Small Scale Retrograde Reaction Textures: Implications for Pressure and Temperature Evolution

Northeastern Vermont | USA

Seth M. H. Hansink

Mentored by Kim A. Hannula – Department Chair

Fort Lewis College, Geology

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ABSTRACT

The Victory Pluton, a Devonian aged granite in northeastern Vermont, is thought to have intruded during movement on the Monroe Fault. Metamorphic rocks in the contact aureole provide clues about the pressure and temperature changes during intrusion of the magma. The goal of this research project is to observe the metamorphic reaction textures within one sample from the eastern (uplifted) side of the fault to examine the temperature and pressure changes that occurred during metamorphism.

Five sites throughout the thin section were analyzed using a petrographic microscope and scanning electron microscope. There are two dominant porphyroblasts within the sample, garnet and cordierite. Sites 1-4 possess garnet porphyroblasts with cordierite and ilmenite inclusions and biotite and fibrolite surrounding the crystal in the pressure shadow. Site 5 contains cordierite porphyroblasts with plagioclase and biotite inclusions. Biotite and sillimanite are also contained in the pressure shadow surrounding the cordierite.

While the porphyroblasts vary between garnet and cordierite from each site, the minerals textures suggest that garnet and cordierite were consumed while biotite and sillimanite grew. This reaction takes place at temperatures between 600 and 800 degrees Celsius and pressures between 2 and 5 kilobars. This reaction is driven by either decreasing temperatures or increasing pressures. These reactions are consistent with cooling after the pluton intruded, or burial of the rocks after pluton intrusion, or both.

INTRODUCTION

In the Devonian Period, the Victory Pluton intruded across the Monroe Fault into a host of pelitic rocks. The contact aureole of western side of the fault provides evidence that the Victory Pluton was emplaced syn-tectonic and during burial. The eastern, uplifted side of the Monroe fault should possess reaction textures that demonstrate decreasing pressures respectively. However, this is not necessarily the case.

Petrographic analysis was conducted with the aim of observing metamorphic reaction textures and minerals in equilibrium. The goal for the rest of this paper is to present the reaction textures and mineral equilibria to decipher the inconsistencies regarding temperatures and pressures. The explanations presented can help further interpret the geologic history of the Vermont and potentially the rest of the Appalachians.

BACKGROUND

Geologic Setting

Appalachian Tectonics

It is easiest to understand a portion of New England's (Northeastern, Vermont) complicated geologic history by first dividing it into two mountain building events: the Taconian Orogeny and the Acadian Orogeny

The Taconian Orogeny took place in the Ordovician period of the geologic time scale (~450 million years ago) and was caused by the subduction of the eastern side of the North American continent underneath the Shelburne Falls Island Arc. Later, in the Devonian period (~420 million years ago), during the Acadian Orogeny the North American continent converged along a large-scale strike-slip fault with Avalonia, an ancient microcontinent. These two mountain building events makes up a large portion of the Appalachian history.

Stratigraphy

Woodland (1965) outlines the stratigraphy surrounding the Victory Pluton which can be viewed in figure 1. There are three mapped stratigraphic formations in the area: the Albee, Waits River, and Giles Mountain formations. The Albee formation is part of the "New Hampshire Sequence" while the Waits River and Giles Mountain formations are part of the "Vermont Sequence." These two sequences are divided by the Monroe Fault.

The Albee Formation consists dominantly of beds of pelitic rocks with amphibolite bands commonly located throughout. The Waits River formation comprises beds of limestone, pelitic rocks, and psammitic rocks, again, with amphibolite bands common. The rock types of the Gile Moutain formation include phyllitic rocks, ranging wide in color; quartzite and schist.

