2007-2008 PROJECTS:

**Tectonic and Climatic Forcing of the Swiss Alps**
John Garver (Union College), Mark Brandon (Yale University), Alison Anders (University of Illinois), Jeff Rahl (Washington and Lee University), Devin McPhillips (Yale University)

Students: William Barnhart, Kat Compton, Rosalba Queirolo, Lindsay Rathnow, Scott Reynhout, Libby Ritz, Jessica Stanley, Michael Werner, Elizabeth Wong

**Geologic Controls on Viticulture in the Walla Walla Valley, Washington**
Kevin Pogue (Whitman College) and Chris Oze (Bryn Mawr College)

Students: Ruth Indrick, Karl Lang, Season Martin, Anna Mazzariello, John Nowinski, Anna Weber

**The Árnes central volcano, Northwestern Iceland**
Brennan Jordan (University of South Dakota), Bob Wiebe (Franklin & Marshall College), Paul Olin (Washington State U.)

Students: Michael Bernstein, Elizabeth Drewes, Kamilla Fellah, Daniel Hadley, Caitlyn Perlman, Lynne Stewart

**Origin of big garnets in amphibolites during high-grade metamorphism, Adirondacks, NY**
Kurt Hollocher (Union College)

Students: Denny Alden, Erica Emerson, Kathryn Stack

**Carbonate Depositional Systems of St. Croix, US Virgin Islands**
Dennis Hubbard and Karla Parsons-Hubbard (Oberlin College), Karl Wirth (Macalester College)

Students: Monica Arienzo, Ashley Burkett, Alexander Burpee, Sarah Chamlee, Timmons Erickson, Andrew Estep, Dana Fisco, Matthew Klinman, Caitlin Tems, Selina Tirtajana

**Sedimentary Environments and Paleoeconomy of Proterozoic and Cambrian “Avalonian” Strata in the United States**
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)

Students: Evan Anderson, Anna Lavarreda, Ken O’Donnell, Walter Persons, Jessica Williams

**Development and Analysis of Millennial-scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)**
Greg Wiles (The College of Wooster)

Students: Erica Erlanger, Alex Trutko, Adam Plourde

**The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico**
Tim Ku (Wesleyan University) Suzanne O’Connell (Wesleyan University), Anna Martini (Amherst College)

Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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ORIGIN OF BIG GARNETS IN AMPHIBOLITES DURING HIGH-GRADE METAMORPHISM, ADIRONDACKS, NY: p129-134
   Project faculty:
   KURT HOLLOCHER: Union College

DETERMINATION OF THE DURATION OF RETROGRADE METAMORPHISM AT GORE MOUNTAIN AND RUBY MOUNTAIN, NY: p135-139
   ALDEN DENNY: Western Washington University
   Research Advisor: David Hirsch

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   ERICA EMERSON: Mount Holyoke College
   Research Advisor: Darby Dyar

COMPARISON OF THE WARRENSBURG AND GORE MOUNTAIN BIG-GARNET AMPHIBOLITES, ADIRONDACK MOUNTAINS, NY: p145-150
   KATHRYN M. STACK: Williams College
   Research Advisor: Reinhard A. Wobus

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)
INTRODUCTION

The megacrystic garnet amphibolites of the Adirondacks are among the most conspicuous and intriguing Proterozoic rocks of the region. Although garnet is a common mineral in the crystalline rocks of New York, a number of localities in the south-central and eastern Adirondacks host hornblende-rimmed garnet porphyroblasts of unusually large size (Fig. 1). It has been reported that the garnets can be as large as 1 meter in diameter, although a range of 5-35 cm is more common (Krieger, 1937; Ciurca, 1962).

This study presents a comparison of the mineralogy and geochemistry of the Warrensburg and Gore Mountain big-garnet amphibolites as a way to further constrain the formation of the Adirondack mega-garnet deposits. We employ modern analytical methods not available in many of the previous studies in order to provide a higher level of precision in the geochemical descriptions and comparisons. The mineralogy and bulk chemistry at the two localities serve as the basis for preliminary thermodynamic modeling that attempts to (1) identify the pressure and temperature constraints on the Warrensburg big-garnet amphibolite, and (2) test whether silica-rich partial-melt was involved in the formation of the big-garnet porphyroblasts.

FIELD SITES

Warrensburg

Located in the southwest corner of the Bolton quadrangle, this occurrence provides excellent three-dimensional exposures in two roadcuts along Wall Street, just east of Interstate Highway 87 about 1.5 km northeast of Warrensburg, NY. The Warrensburg big-garnet amphibolite occurs at the edge of a meta-gabbro body, and is cut through by a deformed syenite dike. Gneissic syenite and granite occur at the northern contact of the exposure.

