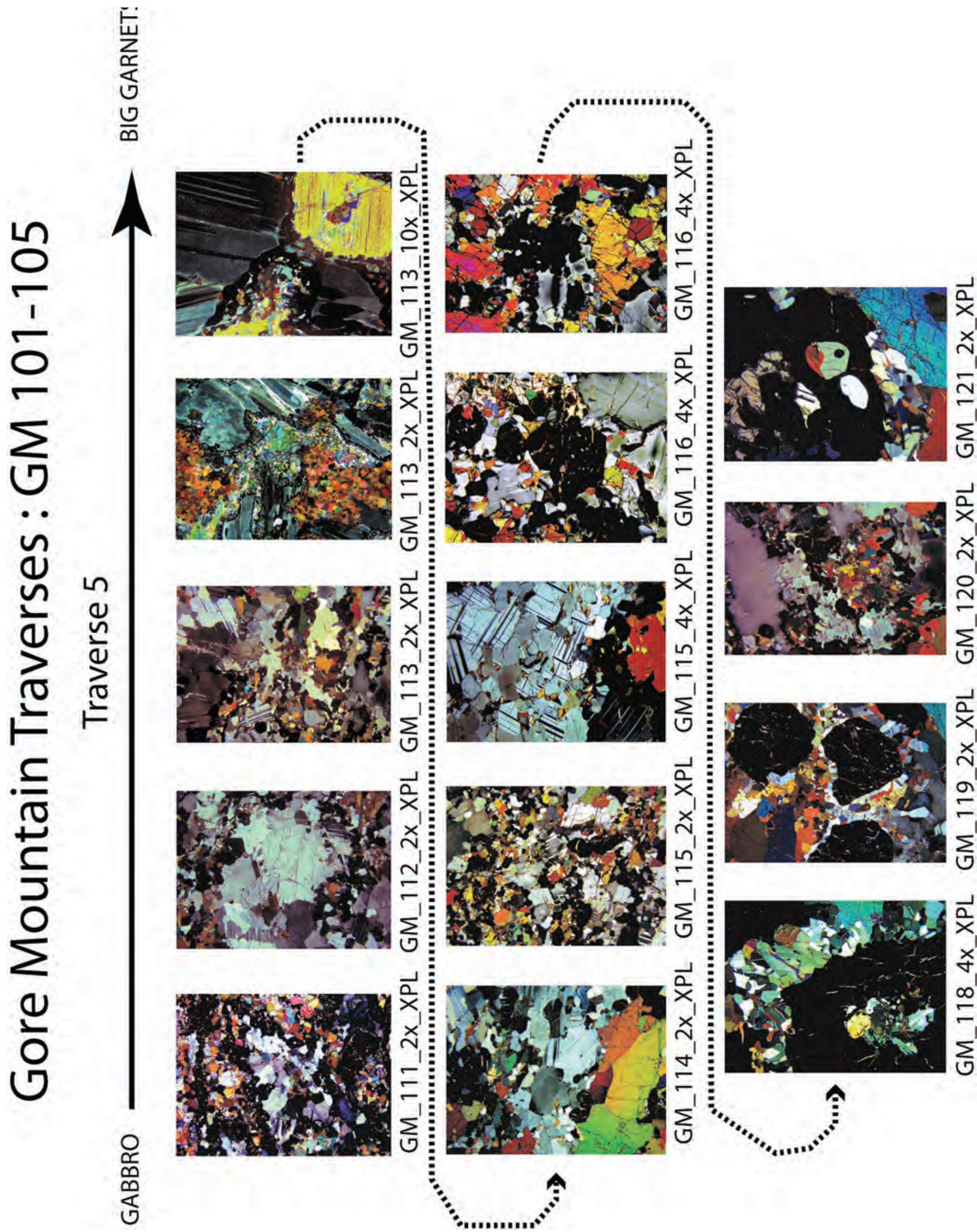

Figure 17: Gore Mountain traverse 5, showing the transition from the corona gabbro to the garnet bearing ore.

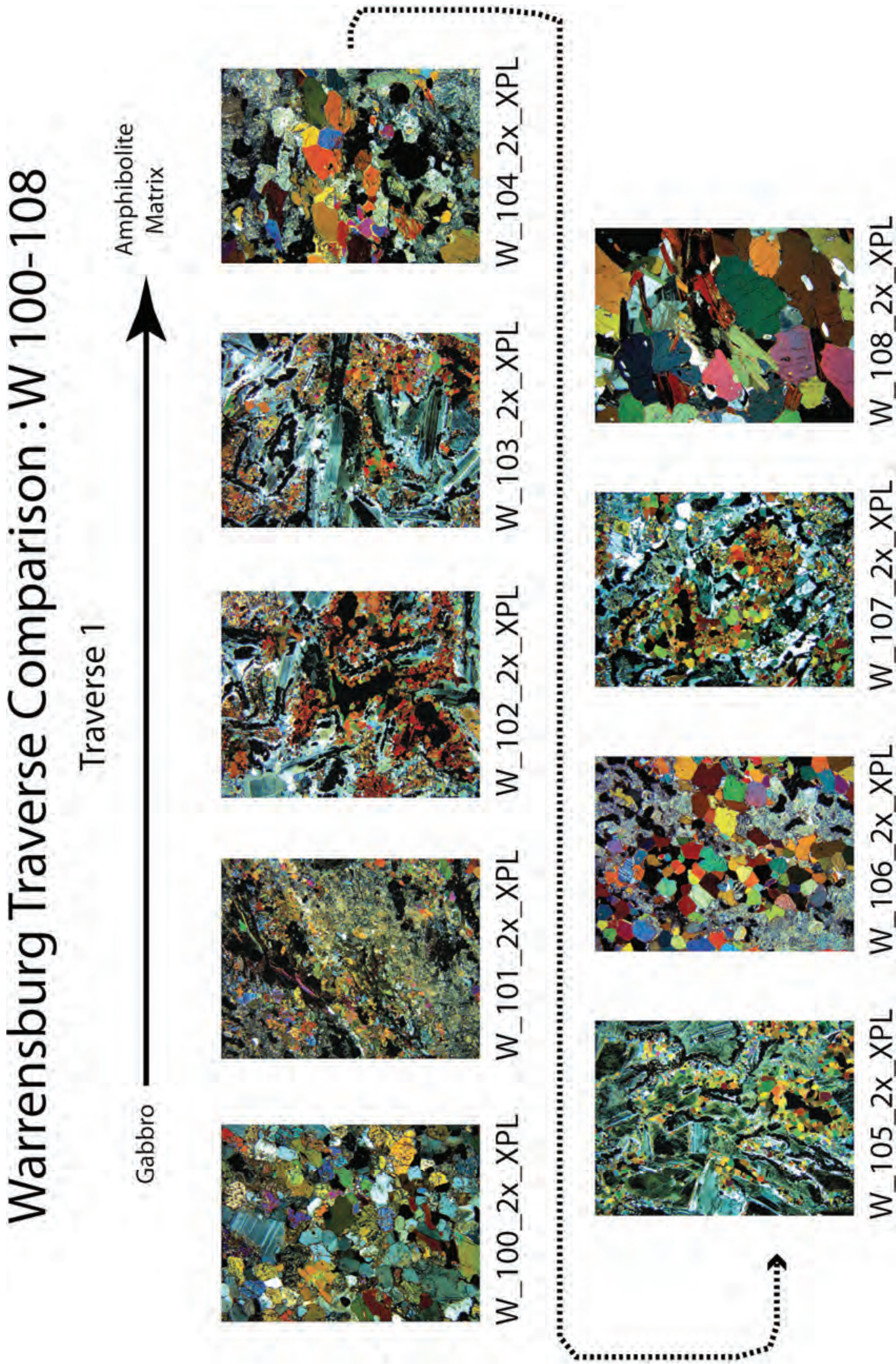

Figure 18: Warrensburg traverse 1, showing the transition from the corona gabbro to the amphibolite produced next to pegmatites on the I-87 Warrensburg northbound exit ramp.