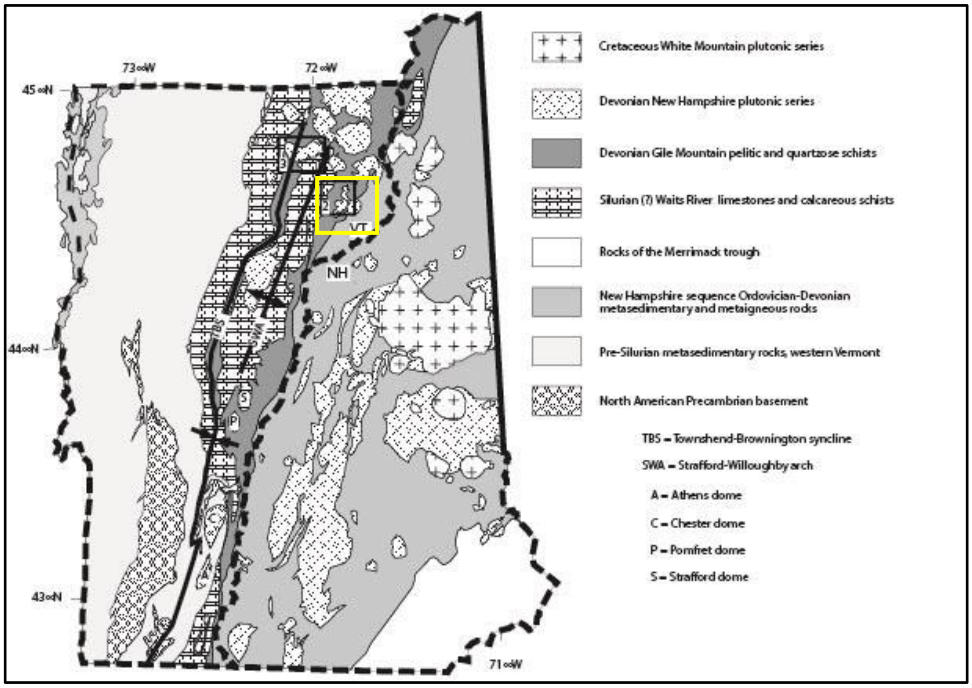


Figure 1. Simplified geologic map of New Hampshire and Vermont adapted from Hannula (1999). The yellow outline highlights the study area of the Victory Pluton and the Monroe Fault.

Victory Pluton and Monroe Fault

The Victory Pluton is a granitic intrusive body belonging to the New Hampshire plutonic series. According to the Vermont Geological Survey, the pluton is comprised of granite, quartz monzonite, granodiorite, diorite, and monzonite (Woodland, 1965). The Victory Pluton is Devonian in age. (Hannula 1999). Syn-tectonic metamorphic reaction textures suggest that this is, as well, the approximate age of movement along the Monroe Fault. The Monroe fault is a thrust fault and runs northeast-southwest and can be seen in figure 1.

Metamorphism of Pelites

Pelites are one of the most important metamorphic rocks such that they respond sensitively to changes in pressure and temperature. At low to moderate pressures, pelitic rocks have the most mineral changes as pressure and temperature change, which means that the minerals in the rocks are useful indicators of changing temperature and pressure conditions. This makes pelitic rocks good indicators of pressure and temperature during metamorphism (Spear 1995). Changes in temperatures in pressures are recorded within the mineral equilibrium. Understanding what is in equilibrium can lead to the interpretation of the temperatures and pressures experienced during metamorphism.

METHODOLOGY

This research paper uses one sample predominantly throughout. Sample NEK97-13 was collected on the eastern, uplifted side of the Monroe Fault by Kim Hannula in 1997. Thin section 7246 was cut from NEK97-13 and is the focus of analysis.

Sample NEK97-13 7246 is divided into specific areas of interest within the thin section, referred to as sites. There are five reaction sites across thin section 7246. Each reaction site exemplifies different metamorphic textures and minerals in equilibrium. I first used petrographic analysis to observe the reaction sites in interest using a Leica DM 750P petrographic microscope at 40x, 63x, and 100x zoom. Each metamorphic texture and mineral in equilibrium was described and imaged at 40x zoom using a Canon EOS Rebel T4i camera attachment.

After identifying reaction sites in thin section 7246 from sample NEK97-13, it was analyzed using the Fort Lewis College Scanning Electron Microscope over the course of two different sessions. The first session was focused heavily on imaging the metamorphic textures using backscatter electrons. Each of the five reaction sites were imaged at 40x zoom using the SEM with sites (x and y) imaged at 125x zoom. The second session used a combination of site and area spectrum analysis which allowed me and Dr. Hannula to identify the elemental composition of the minerals in equilibrium. The data was viewed using Aztec software, which is used to view the energy-dispersive x-ray spectroscopy of the sample.

In addition to the spectrum analysis conducted during the SEM sessions, electron microprobe data collected by Kim Hannula provided additional elemental composition data. This electron microprobe data was collected at Louisiana State University, 2003.

Review of published literature is used to help decipher the reactions which occurred during metamorphism and determine the pressures and temperatures accordingly.