Gore Mountain

The Gore Mountain big-garnet deposit is located in the Thirteenth Lake Quadrangle, in the town of North River, NY. This site is approximately 30 km northwest of Warrensburg in an area underlain by meta-anorthosite, meta-syenite, meta-gabbro, and amphibolite. The garnet ore body occurs as an E-W trending lens-like deposit nearly 1.2 km long, vary-
ing between 15 to 100 m in width. The big-garnet amphibolite grades into an olivine corona gabbro to the north and a garnet-rich gabbroic anorthosite to the east. The ore body is in contact with anorthosite to the west, and is in fault contact with pyroxene-rich syenite to the south.

Sample Collection

Fieldwork took place June 25th through June 27th, 2007. Samples of the Warrensburg big-garnet amphibolite were collected at five locations along the Wall Street roadcut. The primary objective in the field was to collect samples containing representative matrix and coarse garnet-bearing zones. Gore Mountain samples were collected at the historic Barton Mine from three inactive open pit mines. Samples of the olivine corona gabbro, small-garnet rock, large-garnet rock, hornblendite, and matrix were collected from both the floor and walls of the pits.

PETROGRAPHY

Warrensburg

The Warrensburg garnet occurs almost exclusively in irregular coarse patches (8-20 cm) of garnet, plagioclase, orthopyroxene, hornblende, and biotite, with essentially no garnet in the matrix. Some, but not all of the garnet porphyroblasts are surrounded by hornblende rims, and many of these rims are discontinuous (Fig. 2A). Coarse zones commonly contain several garnet porphyroblasts in a row. Within the coarse zones, subhedral to anhedral grains of orthopyroxene range in size from 1-25 mm, and plagioclase occurs in polygonal aggregates of subhedral to anhedral grains (Fig. 2B). Accessory pyrrhotite, ilmenite, apatite, and zircon have been identified within these coarse patches.

The garnet porphyroblasts and coarse zones are set in a matrix containing brown hornblende (45-55%), plagioclase (30-35%), highly altered orthopyroxene (2-15%), and biotite (5-10%). Opaque minerals including pyrrhotite and ilmenite make up 1 to 2% of the matrix. Trace amounts of clinopyroxene have been identified with the SEM. The matrix amphibolite is granoblastic, with no evidence of relict igne-
ous minerals (Fig. 2C). Although the biotite grains show no preferred alignment, the subhedral to anhedral grains of hornblende (1.4-4.5 mm) exhibit a weak preferred orientation of cleavage in some thin section samples. Subhedral to anhedral plagioclase ranges in size from 1-2 mm. Altered and serpentinized orthopyroxene occurs as anhedral to subhedral grains in linear masses (<1.5 mm).

**Gore Mountain**

The petrography of the Gore Mountain big-garnet amphibolite has been extensively discussed by a number of previous workers (Levin, 1950; Bartholomé, 1960; Luther 1976; Goldblum and Hill, 1992; Kelly and Darling, 2002). Garnet occurs in the Gore Mountain Barton Mines ore body predominantly as hornblende-rimmed porphyroblasts ranging in size from 1mm to ~35 cm (Fig. 3A). Elongate pressure shadows of coarse plagioclase, orthopyroxene, and hornblende trail many of the garnet porphyroblasts. Parallel fracture planes characterize the garnet porphyroblasts. Symplectite rims (~1.0-1.5 mm) of plagioclase, orthopyroxene, and hornblende surround some, but not all, of the small garnets (0.5-1 cm) examined in thin section, and most or all of the big garnets (Fig. 3B).

The Gore Mountain garnet porphyroblasts are set in a granoblastic matrix that contains green hornblende (35-70%), anhedral plagioclase (20-35%), highly pleochroic orthopyroxene (10-25%), and biotite (<1%) exhibiting no preferred alignment. Trace amounts of apatite, ilmenite, and pyrrhotite are also found in the matrix. Micro-scale symplectite boundaries between grains of hornblende, plagioclase, orthopyroxene, and biotite are common in the matrix (Hollocher, this volume, Fig. 4B-C).

**GEOCHEMISTRY**

Minerals from eight polished Warrensburg sections and three Gore Mountain thin-sections were analyzed for major element chemistry by SEM-EDS at Union College. Approximately five points per grain were analyzed for plagioclase, hornblende, and orthopyroxene found in the Warrensburg matrix and coarse zones and the Gore Mountain matrix. These analyses along with garnet compositions are plotted on triangular diagrams in Figure 4. Major element traverses of both the Warrensburg and Gore Mountain small garnet porphyroblasts showed little to no evidence of zoning. Average compositions for the major minerals of the Warrensburg and Gore Mountain big-garnet amphibolites are reported in Table 1.

In the laboratory at Union College, 43 bulk samples from Gore Mountain and 4 samples from Warrensburg were prepared and analyzed for minor and trace element chemistry by ICP-MS. Gore Mountain samples included corona gabbro, small-garnet
amphibolite, matrix, hornblendite, and garnet. The four analyses from Warrensburg included two matrix samples and two samples from coarse zones of garnet, plagioclase, orthopyroxene, and hornblende.

Both the Warrensburg matrix amphibolite and the coarse patches are enriched in REEs relative to chondrites (Figure 5A). Matrix samples are slightly more enriched in the LREEs than are coarse zone samples, which are more enriched in the HREEs, a trend that is consistent with garnet’s affinity for the HREEs. The four Warrensburg samples show no Eu anomalies.