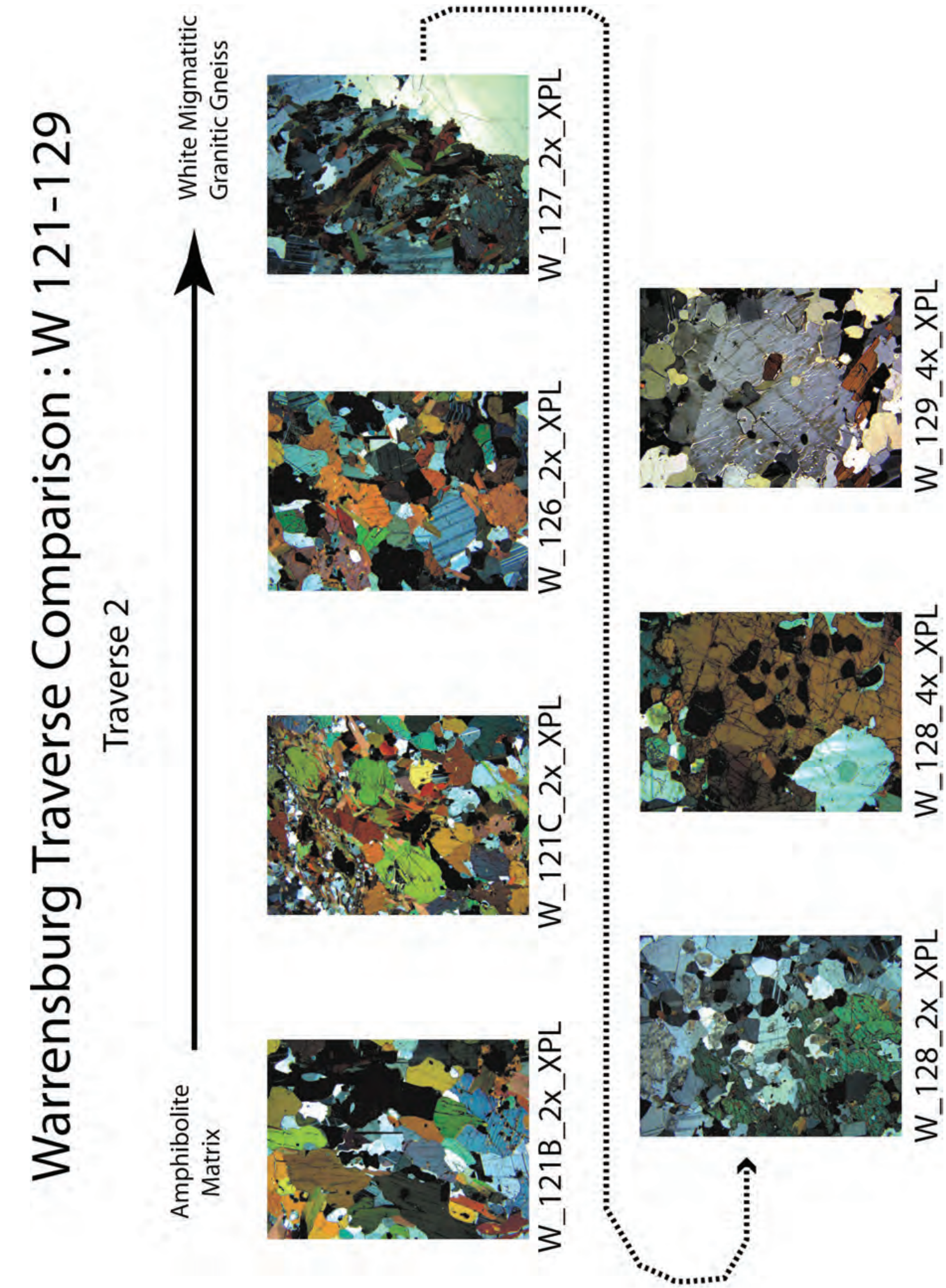

Figure 19: Warrensburg traverse 2 showing the a sequence from the garnet amphibolite to the white migmatitic granitic gneiss.

GEOCHEMICAL DATA

Trace element variations and fluid flux

The concentrations of major and trace elements in the analyzed samples are given in Appendix 1, Table 1. Previous research conducted by Kurt Hollocher (2008) has found that the corona gabbros are LREE-enriched, but the ore rocks are variably depleted in La and Ce, with one group of matrix amphiboles being particularly depleted.

Based on of the chemical analyses, it seems that the aqueous fluids that went through both the Gore Mtn. and Warrensburg rock bodies affected the some minor and trace elements, especially alkali metal and thorium contents of the big garnet amphibolites. Figure 20A shows that in the Warrensburg samples, the fluids enriched the rocks in lithium and depleted them in thorium compared to the corona gabbros. Gore Mountain corona gabbro samples start out with a less enriched lithium and thorium content. The Gore Mountain transition zone whole rocks garnet ore matrix are enriched in lithium and thorium. Figure 20B shows that in the Warrensburg samples there is enrichment in both lithium and cesium. The Gore Mountain matrix and whole rock samples are enriched in lithium but depleted in cesium. These two graphs show that there was chemical change at the two localities, facilitated by aqueous fluids, however to the fluids were apparently different at each locale and changed the compositions in somewhat different ways.

The geochemistry supports the idea that that a fluid was available during the large-garnet formation, which was probably the catalyst in creating the famous giant Gore Mtn. and Warrensburg garnets. In looking at Figure 20, the most striking geochemical changes seen in the amphibolite matrix at Warrensburg are in Cs concentrations, which are a factor of approximately 5 higher in the big garnet amphibolite as compared to the parental corona gabbro on the exit ramp (Fig. 20). Li concentrations are higher by a factor of 2, and Th concentrations lower by a factor of 1.5. These changes are more modest than what is found at Gore Mountain, where the Cs, Li and Th concentrations in the big garnet amphibolite differ from the parental corona gabbro by factors of 5 (higher) 15 (lower) and 30 (lower) respectively. It is important to note that Th is often considered by geochemists to be a relatively immobile element under metamorphic conditions, clearly not the case here. The large changes and variability at Gore Mountain are seen in some of the trace elements, but not significantly in most of the major

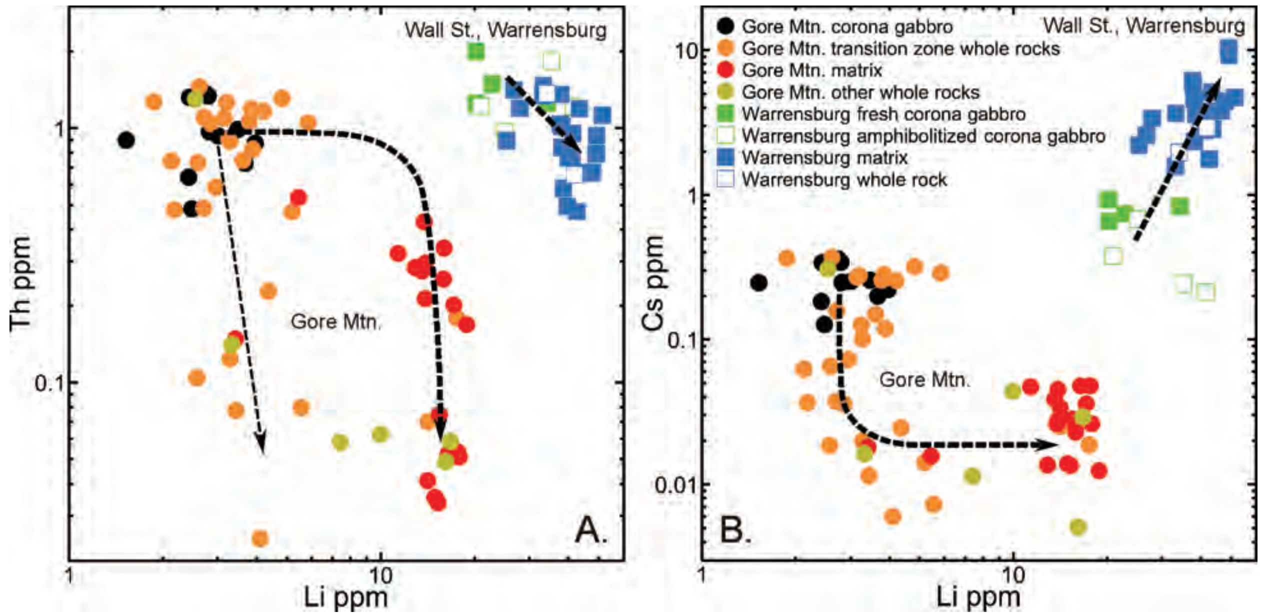

Figure 20. Bulk rock chemical variation diagrams. A. Li plotted versus Th. B Li plotted versus Cs.