OBSERVATIONS

Hand Sample and Field Description

NEK97-1311 is an ilmenite-bearing, chlorite-staurolite-sillimanite-biotite-garnet-cordierite-plagioclase-quartz gneiss with a porphyoblastic-gneissose foliation. The sample is silvery, light gray to gray-brown with alternating light and dark foliation bands.

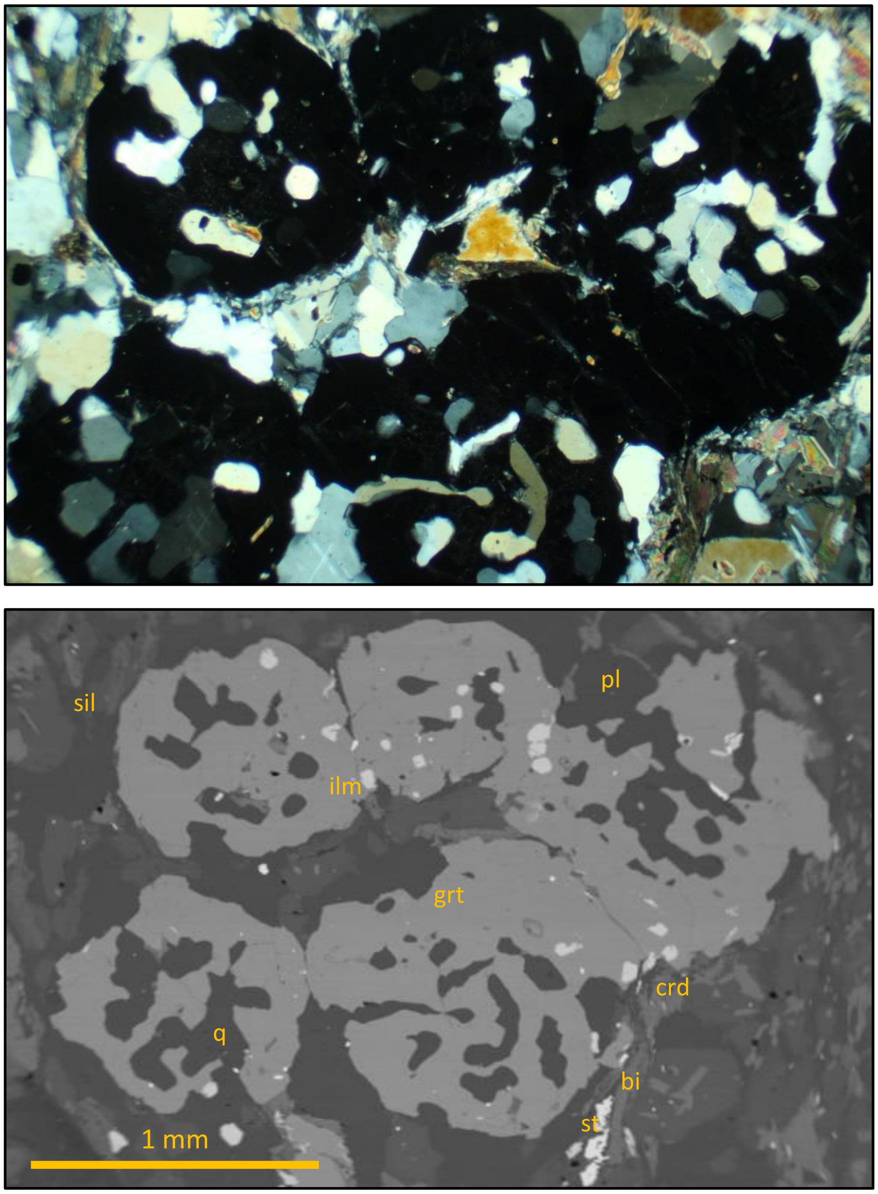
Petrographic Analysis

Sample NEK97-1311 thin section 7246 contains quartz, plagioclase, cordierite, garnet, biotite, sillimanite, staurolite, chlorite and ilmenite. Garnet and cordierite are located throughout the entire sample and are the dominant porphyroblasts.

Inclusions in the porphyroblasts vary between porphyroblasts in the sample, but are dominantly quartz, plagioclase, ilmenite and some biotite. Often, radioactive monazite is found included and breaking down in cordierite crystals, distinguished by their pleochroic halos in thin section.