The Gore Mountain matrix corona gabbro, matrix amphibolite, and hornblendite rims show enrichment in the REEs relative to chondrites (Figure 5B). The matrix and corona gabbro samples are LREE-enriched, and the corona gabbro and matrix show slight positive Eu anomalies.

**THERMODYNAMIC MODELING**

The upper amphibolite-grade of the Gore Mountain big-garnet ore has been estimated based on stability ranges of the major mineral phases (Goldblum and Hill, 1992; J. McLelland, pers. comm., 2007); no such conditions have yet been published for the Warrensburg big-garnet amphibolite. The bulk chemical analyses and mineral chemistry of the Warrensburg coarse zones are serving as the basis for ongoing thermodynamic modeling in the program Perple-X 07.

A number of simulations constrained by the Warrensburg coarse-zone bulk composition have been modeled in Perple-X. Reasonable stable mineral phases (gnt+hbl+plag+OPX+il±qtz) in agreement with the mineral phases observed in the coarse pockets at Warrensburg.

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<th>Warrensburg Matrix</th>
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<td>Plagioclase</td>
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<td>Orthopyroxene</td>
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<tr>
<td>Garnet</td>
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<th>Gore Mountain Matrix</th>
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Table 1. Average chemical composition for the major minerals of the Warrensburg and Gore Mountain big-garnet amphibolite.
have been calculated over a range of pressures (6-8 kbars) and temperatures (800-1200 ºC). Work involving the addition of a silica-rich partial melt phase and further constraint of the thermodynamic calculations with various solution models is currently in progress.

**COMPARISON OF THE BIG-GARNET AMPHIBOLITES**

The Warrensburg big-garnet amphibolite, referred to by McLelland et al. (2002a) as a “Poor Man’s Gore Mt,” has a mineral assemblage similar to that of the Gore Mt. Barton Mines ore-body. While both big-garnet amphibolites consist of large garnet porphyroblasts set in a matrix of hornblende-plagioclase-orthopyroxene-biotite±CPX, a number of textural, mineralogical, and geochemical distinctions can be made. Garnet porphyroblasts are generally smaller and less abundant at Warrensburg than at Gore Mountain, and garnets with thick, continuous hornblendite rims like that seen in Figure 3A are rare at Warrensburg. The Warrensburg matrix contains more biotite and brown hornblende and is finer-grained than the Gore Mountain matrix. The Gore Mountain matrix hosts abundant orthopyroxene and green hornblende and is characterized by symplectite reactions rims, both around garnets and at a finer-scale between matrix grains (Fig. 3B).

The average chemical compositions obtained by SEM-EDS analysis for the major mineral constituents of the amphibolites reveal that the Gore Mountain matrix plagioclase is more calcic than the Warrensburg plagioclase (Fig. 4A). The Warrensburg garnets, hornblende, and orthopyroxene are Fe-rich compared to the Gore Mountain minerals, which are relatively enriched in Mg (Fig. 4B). While there may be a slight enrichment of Mg in the Warrensburg coarse zone orthopyroxene relative to the Warrensburg matrix orthopyroxene, the diagrams in Figure 4 reveal that major mineral chemistry of the coarse zones and matrix are nearly indistinguishable.

Preliminary thermodynamic modeling suggests that the Warrensburg big-garnet amphibolite initially formed under upper-amphibolite facies conditions similar to the Gore Mountain garnet body. However, the textural differences between the samples from Warrensburg and Gore Mountain suggest that the two big-garnet amphibolites experienced unique late-stage P-T conditions. The symplectite rims and grain boundaries of the Gore Mountain rocks may indicate a depressurization event not experienced by the Warrensburg rocks (K. Hollocher, pers. comm., 2008).

We also recognize a likely difference in the original composition of the two big-garnet amphibolite protoliths. The enrichment of the Warrensburg samples in all REEs relative to the Gore Mountain rocks suggests that the Warrensburg protolith may be more evolved, i.e. by crystal fractionation, than the Gore Mountain corona gabbro. This trend is also consistent with the higher Ti and K abundances in the Warrensburg rocks (Hollocher, this volume). The REE plots of the Gore Mountain rocks show a slight positive Eu anomaly, consistent with the interpreta-
tion of the corona gabbro as a layered cumulate. The Warrensburg rocks do not show any Eu anomaly, but this comparison is difficult to make because the Warrensburg protolith may or may not be a cumulate.

FUTURE WORK

The similarities and differences between the Warrensburg and Gore Mountain big-garnet amphibolites identified in this study will be useful in interpreting and evaluating the results of future thermodynamic modeling that more tightly constrains the conditions and origins of the Adirondack mega-garnet formation. Future work should also include locating (if possible) and analyzing samples of the protolith gabbro of the Warrensburg big-garnet amphibolite that would allow for more extended comparison between the two big-garnet amphibolites.

REFERENCES