elements. The large variability in some trace element concentrations at both Gore Mtn. and Warrensburg suggests that large volumes of fluid moved through the rock and that flow was channelized. The differences between the compositional changes seen at Gore Mountain compared to Wall St. indicates perhaps less fluid at Wall St., and certainly that the composition of the fluid was different (Th is lower in the big garnet amphibolite at Gore Mtn. compared to the parental gabbro, whereas at Warrensburg the garnet amphibolite has higher Th)

Major and trace element changes and the pegmatites

At Warrensburg, Wall St., the big garnet amphibolite is in fault contact with felsic rocks to the north. The fault surface is biotite-rich but the geochemical work shows no major change in chemical composition in the amphibolite with distance from the fault (Figs. 21, 22). Figure 21 shows a graph of the weight percentage of the oxide components of the Warrensburg rocks as compared to their location to the pegmatite and the fault. The graph shows that the rocks display no major oxide changes that seem to be influenced by the pegmatite or the fault. Figure 22 shows a graph comparing the concentrations of the trace elements Li, Cs, and Th in the rocks as they come in contact with the pegmatite and the fault. The graph shows no major chemical fluctuation as a result of the pegmatite or the fault.

DISCUSSION

Firstly, it does not seem that the pegmatites at the Warrensburg I-87 exit ramp are related to the big garnet growth event. At least some of these pegmatites are early (pre- or syn-Ottawan), as indicated by garnet garlands around pyroxenes that grew under granulite facies conditions. With the amphibolitization of the corona gabbro around the pegmatites, and the fact that some of the pegmatites do not seem to have garnet garlands around their pyroxene, it may, in fact, be that some of the pegmatites post-date granulite facies metamorphism (i.e. two periods of pegmatite intrusion).

The transition at Gore Mtn. between corona gabbro and big garnet amphibolite takes place in a transition zone about 2 m wide. Over this distance, garnets grew from ~100μm diameter to ~100,000μm (~10 cm), which equates to a factor of 1000 increase in diameter and an increase of a billion in volume.

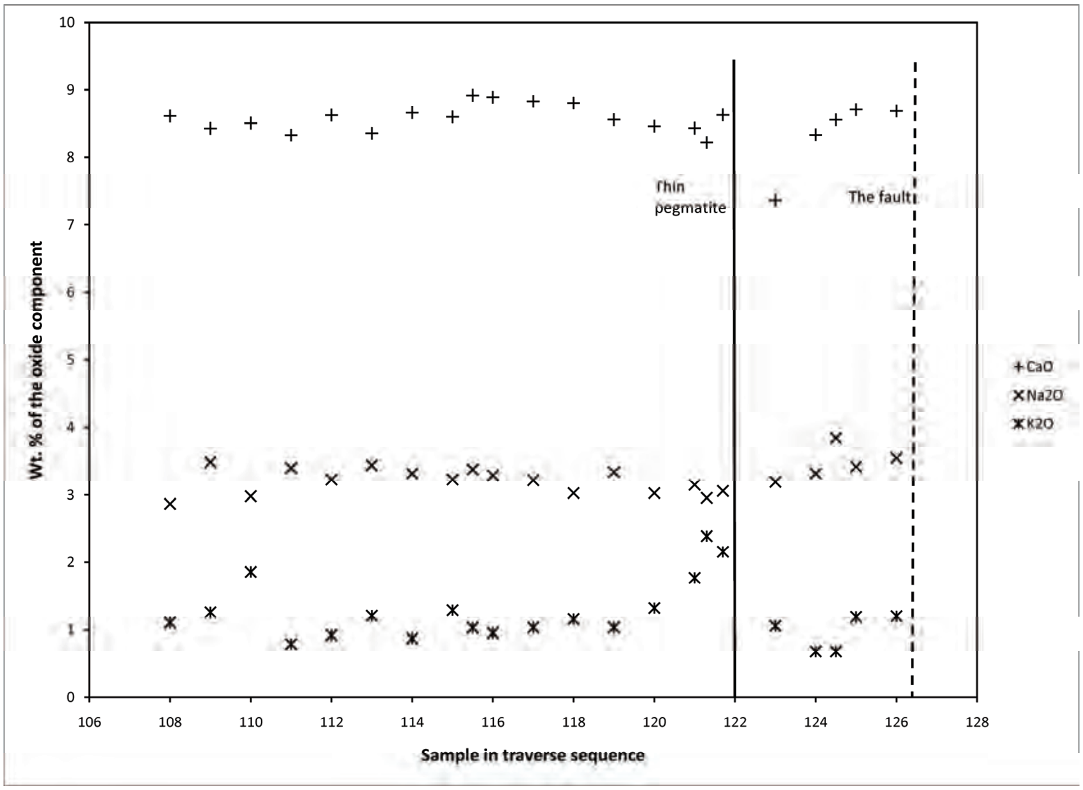

Figure 21. Graph comparing the weight percent of CaO, Na_2O, and K_2O versus the sample location with the Warrensburg traverse sequence.

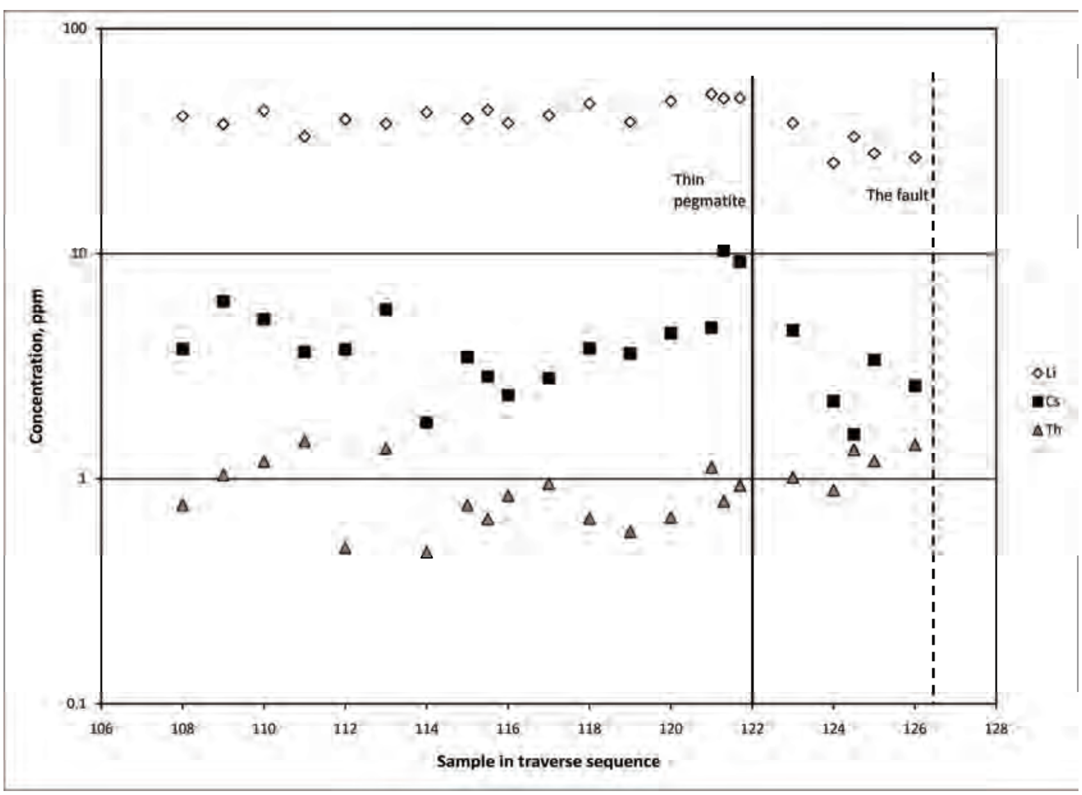

Figure 22: Graph comparing the concentration of the trace elements Li, Cs, and Th versus the sample location with the Warrensburg traverse sequence.