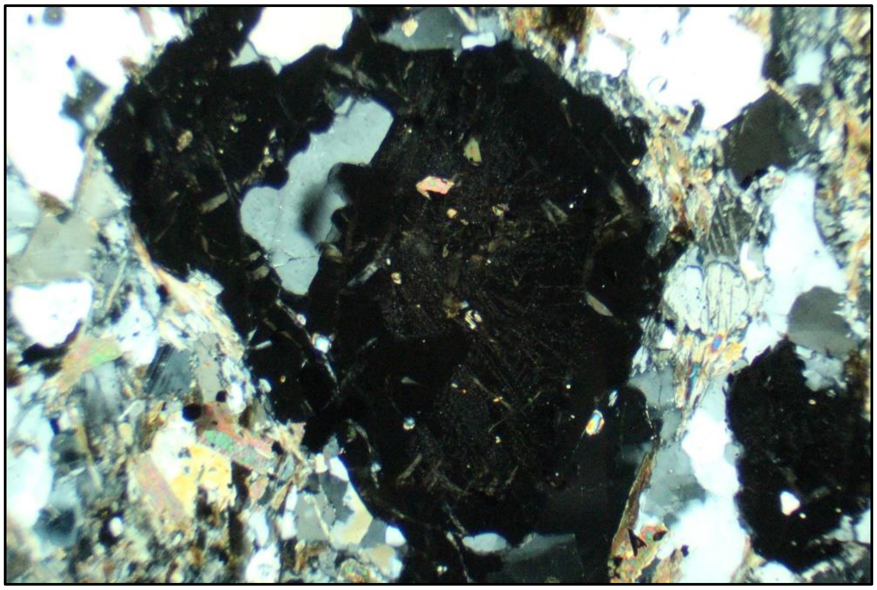
Pressure shadows surround almost all porphyroblasts within the sample. Elongated biotite crystals and fibrolite (fibrolitic sillimanite) predominately form the pressure shadows.

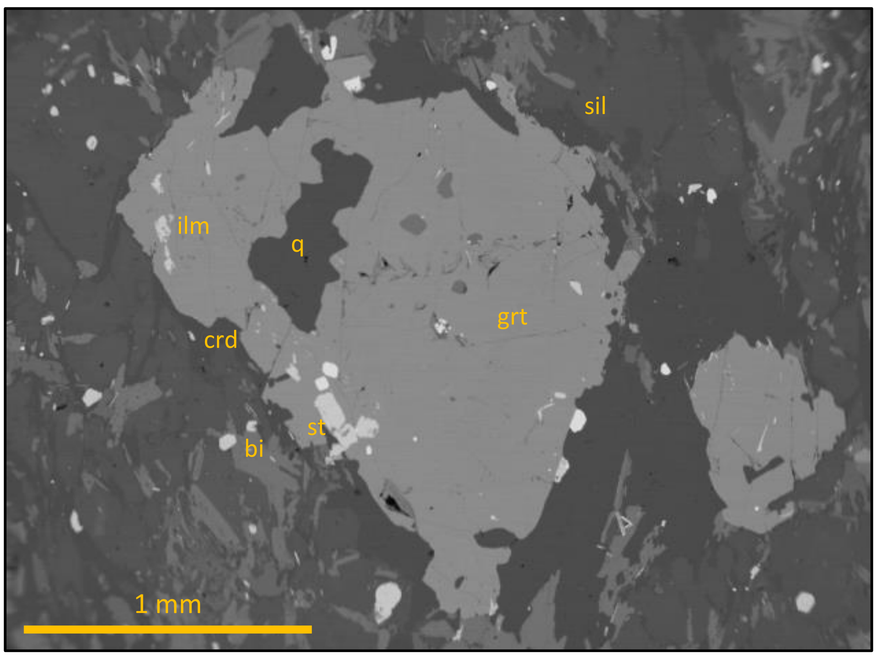
Although less common, garnet shreds and chlorite are also found in the pressure shadows of the garnet and cordierite porphyroblasts.



SITE 1. (Top) photomicrograph with polarized light. (Bottom) BSE – Image. 1 mm scale bar.

