An Analysis of an Appalachian Metamorphic Suite

Chadwick A. Williams
Grand Valley State University

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An Analysis of an Appalachian Metamorphic Suite

Introduction

The Eastern Blue Ridge Mountains of North Carolina are home to high-grade Taconian metamorphic rock suites in the Appalachian Mountains. The significant pressures and temperatures experienced by these rocks suggest that they are formed in the lower crust. The rocks of interest to this study are found in the areas of Winding Stair Gap and Chunky Gal Mountain in southwestern North Carolina (Figure 1). Rocks from the Winding Stair Gap preserve granulite facies conditions (850°C, 8kbar) while data from the Chunky Gal complex preserve lower P-T conditions (520°C-725°C, 4-6 kbar) typical of amphibolite facies (McElhaney and McSween, 1983). The mineral textures and compositions are examined to determine pressures and temperatures of peak metamorphism. The presence of particular minerals can be useful in determining these peak conditions because different mineral assemblages are stable at different pressures and temperatures. There can be difficulty with determining the temperatures and pressures of formation during mountain building processes because minerals can re-equilibrate as they are brought toward the surface by uplift and erosion which removes the history of previously formed minerals. For this study, I examined the mineral texture and composition of rocks from the Jake Ridge exposure to characterize the deformation history and compare the metamorphic conditions to rocks from the Winding Stair Gap.

Regional Setting and Previous Work

Rocks from the Jake Ridge outcrop located along the Chunky Gal Mountain fault are very aluminous with similar mineral assemblages and compare to rocks from the Winding Stair Gap outcrop. A focus of this project is to determine whether the difference in P-T estimates at Winding Stair Gap and the Chunky Gal area are true or due to differences in rock composition and mineral assemblage or re-equilibration. Examining mineral assemblages and textures in rocks from Jake Ridge to determine if the rocks underwent similar deformation to aluminous rocks from Winding Stair Gap without preserving peak metamorphism may help to further constrain metamorphic zones in this region. If Jake Ridge rocks found along the Chunky Gal Mountain Fault preserve evidence of granulite-facies metamorphism, it is possible that a greater extent of Central Blue Ridge rocks have been more deeply buried than previously thought.

Previous work in the Central Blue Ridge has examined the peak metamorphic conditions of rocks in the vicinity of the Winding Stair Gap and Chunky Gal Mountain metamorphic suites. Moecher et al. (2004) determined peak metamorphism in Winding Stair Gap to be at 850°C and 8kbar. McElhaney and McSween (1983) determined peak metamorphic condition in the amphibolites of the Chunky Gal Mountain complex to be 520°C-725°C and 4-6 kbar. The temperatures and pressures of peak metamorphism of the Buck Creek Complex have been constrained to 850°C and 9-10 kbar based on sapphireine replacement of spinel (Tenthorey et al., 1996). This supports the theory that rocks outside of the current zone of granulite facies may have reached higher peak metamorphic conditions than indicated by the Chunky Gal Mountain data. Preservation of a complex metamorphic history in Jake Ridge samples may provide further constraints on the metamorphic and tectonic history of this part of the Central Blue Ridge.

Methods

Sample Analysis: Jake Ridge

Descriptive analysis was conducted on an oriented sample from the Jake Ridge outcrop to characterize the mineralogy and textures (Figure 2). Thin section observations helped identify key areas for analysis using the scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS).
X-ray Mapping

The Jake Ridge thin section was examined using a Hitachi 9300 SEM/EDS at Hope College. The SEM/EDS was used to obtain x-ray maps and point analyses. The slide was carbon coated because rock thin sections were non-conductive. Thin-section slides were mounted onto a pedestal and placed within the evacuation chamber of the SEM. Air is then evacuated from the SEM over a period of approximately two minutes. Once the air is removed, the cathode lens of the microscope began to create a focused beam of electrons that hit and bounced off the surface of the slide. The beams of electrons were at different angles that depended on the elemental composition of the target. These refracted beams were detected and used to produce an image of the slide surface. The elemental composition was also detected and recorded (Figure 3). X-ray maps were created by counting electrons over an area on the slide for a longer period of time in order to observe any variations in mineral chemistry within and among grains.

Point Analysis

To determine the composition of specific points within a mineral grain, the beam was focused on a very small area of the grain. To constrain data for thermobarometry, the elements that were recorded for point analysis were oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K), iron (Fe), titanium (Ti), sodium (Na), calcium (Ca), and manganese (Mn). Point analysis was performed on sites identified in the thin section based equilibrium composition. Point analyses that represent peak metamorphic equilibrium conditions were collected from a garnet core with biotite and plagioclase inclusions. The atomic wt% of each element was converted to wt% oxides and used with the Thermobarometry with Estimation of Equilibrium State (TWQ) computer program. The garnet, biotite and sillimanite weight % oxides, which were determined from SEM/EDS data, were used to obtain preliminary pressures and temperatures for peak metamorphism for the Jake Ridge sample.