Also, the garnets maintain about the same chemical composition throughout the transition from parental gabbro to big garnet amphibolite ($Al_{47}Py_{40}Gr_{12}Sp_1$), according to Sharga and Sclar, 1987. At the Warrensburg location, no transition zone is exposed between the corona gabbro and nearby big garnet amphibolite. The Warrensburg outcrop has more magmatically evolved parental corona gabbro compositions than those at Gore Mtn. However, like at Gore Mtn., at Warrensburg the garnets in the coronas and in the big garnet amphibolite are very similar in composition ($Al_{60}Py_{24}Gr_{13}Sp_3$).

It was observed in Gore Mountain that the garnets persist in the corona gabbro, through the transition zone, and into the big garnet amphibolite, all the while maintaining about the same chemical composition within their respective locations. This leads to the conclusion that the presence of small numbers of enormous garnets in the amphibolite cannot be the result of small numbers of garnet nuclei. For this proposed mechanism of low-nucleation rates to have actually functioned, garnets would have to have vanished from the assemblage at some point in the transition zone, then nucleate sparsely farther in toward the garnet ore. In actuality, thin section and 'eye-ball' petrography shows that the tiny garnets in the corona gabbro gradually recrystallized and grew into larger and fewer garnets in transition zone, along with recrystallization of plagioclase and hornblende replacing pyroxenes. Thusly, the driver for garnet growth seems to have been surface energy reduction.

REGIONAL CORRELATION AND SIGNIFICANCE

It has been shown that two places, Warrensburg and Gore Mountain, have big garnets and are similar petrographically, are derived from corona gabbro, and have undergone similar though not identical bulk rock chemical changes during the transition. Upon thorough examination of the researched areas, it has been concluded that the creation of the large garnets is a rare occurrence. It is mind-boggling to think that, all throughout geologic history, large plutonic bodies have come in contact with sub-surface fluid flow. However, in order to ensure the creation of large and brilliant garnets three specific, though poorly known in detail, requirements need to occur. First, the parent rock (corona gabbro) needs to have the proper chemical composition from which the garnet amphibolite will form at the ambient temperature and pressure. Second, there must be a source of aqueous fluid below the parental rock, with fluids released from hornblende or biotite by decompression-induced dehydration during tectonic and erosional uplift and unroofing following crustal thickening. Third, the fluid passing through the parent rock needs to be available for a sufficient time to grow big garnets, despite the small driving force of surface energy reduction. It seems improbable that there would be numerous locations within the Adirondack State Park that have these aforementioned garnets, but as mentioned above this region is unusual for its abundance of large almandine garnets.

Overall, there are four main conclusions of this study (1) the pegmatites located at the Warrensburg outcrop are not clearly related to the origin of the big garnet amphibolite. Although pegmatites are known to carry fluids and thusly can locally change the composition of rock bodies upon intrusion, in the case of Warrensburg there is no such clear effect, and indeed garnets are missing from the amphibolite close to the pegmatites. (2) Both site locations have evidence that corona gabbro transforms to a big-garnet amphibolite. However, the trace elements reveal that the actual chemical composition changes at each location differ (Warrensburg and Gore). (3) The evidence shows that the growth of large garnets was NOT due to low nucleation rates. Garnet is present throughout all the traverses and does not disappear at any point. This signifies that the garnets must have grown due to a reduction of surface energy. (4) The channelized fluid flow during big garnet formation caused large compositional differences in some trace elements between otherwise identical rocks at both Gore Mountain and Warrensburg. This variation merely shows the existence of channelized fluid flow.

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APPENDIX 1

Table 1: Warrensburg major element concentrations in weight %.

Bulk chemistry samples	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	C	S	SUM	LOI
W100	46.71	5.26	12.53	13.87	0.20	5.72	11.40	3.13	0.56	0.15	0.08	0.02	99.64	0.2
W101	46.64	1.86	18.31	11.91	0.18	6.71	7.48	3.42	1.24	0.26	0.03	0.07	98.12	1.8
W102	47.02	2.67	17.56	13.35	0.19	6.43	8.41	2.99	0.92	0.29	0.02	0.07	99.94	-0.1
W103	47.46	1.98	17.30	12.19	0.17	7.24	9.08	2.99	0.75	0.28	0.03	0.07	99.54	0.3
W104	47.00	1.73	17.80	11.28	0.15	7.32	6.61	3.72	1.58	0.27	0.17	0.06	97.70	2.2
W105	45.84	2.21	17.60	11.92	0.16	7.79	8.32	2.94	1.18	0.30	0.06	0.03	98.36	1.4
W106	46.44	1.97	17.47	11.70	0.16	7.61	7.72	3.51	1.44	0.25	0.09	0.02	98.37	1.4
W107	46.72	2.26	17.39	12.28	0.17	8.00	8.51	2.60	1.09	0.27	0.02	0.06	99.37	0.4
W-3-3	45.36	2.61	16.20	13.33	0.15	8.57	8.92	3.38	1.03	0.40	0.03	0.05	100.04	0.5
W-1-2	46.02	2.84	16.10	13.04	0.18	8.24	8.55	3.84	0.68	0.41	0.03	0.11	100.05	0.3
W108	44.48	2.81	14.44	14.64	0.18	9.11	8.61	2.87	1.11	0.43	0.05	0.08	98.81	1
W109	46.15	2.25	16.72	12.45	0.14	7.36	8.43	3.49	1.26	0.34	0.07	0.07	98.73	1.1
W110	45.97	2.31	16.36	12.23	0.14	8.27	8.51	2.98	1.86	0.34	0.02	0.04	99.04	0.7
W111	46.58	2.42	16.38	12.53	0.16	7.69	8.33	3.40	0.79	0.34	0.03	0.08	98.73	1.1
W112	45.59	2.34	16.62	12.84	0.17	8.08	8.62	3.23	0.92	0.37	0.03	0.07	98.88	0.9
W113	46.54	2.26	16.91	12.45	0.15	7.50	8.36	3.44	1.21	0.32	0.02	0.09	99.25	0.6
W114	46.01	2.39	16.49	12.40	0.12	7.99	8.66	3.32	0.87	0.33	<0.02	0.06	98.64	1.1
W115	45.76	2.52	16.69	13.23	0.17	7.34	8.60	3.23	1.29	0.38	<0.02	0.04	99.24	0.5
W116	45.71	2.66	15.93	13.26	0.14	7.97	8.89	3.29	0.95	0.39	0.03	0.06	99.28	0.5
W117	45.54	2.63	15.88	13.29	0.15	8.15	8.83	3.22	1.04	0.40	<0.02	0.06	99.18	0.6
W118	44.75	2.69	15.82	13.75	0.16	8.55	8.80	3.03	1.16	0.37	<0.02	0.06	99.14	0.6
W119	45.86	2.52	16.39	13.36	0.19	7.41	8.56	3.34	1.04	0.37	0.03	0.13	99.19	0.7
W120	44.49	2.59	15.87	13.76	0.14	8.78	8.46	3.03	1.32	0.37	0.03	0.08	98.92	0.9
W121A	44.74	2.62	15.55	14.22	0.18	7.53	8.63	3.06	2.15	0.40	0.03	0.08	99.20	0.6
W121B	45.19	2.48	15.29	13.89	0.17	7.99	8.22	2.96	2.39	0.37	0.02	0.07	99.02	0.7
W121C	45.11	2.58	15.16	14.00	0.17	8.35	8.43	3.15	1.77	0.40	<0.02	0.08	99.20	0.6
W123	46.58	2.62	14.56	14.72	0.21	8.46	7.36	3.19	1.06	0.38	0.04	0.12	99.29	0.6
W124	45.92	3.32	14.65	15.36	0.20	7.17	8.33	3.32	0.68	0.47	0.05	0.20	99.66	0.3
W125	45.02	3.31	15.07	15.07	0.21	6.53	8.71	3.42	1.19	0.49	0.03	0.06	99.10	0.7
W126	45.68	3.27	14.76	15.04	0.21	6.26	8.68	3.55	1.20	0.46	0.06	0.04	99.22	0.6
W122	64.28	0.04	20.67	1.00	0.01	0.63	4.20	6.77	0.83	0.01	0.12	<0.02	98.57	1.5
W127	72.68	0.59	13.78	2.54	0.01	0.74	3.37	3.66	1.46	0.10	0.06	0.03	99.03	0.8
W128	67.62	0.72	16.19	3.87	0.04	0.67	3.85	4.38	1.44	0.06	0.03	0.40	99.28	1
W129	73.49	0.30	12.81	2.68	0.04	0.11	1.24	2.50	6.20	0.02	0.04	<0.02	99.43	0.4
W130	71.13	0.41	13.14	4.00	0.07	0.18	1.73	3.02	5.38	0.05	0.04	<0.02	99.15	0.6
W131	71.44	0.44	12.93	4.02	0.07	0.20	1.69	2.92	5.43	0.07	0.05	0.03	99.30	0.5