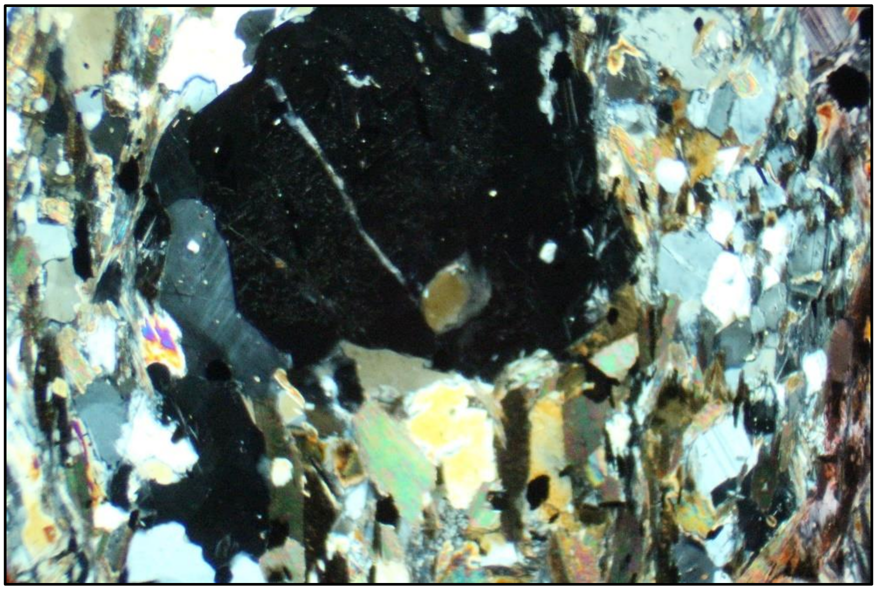
Cluster of skeletal, subhedral garnet porphyroblasts. Anhedral quartz, ilmenite, and plagioclase crystals are included within the garnet. Cordierite blebs are located near the garnet crystals, separated by quartz in contact with the garnet porphyroblasts. The matrix surrounding the garnet cluster is composed of fibrolite and elongated biotite crystals. Plagioclase and staurolite crystals are present near the porphyroblasts, separated by the fibrolite-biotite in the pressure shadow.

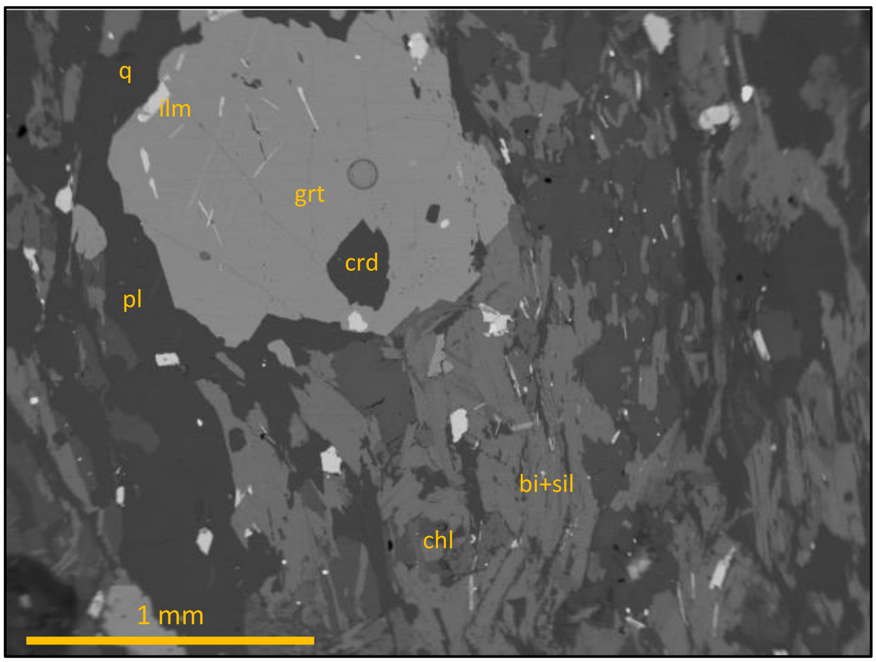




SITE 2. (Top) photomicrograph with polarized light. (Bottom) BSE – Image. 1 mm scale bar.