TWQ Analysis

The TWQ computer program facilitated the calculation of mineral-fluid equilibria by using an internally consistent thermodynamic database for metamorphic minerals in chemical-equilibrium (Berman 2007). Selected elemental data obtained with the SEM/EDS were input into the TWQ program. The oxide data from garnet and biotite grains, namely the exchange between Fe and Mg, were used for thermometry. Oxide data from the Al-Si exchange between garnet and plagioclase were used for barometry.

Results

Descriptive Analysis

Hand sample and thin section analysis of the Jake Ridge rock show that the rock-forming minerals abundant in the sample are garnet, sillimanite, biotite, plagioclase and quartz. In thin section, garnet grains form large porphyroclasts and compose approximately 40% of the slide. None of the garnets exhibit a euhedral crystal form. They range from 2-5 mm in size and some grains contain inclusions. The cores of the garnet grains are approximately 0.5 mm in diameter and contain inclusions of biotite, plagioclase, quartz, and accessory minerals (Figure 4). In some grains, the inclusions seem oriented in a position perpendicular to the matrix fabric. The zone surrounding the cores of the garnets is inclusion-free. These zones extend to the rims and tails of the garnet grains and are approximately 1 mm wide. Garnet crystals which have tails contain thin, fibrous sillimanite grains within those tails. The fibrous sillimanite inclusions are oriented parallel to the sillimanite grains within the matrix. Figure 3 is an x-ray map of a garnet with inclusions and Figure 4 are examples of the garnet grains with an inclusion rich core, an inclusion free zone surrounding the core and the sillimanite-rich tails.

A final stage of mineral ground can be identified within the fractured zones of garnet grains. Some minerals in these zones are not found as garnet inclusions or within the ground mass. K-feldspar grains that are rimmed by grains with a myrmekitic texture are found in these fractured zones. The photomicrographs in Figure 5 show a specific location in both plain and cross-polarized light. In this area, the k-feldspar appears at the borders of fractured garnet crystals. There are also mica grains found in the fractured zones that are pleochroic, ranging from colorless to a pale green color in plain polarized light. Figure 6 shows two locations in the thin section where these grains can be identified. In both areas, the pale green mica is located in the cracks of broken garnet crystals along with biotite. The mica can be found in several other locations in the thin section but is always found within or along the edges of fractured garnet crystals.

The groundmass of the sample is primarily comprised of sillimanite, biotite, plagioclase and quartz. Sillimanite forms as coarser prismatic grains and are thicker than those found as fibrous inclusions in the garnet tails. Platy biotite grains are interspersed with the sillimanite grains and the two minerals sweep around garnet grains as shown in Figure 2.

Compositional Mapping

A magnesium (Mg) x-ray map was produced for a garnet porphyroblast that contained biotite and sillimanite inclusions (Figure 3). The map shows that Mg is concentrated uniformly across the grain but is slightly less concentrated at the rim of the grain. Similar homogeneity is observed for other elements. The map shows that Mg concentration becomes lower in the garnet at grain edges where biotite in the groundmass is adjacent to the garnet grain. Mg concentration is high in the biotite but depleted in the garnet. The point analyses that were completed using the EDS produced data tables showing the distribution of selected elements (O, Si, Al, Mg, K, Fe, Ti, Na, Ca, and Mn). Point analyses were also used to confirm the mineralogy of accessory minerals which include monazite, apatite, and ilmenite.

Discussion

Textural Analysis

The textures of garnet porphyroblasts along with compositional zoning suggest that there are multiple stages of distinct garnet growth and deformation (Tracy and Robinson, 1976). This zoning can be seen in the photomicrographs of the garnet grain in figure 4. In that grain, the core is inclusion rich and it is surrounded by a zone that is void of inclusions. In the tail of the garnet, fibrous sillimanite inclusions can be identified. This could be proof that
The garnet experienced multiple growth stages: (i) initial growth that encompassed the grains at its center; (ii) a period of growth with no inclusions, and (iii) a final growth stage which included fibrous sillimanite in the tails.

The inclusion-rich garnet cores appear to preserve evidence of the earliest stage of growth. The next stage of growth could be defined by the inclusion-free zone surrounding the garnet's core. Because there are no inclusions within this area, it can be inferred that during this stage, no excess material was left to form inclusions. A third stage in the garnet's growth can be identified in the tails of the garnet grains where we find fibrous sillimanite inclusions. These sillimanite crystals are not prismatic as found in the matrix and this suggests that they formed along with the tails of the garnets, separate from the matrix material. The orientation of the fibrous sillimanite inclusions is parallel to the matrix fabric which suggests that they formed during the same deformation event that produced the mylonitic foliation in the matrix.