Table 2: Warrensburg ICPMS trace element concentrations (ppm).

Bulk chemistry samples	Li	Be	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
W100	25.0	0.6	49.5	479.6	70.1	46.4	35.0	19.6	117.3	19.7	17.5	280.9	29.9	124.8	8.5	2.0	1.6	0.4	0.7	157.5	10.0	22.0	3.5	16.8	4.3	1.7	5.3	0.8	5.2	1.1	2.9	0.4	2.8	0.5	3.6	0.6	2.8	1.0	0.4
W101	35.3	0.9	10.8	113.5	20.6	56.9	90.3	31.5	102.2	20.0	44.8	487.4	31.7	143.1	8.0	0.5	1.5	0.2	0.2	180.8	13.7	32.5	4.6	20.0	5.0	1.7	5.4	0.9	5.2	1.1	3.0	0.4	2.9	0.5	3.5	0.5	1.9	1.8	0.0
W102	20.2	0.9	20.5	179.6	33.1	55.2	94.1	40.8	119.8	21.1	22.1	304.2	34.7	184.3	9.6	0.6	1.5	0.1	0.9	201.4	15.5	36.0	5.0	22.2	5.5	1.9	6.1	1.0	6.0	1.2	3.4	0.5	3.3	0.5	4.7	0.6	4.4	2.0	0.7
W103	22.8	0.8	22.7	167.3	39.9	58.2	122.1	37.9	108.9	20.9	16.4	324.2	30.9	154.1	7.1	0.5	1.3	0.1	0.7	184.3	13.4	31.0	4.4	20.0	5.0	1.8	5.5	0.9	5.2	1.1	3.0	0.4	2.8	0.4	3.9	0.4	3.6	1.5	0.5
W104	41.5	0.7	18.1	140.3	32.0	56.5	132.2	33.7	116.8	20.2	53.6	574.3	26.4	133.9	6.5	0.4	1.2	0.4	0.2	201.8	11.5	27.0	3.8	17.1	4.4	1.5	4.7	0.7	4.6	0.9	2.6	0.4	2.5	0.4	3.4	0.4	4.7	1.2	0.5
W105	34.2	0.7	20.7	172.2	40.7	60.4	143.3	32.1	106.8	20.2	44.0	348.7	28.0	152.8	7.5	0.5	1.8	0.2	0.8	259.3	11.9	23.7	4.1	18.9	4.3	1.7	5.1	0.8	4.9	1.0	2.7	0.4	2.6	0.4	3.8	0.5	2.4	1.3	0.4
W106	20.9	0.7	19.2	158.2	40.4	60.5	147.8	21.5	107.3	20.0	52.8	434.4	27.0	140.7	7.0	0.4	1.0	0.1	0.4	296.3	11.9	23.1	4.0	18.0	4.5	1.6	4.9	0.8	4.6	0.9	2.6	0.4	2.5	0.4	3.5	0.4	2.3	1.2	0.5
W107	20.3	0.7	20.6	175.3	44.3	62.0	158.3	31.8	106.7	20.0	34.7	364.1	28.0	146.0	7.6	0.4	1.2	0.1	0.7	254.6	12.0	23.7	4.1	18.4	4.5	1.6	4.9	0.8	4.7	1.0	2.6	0.4	2.5	0.4	3.5	0.4	2.6	1.2	0.4
W-3-3	43.6	0.0	23.2	222.4	30.3	62.5	120.5	30.2	122.2	21.0	29.9	305.7	35.7	104.1	0.0	0.6	1.0		2.0	244.1	14.2	34.0	5.1	23.5	5.7	2.0	6.2	1.0	5.9	1.2	3.3	0.5	3.2	0.5	4.5	0.5	4.3	0.7	0.3
W-1-2	33.1	1.0	23.8	209.5	41.2	59.1	123.6	45.9	113.5	21.0	11.6	338.8	36.8	205.8	9.8	0.6	1.7		1.6	123.4	16.0	33.2	5.4	24.9	6.1	2.0	6.6	1.0	6.4	1.3	3.6	0.5	3.3	0.5	5.0	0.5	4.5	1.3	0.6
W108	41.0	1.0	24.2	237.5	47.4	73.1	165.9	31.0	161.0	22.6	32.3	237.2	35.1	206.1	9.8	0.5	1.9	0.1	3.8	196.3	16.7	41.8	6.0	28.1	6.9	2.2	7.2	1.1	6.3	1.2	3.3	0.5	3.0	0.5	5.1	0.5	3.7	0.8	0.6
W109	37.6	0.8	19.3	178.9	38.0	59.4	130.9	38.7	118.6	20.6	50.7	307.5	31.0	176.5	8.1	0.5	1.6	0.0	6.2	273.3	14.1	33.4	4.6	21.1	5.2	1.8	5.6	0.9	5.3	1.1	3.0	0.4	2.8	0.4	4.4	0.5	5.4	1.0	0.6
W110	43.3	1.3	19.7	198.4	41.2	63.7	157.6	28.2	123.1	21.0	85.7	304.6	31.1	182.2	8.5	0.6	3.1	0.1	5.1	211.2	13.7	33.6	4.8	21.8	5.5	2.0	5.8	0.9	5.4	1.1	2.9	0.4	2.7	0.4	4.5	0.5	6.1	1.2	0.9
W111	33.2	0.8	20.7	208.0	42.4	60.1	140.0	42.7	114.7	20.7	23.8	340.9	34.3	189.4	8.9	0.6	1.6	0.1	3.7	158.2	15.7	36.6	5.1	23.3	5.9	1.9	6.4	1.0	6.0	1.2	3.4	0.5	3.2	0.5	4.8	0.5	5.4	1.5	0.6
W112	39.5	0.8	20.5	186.2	37.1	63.7	142.5	33.8	113.3	21.0	28.6	339.7	33.4	177.9	8.5	0.7	1.5	0.0	3.8	148.0	13.4	33.1	4.8	22.3	5.5	1.9	6.0	0.9	5.8	1.2	3.2	0.5	3.0	0.5	4.5	0.5	4.7	0.5	0.3
W113	37.8	0.8	20.1	180.6	36.1	58.3	131.8	35.5	112.1	20.7	45.2	315.8	31.7	177.7	8.3	0.5	1.5	0.0	5.6	253.3	13.8	33.1	4.6	21.4	5.3	1.8	5.7	0.9	5.5	1.1	3.1	0.4	2.9	0.5	4.4	0.5	5.5	1.4	0.5
W114	42.5	0.8	21.3	192.1	38.9	59.5	128.4	42.0	122.0	20.9	21.8	334.5	31.3	164.5	8.7	0.6	1.4	0.0	1.8	218.9	13.2	32.9	4.7	22.3	5.4	2.0	5.9	0.9	5.5	1.1	3.0	0.4	2.9	0.5	4.2	0.5	4.9	0.5	0.4
W115	39.9	0.8	21.6	210.0	38.6	57.3	115.4	32.7	114.3	21.3	43.4	303.5	34.9	204.1	8.9	0.7	2.1	0.0	3.5	240.4	14.4	35.2	5.0	23.5	5.8	2.0	6.4	1.0	6.2	1.3	3.4	0.5	3.3	0.5	5.1	0.5	4.1	0.8	0.4