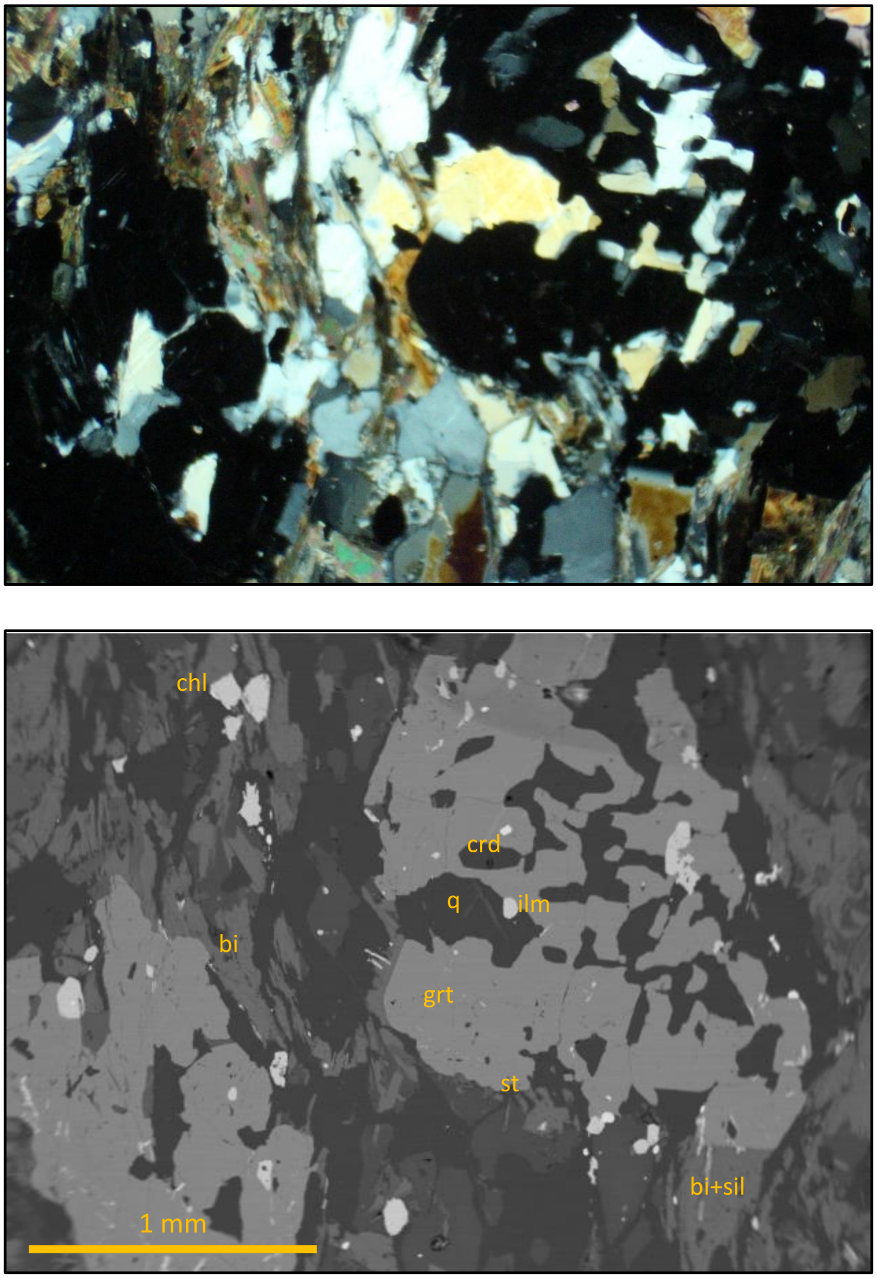
Subhedral garnet porphyroblast. The porphyroblast is notably fractured. Subhedral to anhedral quartz, plagioclase, biotite and ilmenite are included within the garnet crystal. Coarse sillimanite crystals are present near the porphyroblast, separated by both small quartz and cordierite blebs. Fibrolite, elongated biotite, and chlorite form the crude pressure shadow surrounding the garnet porphyroblast. Near the garnet, are tiny staurolite crystals and more plagioclase.