Some garnet grains have green mica located within the fracture zones of the grain (Figures 5 and 6). This shows that the mica mineralized as the garnet fractured and did not form prior to the garnet like the biotite inclusions. In this sample, the light green mica is only present within fracture zones of garnet crystals (Figure 6). The formation of these fracture zones could indicate the final deformation period for minerals in the Jake Ridge exposure in which garnet grains cooled and were fractured. K-feldspar was also identified in the fractured zones of garnet grains, but it was not abundant in the sample. K-feldspar was only observed within the fractured zones of garnet grains within the sample (Figure 5). In this figure, K-feldspar can be observed with myrmekitic texture lining the rim of the grains.

**X-ray Analysis and Thermobarometry**

The x-ray map obtained using EDS (Figure 3) does not show a fluctuation in Mg across the garnet grain containing the large biotite inclusion. This does not reveal the zoning that was expected to exist between the inclusion-rich and inclusion-free zones of the garnet. However, it does show homogenization across the garnet grain. Plagioclase and biotite could possibly serve as a key for maximum pressure of metamorphism. The garnet-plagioclase-sillimanite-quartz (GASP) barometer would be used to get pressure estimates and those estimates would be compared with values real values (Spear and Florence, 1992). Microprobe data will be necessary to identify this. Oxide data obtained from point analysis in and around the garnet in Figure 3 were used with TWQ to get P-T data. Figure 7 shows a pressure and temperature of peak metamorphism as well as the aluminosilicate phase diagram. The current P-T of 5.5-6 kbar and 600°C is not accurate given the element data. Due to homogeneity that we see across the x-ray maps, we expected to see higher temperatures and pressures with the TWQ plot. Further analysis with an Electron Microprobe should produce more accurate results.

**Conclusions**

The rocks from Jake Ridge are similar to rocks from Winding Stair Gap in regard to rock forming minerals (sillimanite, biotite, garnet, plagioclase, and quartz). Distinct zoning in garnet grains highlight multiple stages of crystallization and a final deformation event during which garnet grains cooled and fractured. Preliminary P-T data shows that rocks from Jake Ridge (600°C, 5.5-6 Kbar) did not reach temperatures and pressures as high as the rocks at Winding Stair Gap (850°C, 8 kbar). However, this is preliminary data and more specific P-T calculations may yield different results that could provide a better explanation for the history of rocks at the Jake Ridge and the overall history of the Central Blue Ridge Mountains.
Figure 1: This map shows the study area in the Blue Ridge Mountains of Southwestern North Carolina. JR: Jake Ridge, CG: Chunky Gal, WSG: Winding Stair Gap, BC: Buck Creek, LC: Lake Chatuge. The blue area represents the constraints of gruanlitech-facies metamorphism in the Central Blue Ridge. Adapted from Peterson and Ryan (2009).

Figure 2: A scan of the Jake Ridge thin section. Garnet grains appear as porphyroblasts with unusual tails. Sillimanite and Biotite form around garnet grains in the matrix. The boxes highlight the locations of other figures that show pertinent mineral assemblages.
Figure 3: Mg x-ray map of garnet 7. The green coloring indicates the magnesium-rich biotite grains. Some homogeneity of Mg concentrations is visible across the garnet grain. Core inclusions are plagioclase, quartz, biotite and accessory minerals (monazite, apatite, illmenite).
**Figure 4:** Photomicrographs showing a garnet grain in plain polarized light with inclusions in the center of the grain and the tail of the grain. The arrows in the left photo indicate the orientation of sillimanite inclusions. The area encompassed by red in the right photos shows the inclusion rich garnet core.
Figure 5: Microphoto of feldspar grains positioned within garnet crystals (Top: plain polarized light, Bottom: cross polarized light). A perthitic texture can be identified in the feldspar grains indicating that these are K-feldspar grains. Light green mica grains are also visible along the borders of the fractured garnet grains.
Figure 6: Photomicrographs of two fractured garnet grains viewed in plain polarized light (Top Left and Top Right) and cross polarized light (Bottom Left and Bottom Right). The light green mica is located in between fragments of garnet grains which were one at some point during crystallization.
Figure 7: This is a P-T plot produced using the TWQ program. The lines that form a triple point indicate the P-T borders between the polymorphs kyanite, sillimanite and andalusite. The lines that intersect just above the kyanite and sillimanite border indicate an estimate for the Jake Ridge peak metamorphic conditions (600°C, 5.5-6 Kbar).
References Cited