W116	38.1	0.9	21.9	214.3	40.5	61.7	130.8	44.3	131.5	21.5	24.2	308.1	31.5	206.1	9.4	0.5	1.5	0.0	2.3	247.8	15.2	37.4	5.3	24.9	6.0	2.1	6.3	1.0	5.7	1.1	3.0	0.4	2.8	0.4	5.1	0.5	4.3	0.8	0.4
W117	41.3	0.9	21.9	225.6	41.9	63.5	144.1	42.0	131.0	21.8	25.7	301.6	33.2	194.9	9.3	0.6	1.6	0.0	2.8	234.2	15.4	37.5	5.4	25.0	6.0	2.1	6.4	1.0	5.7	1.2	3.1	0.5	2.9	0.4	4.8	0.5	4.4	1.0	0.5
W118	46.5	0.8	22.3	235.3	46.3	67.6	145.8	27.9	135.3	20.9	38.7	281.6	32.1	169.8	9.1	0.5	1.7	0.0	3.8	278.1	13.7	34.3	5.0	23.6	5.8	2.0	6.2	1.0	5.7	1.2	3.1	0.5	2.9	0.5	4.4	0.5	3.9	0.7	0.4
W119	38.5	0.9	21.6	234.9	41.2	56.5	123.4	46.6	126.0	20.9	34.8	330.1	34.6	195.0	9.0	0.6	2.0	0.0	3.6	179.3	14.8	36.1	5.1	23.8	5.5	2.0	6.3	1.0	6.0	1.2	3.3	0.5	3.2	0.5	4.8	0.5	5.0	0.6	0.3
W120	47.8	0.9	22.0	244.1	43.0	70.5	159.4	40.5	136.7	21.7	42.1	274.6	33.0	184.7	9.0	0.6	1.8	0.0	4.4	325.9	14.3	35.8	5.2	24.0	5.9	2.0	6.3	1.0	5.7	1.2	3.2	0.5	3.0	0.5	4.7	0.5	4.0	0.7	0.4
W121A	49.2	1.8	22.9	206.6	40.3	57.8	129.8	39.7	197.2	22.7	130.5	291.3	46.1	215.9	10.4	0.7	12.3	0.4	9.2	212.3	20.8	52.8	7.3	32.4	7.9	2.3	8.0	1.3	7.7	1.6	4.4	0.7	4.4	0.7	5.4	0.6	9.9	0.9	1.4
W121B	49.1	1.2	22.2	264.6	43.6	62.1	138.0	39.3	181.4	20.8	155.2	302.7	38.0	199.6	9.3	0.6	8.2	0.2	10.3	278.3	17.4	41.3	5.7	25.7	6.1	2.0	6.7	1.0	6.4	1.3	3.6	0.5	3.4	0.5	4.9	0.5	9.0	0.8	1.2
W121C	51.3	0.9	22.9	283.4	47.5	65.3	144.4	39.2	137.2	21.1	61.9	299.4	38.4	188.9	9.2	0.6	2.4	0.1	4.7	219.1	16.5	39.1	5.7	26.3	6.5	2.1	7.0	1.1	6.7	1.3	3.7	0.5	3.4	0.5	4.9	0.5	7.4	1.1	0.6
W123	30.1	0.9	22.7	163.2	30.0	65.1	144.7	45.0	170.5	20.1	35.3	325.0	34.0	205.9	9.4	0.6	1.3	0.1	4.6	102.6	14.9	34.4	4.9	22.3	5.5	1.9	6.0	0.9	5.0	1.2	3.3	0.5	3.1	0.5	4.9	0.6	5.6	1.0	0.6
W124	25.3	1.2	30.0	218.5	44.7	63.2	121.2	34.9	178.7	23.6	13.2	331.1	47.8	254.2	11.9	0.7	1.8	0.0	2.2	104.8	18.7	45.3	6.5	30.1	7.5	2.4	8.3	1.3	8.0	1.5	4.5	0.7	4.4	0.7	6.2	0.7	4.8	0.9	0.5
W125	27.9	1.2	28.7	208.4	44.9	54.2	75.5	28.5	157.8	23.7	32.2	274.0	49.8	241.7	12.3	0.6	2.2	0.0	3.4	205.7	19.2	47.6	6.8	31.6	8.0	2.5	8.7	1.4	8.6	1.3	4.8	0.7	4.7	0.7	6.1	0.7	6.3	1.2	0.7
W126	26.8	1.2	28.6	209.4	43.8	56.2	70.9	16.3	166.1	24.0	29.8	262.1	50.9	249.7	12.3	0.5	2.2	0.0	2.6	232.5	19.7	47.9	6.9	31.3	8.2	2.5	8.9	1.4	8.6	1.3	4.9	0.7	4.8	0.7	6.3	0.7	6.0	1.4	0.6
W122	42.5	4.6	0.4	2.7	0.8	2.4	5.7	3.1	12.6	33.9	23.8	538.2	6.4	80.4	0.8	0.1	0.7	0.5	1.2	133.1	6.6	10.7	1.1	4.3	1.0	1.4	0.9	0.2	1.0	0.2	0.6	0.1	0.7	0.1	2.6	0.1	14.0	4.3	3.4
W127	28.2	3.2	1.2	13.4	2.7	6.5	6.4	4.3	66.8	22.6	76.8	296.7	8.1	1011.4	5.9	0.2	0.5	0.0	1.9	560.1	13.6	24.1	2.7	9.8	1.7	1.2	1.4	0.2	1.2	0.3	0.9	0.2	1.3	0.2	27.1	0.2	8.9	2.0	2.3
W128	26.7	3.9	1.5	12.0	2.2	14.1	12.8	30.8	61.5	27.5	74.1	357.2	33.3	658.8	7.8	1.5	0.6	0.1	2.0	550.4	14.5	25.3	2.7	9.9	1.3	1.4	2.1	0.5	3.9	1.1	4.2	0.8	6.1	1.1	17.5	0.3	10.4	2.0	1.8
W129	9.5	2.2	3.9	2.7	2.1	1.4	2.7	2.3	103.6	26.3	102.9	101.0	105.6	613.1	10.3	1.3	2.4	0.0	0.7	011.4	06.7	100.1	24.1	95.0	21.1	3.1	19.1	3.1	13.6	3.0	10.3	1.5	9.3	1.3	16.4	0.0	25.9	20.5	2.9
W130	13.6	3.5	5.8	4.7	2.3	1.9	2.9	2.8	160.7	29.1	185.4	118.1	121.6	653.4	26.2	1.2	4.8	0.0	2.4	947.2	82.1	177.4	23.2	93.2	21.7	3.8	20.5	3.3	20.4	4.2	11.8	1.8	11.3	1.7	16.0	1.4	24.8	18.9	2.4
W131	12.4	3.6	5.5	4.7	2.3	2.0	2.8	2.2	140.3	27.6	189.8	112.3	114.3	703.0	26.2	1.4	4.7	0.0	2.5	954.1	81.8	174.3	22.6	90.2	20.8	3.7	19.5	3.1	19.4	4.0	11.2	1.7	10.9	1.7	17.7	1.5	25.4	20.2	3.7

Table 3: Gore Mountain major element concentrations in weight %.