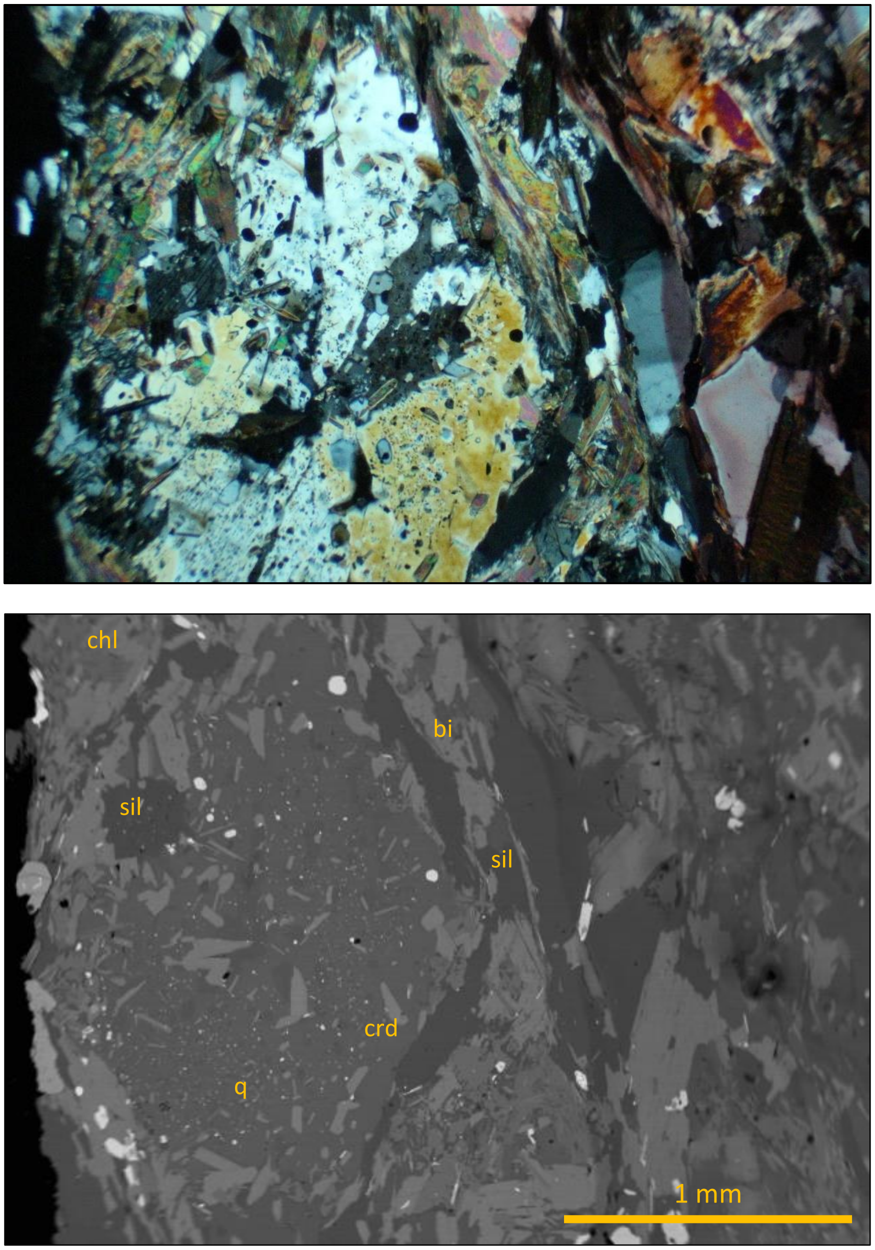
SITE 3. (Top) photomicrograph with polarized light. (Bottom) BSE – Image. 1 mm scale bar.

Subhedral fractured garnet porphyroblast. There are fewer inclusions in the site 3 porphyroblast than previous garnets. Still, quartz, cordierite, ilmenite and radioactively decaying monazite are included in the garnet crystal. Fibrolite, biotite, chlorite and garnet shreds compose the crude pressure shadow surrounding the garnet porphyroblast. Subhedral quartz crystals border the garnet boundary.



SITE 4. (Top) photomicrograph with polarized light. (Bottom) BSE – Image. 1 mm scale bar.

Pair of subhedral, skeletal garnet porphyroblasts. Quartz, cordierite and ilmenite are included in the garnet crystals. Fibrolite and elongated biotite crystals form the pressure shadow around the two garnet crystals. Notably, chlorite is in the pressure shadow, but possesses a radial habit. Relatively large quartz crystals border the garnet along with very small staurolite crystals.



SITE 5. (Top) photomicrograph with polarized light. (Bottom) BSE – Image. 1 mm scale bar.

Oval shaped, anhedral to subhedral skeletal cordierite porphyroblast. Quartz, ilmenite and biotite are included within the cordierite crystal. However, significantly more biotite is included in the cordierite than the previous garnet porphyroblasts. Radioactively decaying monazite is also present within the cordierite. Fibrolite, elongated biotite and chlorite form the pressure shadow around the porphyoblast. Included in, but not part of, the pressure shadow are plagioclase and coarse, zoned sillimanite.