Bulk chemistry samples	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	C	S	SUM	LOI
GM100G	39.66	0.09	22.00	21.15	0.47	11.14	5.03	0.17	0.03	0.05	0.09	0.05	99.93	0
GM100H	45.54	0.99	15.37	10.39	0.08	12.88	9.74	3.16	0.61	0.04	0.09	0.06	98.94	0.9
GM100M	47.49	0.72	16.90	9.74	0.09	10.88	8.91	3.53	0.52	0.07	0.07	0.11	99.02	0.8
GM101	47.91	0.65	17.53	11.35	0.15	10.69	8.05	2.32	0.57	0.07	0.12	0.07	99.49	0.4
GM102	47.58	0.67	17.83	10.74	0.14	9.98	7.99	3.55	0.59	0.07	0.06	0.03	99.22	0.6
GM103	45.69	0.70	17.37	11.71	0.15	11.47	8.38	3.03	0.44	0.07	0.05	0.09	99.15	0.7
GM104	45.46	0.75	17.46	11.53	0.14	11.60	8.65	3.00	0.45	0.07	0.06	0.06	99.23	0.6
GM105G	39.51	0.04	22.69	20.27	0.46	11.70	5.35	0.05	0.01	0.06	0.09	0.05	100.28	-0.4
GM105H	43.28	1.07	14.27	12.20	0.10	14.58	10.01	2.40	0.50	0.05	0.08	0.08	98.62	1.2
GM105M	45.83	0.72	17.94	11.07	0.14	10.81	8.30	3.35	0.58	0.06	0.06	0.07	98.94	0.9
GM106	48.22	0.74	18.75	10.18	0.14	9.44	8.46	2.68	0.66	0.07	0.05	0.03	99.42	0.4
GM107	48.28	0.79	19.34	9.68	0.13	8.75	8.76	2.85	0.69	0.08	0.10	0.04	99.49	0.4
GM108	47.91	0.69	18.53	10.01	0.14	9.22	8.59	3.25	0.64	0.07	0.07	0.04	99.15	0.7
GM109	47.81	0.64	18.43	10.18	0.14	9.31	8.34	3.20	0.59	0.06	0.08	0.07	98.85	1.1
GM110G	39.41	0.06	23.11	20.55	0.47	11.45	5.48	0.02	<0.01	0.05	0.05	0.03	100.69	-0.9
GM110H	43.35	1.63	13.54	11.47	0.08	14.51	10.35	2.44	0.76	0.05	0.16	0.04	98.38	1.5
GM110M	47.76	0.72	18.90	8.56	0.09	9.21	9.28	3.71	0.60	0.07	0.06	0.05	98.99	0.9
GM111	47.44	0.69	18.17	11.13	0.15	10.44	8.09	2.55	0.61	0.07	0.07	0.04	99.46	0.4
GM112	47.87	0.66	18.01	10.76	0.14	10.01	8.19	2.68	0.60	0.06	0.09	0.05	99.11	0.8
GM113	47.50	0.69	18.66	10.62	0.14	9.82	8.44	2.80	0.58	0.07	0.07	0.05	99.43	0.4
GM114	46.56	0.68	18.64	11.41	0.16	10.49	8.39	2.58	0.46	0.07	0.06	0.08	99.57	0.3
GM115	48.23	0.77	18.75	10.27	0.14	9.16	8.54	2.78	0.63	0.07	0.06	0.04	99.44	0.4
GM116	48.45	0.74	19.22	9.93	0.13	8.66	8.69	2.83	0.63	0.07	0.08	0.03	99.45	0.4
GM117	47.51	0.78	19.39	10.04	0.13	8.71	9.05	2.84	0.61	0.08	0.11	0.04	99.28	0.6
GM118	46.53	0.80	18.66	11.12	0.15	9.85	8.86	2.73	0.54	0.07	0.06	0.06	99.44	0.4
GM119	45.97	0.77	19.11	11.09	0.15	9.93	8.90	2.56	0.49	0.08	0.13	0.05	99.22	0.7
GM120	48.17	0.78	19.52	9.57	0.13	8.39	8.96	2.90	0.67	0.07	0.08	0.05	99.28	0.6
GM121G	39.77	0.16	22.53	20.94	0.47	11.29	4.96	0.11	0.05	0.06	0.08	0.03	100.46	-0.6
GM121H	43.34	1.66	14.13	11.98	0.10	14.21	10.44	2.17	0.68	0.03	0.09	0.09	98.92	0.9
GM121M	47.79	0.76	19.21	8.48	0.08	8.55	9.78	3.42	0.52	0.08	0.08	0.08	98.85	1
GM122	46.23	0.57	15.62	13.79	0.18	13.39	7.16	2.36	0.51	0.05	0.09	0.10	100.04	-0.2
GM123	47.53	0.67	17.46	11.64	0.15	11.25	7.85	2.66	0.61	0.07	0.06	0.05	100.01	-0.2

Table 4: Gore Mountain ICPMS trace element concentrations (ppm).