DISCUSSION

There are two major porphyroblasts located throughout sample NEK97-13 7246, garnet and cordierite. The minerals in thin section demonstrate syn-tectonic metamorphic textures with pressure shadows surrounding the porphyroblasts. The pressure shadows are consistently comprised of elongated biotite and sillimanite. These pressure shadows are more commonly coupled with the cordierite porphyroblasts versus the garnet porphyroblasts and separate quartz and plagioclase in the matrix from the garnet and cordierite crystals. In addition, garnet and cordierite are also contained within the matrix in small amounts and uncommonly in the pressure shadows.

Relative Ages of Mineral Growth and Deformation

The metamorphic petrogenesis is recorded within sample NEK97-13 through the relative arrangement of porphyroblasts, mineral inclusions, and syn-tectonic reaction textures. We can assume through convention that the inclusions in the porphyroblasts predate the porphyroblasts themselves.

Both the garnet and cordierite crystals consistently contain similar inclusions: quartz, ilmenite, plagioclase, biotite, monazite and garnet and cordierite respectively. Still, minor differences occur in the amounts of each inclusion from garnet to cordierite such as cordierite containing greater amounts of biotite. Therefore, the quartz, ilmenite, plagioclase, biotite and monazite inclusions within the porphyroblasts must have been present before metamorphism.

After the Victory Pluton intruded into the host of pelitic rocks and across the Monroe Fault, the common porphyroblasts formed. During their formation, they included the pre-existing minerals into their crystal lattice as inclusions. Relatively simultaneous, the biotite and sillimanite pressure shadows formed syn-deformation duringthe crystallization of the garnet and cordierite.

Metamorphic Reactions

Originally, my first assumption was the presence of garnet and cordierite porphyroblasts suggested very different reactions were taking place on a small scale within the sample. However, this may not necessarily be the case. Biotite and sillimanite are consistently paired alongside garnet and cordierite throughout the thin section. Spear (1995), in his publication on metamorphic phase equilibria, outlines one key reaction that seems to be occurring. The reaction follows:

$$\mathbf{biotite + sillimanite = garnet + cordierite + H_2O}$$

Biotite and sillimanite forms in the retrograde from the consumption of garnet, cordierite and water. This reaction takes place at temperatures between 600 to 800 degrees Celsius and pressures between 2 and 5 kilobars. The presence of either a garnet or cordierite porphyroblast could be dependent on which of the two minerals is locally in excess.

Another, uncertain reaction that is occur seems to be occurring is the formation of tiny staurolite crystals. These tiny staurolite crystals are much more common forming on the border of the garnet crystals than the cordierite crystals. One explanation could be that the staurolite crystals form from the garnets due to localized increase amounts of Iron. Another, less likely explanation is that the staurolite growth is protected by the pressure shadows during deformation.

Implications of Pressure / Temperature Paths

Previous research conducted by Hannula concluded that the rocks in the contact aureole on western side of the Monroe Fault demonstrated the Victory Pluton intruded during burial. Increasing pressures caused kyanite to replace andalusite. The eastern, uplifted side of the fault should demonstrate a decrease in pressure. However, if they previously mentioned reaction occurred it would need an increase in pressure to take place.

The inconsistencies observed can be possibly explained by looking at the problem from different approaches. The first idea is that there is more thrusting local to the Monroe Fault. Additional thrusting in the region could lead to more rock being emplaced above the Victory Pluton during the time of intrusion, resulting in an increase in pressures syn-deformation. At the time of uplift, if erosion rates did not match the uplift rates or burial rates exceeded uplift rates then an increase in pressure would occur.

CONCLUSION

The Victory Pluton intruded across the Monroe Fault in the Devonian Period. The western side of the fault demonstrates reaction textures consistent with increasing pressures after intrusion. Evidence for this is kyanite replacing andalusite. A single sample, NEK97-13 thin section 7246, from the eastern side of the fault was analyzed.

Sample NEK97-13 7246 contains both garnet and cordierite porphyroblasts in abundance. Included in the minerals commonly is quartz, ilmenite, plagioclase and monazite. Elongated biotite and fibrolitic sillimanite, alongside chlorite, form crude to well-developed pressures shadows surrounding the garnet and cordierite porphyroblasts. One possible reaction that is recorded is the formation of the biotite and sillimanite at the cost of garnet and cordierite. This reaction is consistent with cooling temperatures, or increasing pressures after burial, or both. However, this idea is inconsistent with the eastern side of the fault being the uplifted side. Further research of faulting in the area local to the Victory Pluton could prove useful in explaining the inconsistencies observed in the sample.

References Cited

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