Bulk chemistry samples	Li	Be	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
GM100G	2.3	0.03	15.8	27	20	77	27	13	66.1	7.7	0.6	18	29	23	0.3	0.08	0.03	0.00	0.01	8	0.8	1.8	0.25	1.3	0.69	0.42	2.02	0.48	3.96	0.98	3.02	0.49	3.39	0.57	0.38	0.09	0.28	0.08	0.05
GM100H	4.1	0.38	8.4	78	30	89	143	23	139.8	21.5	5.4	303	9	46	2.4	0.14	0.47	0.00	0.01	89	5.2	14.6	2.17	9.9	2.51	0.98	2.36	0.33	1.68	0.30	0.72	0.10	0.58	0.08	1.47	0.15	1.52	0.16	0.10
GM100M	3.4	0.38	8.7	61	23	81	129	42	121.2	19.1	4.7	484	11	49	2.0	0.19	0.38	0.00	0.02	118	5.2	13.3	1.87	8.2	2.00	0.88	2.10	0.32	1.84	0.37	1.00	0.15	0.92	0.15	1.41	0.13	1.85	0.15	0.11
GM101	3.8	0.38	10.9	85	26	79	113	21	103.5	17.9	10.7	343	13	49	1.8	0.33	0.43	0.07	0.26	139	5.8	13.1	1.77	8.0	1.95	0.81	2.11	0.34	2.16	0.44	1.23	0.19	1.22	0.20	1.38	0.14	2.73	1.06	0.41
GM102	3.1	0.37	10.2	70	22	72	94	18	103.6	17.9	11.9	351	12	55	1.9	0.25	0.44	0.08	0.27	144	5.9	13.1	1.76	7.9	1.89	0.81	2.11	0.34	2.10	0.43	1.23	0.18	1.17	0.19	1.50	0.13	2.79	1.09	0.43
GM103	2.6	0.33	11.1	83	24	85	120	33	114.4	18.2	4.0	362	12	45	1.8	0.20	0.40	0.01	0.02	94	4.7	11.9	1.69	7.7	1.96	0.83	2.17	0.34	2.11	0.43	1.20	0.18	1.17	0.19	1.29	0.11	1.54	0.10	0.10
GM104	3.4	0.33	10.9	91	25	84	117	29	111.0	18.3	3.4	365	13	45	2.0	0.18	0.40	0.00	0.01	80	4.5	11.8	1.70	7.9	2.00	0.83	2.22	0.34	2.13	0.44	1.19	0.17	1.15	0.18	1.33	0.11	1.33	0.08	0.07
GM105G	2.4	0.01	16.5	27	21	82	31	30	62.8	6.7	0.5	12	27	19	0.0	0.07	0.04	0.06	0.01	4	0.5	1.1	0.15	0.9	0.72	0.50	2.12	0.49	3.94	0.96	2.85	0.46	3.23	0.54	0.28	0.01	0.25	0.02	0.02
GM105H	18.9	0.34	8.8	97	37	107	178	36	131.0	21.1	3.0	126	8	44	2.4	0.18	0.56	0.01	0.02	45	4.5	14.4	2.25	10.8	2.59	0.98	2.41	0.31	1.60	0.28	0.66	0.09	0.51	0.07	1.60	0.11	0.97	0.11	0.08
GM105M	15.4	0.33	10.9	104	31	78	103	40	97.0	17.5	6.5	574	14	49	1.9	0.16	0.50	0.00	0.03	151	4.7	11.9	1.74	8.0	2.04	0.82	2.29	0.36	2.29	0.47	1.32	0.20	1.28	0.20	1.44	0.11	2.06	0.07	0.10
GM106	4.8	0.43	10.2	15	31	70	97	18	95.2	19.2	13.5	371	13	55	2.3	0.23	0.52	0.08	0.32	143	6.4	14.2	1.87	8.3	2.01	0.85	2.18	0.35	2.18	0.45	1.27	0.19	1.25	0.20	1.58	0.15	2.89	1.31	0.52
GM107	2.6	0.45	9.2	26	71	63	92	12	90.6	19.8	15.3	377	14	59	2.5	0.23	0.55	0.08	0.37	154	6.9	15.6	2.06	9.0	2.16	0.88	2.36	0.37	2.30	0.47	1.33	0.20	1.31	0.21	1.69	0.16	2.82	1.45	0.57
GM108	1.9	0.40	9.8	100	21	65	94	14	85.9	18.1	13.0	351	13	54	2.1	0.19	0.53	0.07	0.36	138	6.1	13.6	1.81	8.0	1.96	0.81	2.17	0.35	2.20	0.46	1.28	0.20	1.30	0.21	1.57	0.14	2.49	1.27	0.51
GM109	2.7	0.39	10.7	40	244	70	102	18	90.6	18.6	11.0	359	13	49	2.0	0.21	0.49	0.23	0.16	135	5.8	12.9	1.71	7.6	1.85	0.79	2.09	0.34	2.15	0.45	1.28	0.19	1.30	0.21	1.41	0.13	2.60	1.10	0.42
GM110G	1.6	0.00	17.5	51	24	80	28	21	75.0	8.0	0.1	2	33	21	0.0	0.08	0.09	0.01	0.00	1	0.3	0.7	0.10	0.8	0.73	0.45	2.39	0.57	4.60	1.11	3.41	0.57	4.01	0.66	0.32	0.00	0.29	0.03	0.03
GM110H	9.4	0.42	8.3	201	37	103	183	19	151.1	24.7	6.5	89	8	50	3.4	0.22	0.78	0.05	0.02	66	5.7	18.1	2.90	14.0	3.55	1.15	3.14	0.39	1.83	0.30	0.67	0.08	0.45	0.06	1.84	0.16	0.97	0.36	0.16
GM110M	5.4	0.42	8.9	74	22	63	95	13	86.8	19.7	4.9	428	11	48	2.2	0.20	0.63	0.02	0.02	108	5.8	14.0	1.94	8.7	2.13	0.89	2.11	0.32	1.93	0.39	1.04	0.15	1.01	0.16	1.48	0.17	2.15	0.53	0.26
GM111	3.8	0.39	9.9	79	21	71	97	13	88.6	17.2	11.6	338	13	54	2.1	0.22	0.96	0.08	0.28	133	6.0	13.6	1.81	8.1	2.01	0.80	2.16	0.35	2.17	0.45	1.28	0.19	1.26	0.20	1.52	0.15	2.50	1.19	0.47
GM112	4.2	0.38	10.1	81	26	69	104	17	88.5	17.5	11.5	344	13	48	2.0	0.19	0.50	0.08	0.25	128	5.8	12.8	1.68	7.5	1.87	0.79	2.09	0.34	2.13	0.45	1.27	0.19	1.25	0.20	1.39	0.14	2.59	1.16	0.45
GM113	2.6	0.40	9.3	75	19	69	102	16	88.0	18.4	7.4	369	13	54	2.2	0.19	0.46	0.21	0.07	134	5.9	13.4	1.78	7.9	1.95	0.80	2.12	0.35	2.16	0.45	1.28	0.19	1.23	0.20	1.51	0.14	2.60	0.73	0.34
GM114	3.3	0.35	10.0	81	22	74	110	22	88.6	17.4	3.0	338	13	45	2.0	0.10	0.44	0.09	0.02	84	4.9	11.7	1.59	7.2	1.86	0.70	2.07	0.33	2.13	0.45	1.27	0.20	1.30	0.21	1.31	0.12	1.72	0.12	0.11
GM115	3.0	0.41	9.9	87	24	63	89	13	88.6	18.5	8.8	359	13	60	2.3	0.16	0.50	0.04	0.07	133	5.9	13.6	1.84	8.1	2.06	0.83	2.23	0.36	2.22	0.46	1.29	0.19	1.26	0.20	1.67	0.15	2.62	0.59	0.30
GM116	3.9	0.41	9.3	84	21	59	82	12	82.6	18.8	10.5	371	14	56	2.2	0.18	0.50	0.04	0.12	133	6.1	13.9	1.85	8.1	2.05	0.84	2.32	0.37	2.34	0.48	1.37	0.20	1.32	0.21	1.58	0.14	2.95	0.83	0.38
GM117	4.4	0.41	9.7	91	23	60	82	12	82.3	19.1	5.4	375	15	55	2.4	0.17	0.63	0.01	0.02	122	6.1	14.2	1.94	8.6	2.16	0.86	2.42	0.39	2.40	0.51	1.39	0.21	1.35	0.21	1.58	0.15	2.38	0.23	0.17
GM118	5.5	0.38	10.2	99	29	65	89	16	90.2	18.6	3.0	350	15	52	2.5	0.13	0.54	0.01	0.01	93	5.0	12.7	1.83	8.2	2.11	0.83	2.35	0.38	2.39	0.50	1.41	0.21	1.41	0.23	1.49	0.15	1.60	0.08	0.08
GM119	4.1	0.37	10.2	101	28	69	103	19	91.6	18.7	2.2	362	15	48	2.2	0.13	0.47	0.00	0.01	84	4.8	12.5	1.78	8.3	2.07	0.84	2.32	0.39	2.45	0.50	1.39	0.21	1.38	0.22	1.37	0.14	1.50	0.02	0.03
GM120	3.6	0.43	9.8	96	30	58	84	15	88.5	19.6	13.9	389	14	63	2.6	0.17	0.52	0.03	0.15	149	6.2	14.2	1.90	8.4	2.04	0.83	2.27	0.36	2.24	0.47	1.32	0.20	1.27	0.21	1.71	0.17	2.66	0.75	0.36
GM121G	4.2	0.02	17.5	47	19	79	27	14	61.3	8.0	2.3	9	28	51	1.4	0.31	0.21	0.01	0.06	14	0.8	1.5	0.18	1.0	0.77	0.48	2.36	0.54	4.14	0.97	2.88	0.46	3.13	0.52	0.93	0.15	0.21	0.19	0.12
GM121H	24.5	0.46	8.5	220	41	107	214	29	148.6	25.4	4.1	94	9	61	3.4	0.29	0.93	0.01	0.03	69	6.0	18.8	3.04	14.8	3.84	1.20	3.41	0.41	1.97	0.32	0.73	0.09	0.53	0.08	2.13	0.18	0.91	0.34	0.18
GM121M	18.8	0.44	9.7	84	17	62	96	20	86.7	19.1	3.3	480	14	57	2.2	0.25	0.56	0.00	0.01	100	5.9	14.5	2.03	9.1	2.22	0.93	2.42	0.38	2.36	0.49	1.33	0.20	1.29	0.20	1.69	0.14	2.05	0.17	0.13
GM122	3.7	0.30	10.6	81	28	98	147	35	113.4	15.6	8.6	312	10	37	1.5	0.18	0.40	0.04	0.20	117	4.4	9.7	1.31	5.9	1.46	0.68	1.61	0.26	1.64	0.34	0.96	0.14	0.96	0.16	1.09	0.10	2.51	0.73	0.28
GM123	5.8	0.37	10.7	97	28	78	103	16	102.5	17.1	11.8	348	12	49	2.0	0.28	0.58	0.06	0.29	137	5.7	12.6	1.70	7.5	1.84	0.78	2.02	0.33	2.02	0.42	1.18	0.18	1.17	0.18	1.42	0.14	2.50	1.05	0.40