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Mineralogical Study of Biotite in Metapelites from Mount Mitchell State Park, North Carolina, United States of America

Cameron Evans
Environmental Studies Department
University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804

Faculty Advisor: Brittani D. McNamee

Abstract

Mount Mitchell lies within the Ashe Metamorphic Suite rock formation and consists of highly deformed and metamorphosed rocks. The suite consists primarily of metagreywacke rocks such as amphibolite gneiss and schist, mica gneiss and schist, quartzite, and even marble[1]. The rocks are very resistant to weathering due to the high quartz content, allowing Mount Mitchell to remain North Carolina's tallest peak[2]. The rock types tell that this area was once a beach or shallow sea due to the clay-rich sedimentary protolith but have undergone metamorphism during the events that created the Appalachian Mountains. Mount Mitchell, along with the rest of the mountains in North Carolina is a primarily a product of three orogenies; the Taconic (460 million years ago), Acadian (410- 345 mya), and the Alleghanian (325 mya) which signaled the formation of Pangea[3]. These mountain building events put the rocks in this region through some intense metamorphic changes that created the Ashe Metamorphic Suite. The exact temperature and pressure constraints of different rocks within the Mount Mitchell region during metamorphism is not fully known due to the lack of research in the last twenty plus years. However with more research opportunities such as this one being available, more answers can be found by studying the mineralogy in closer detail with modern instruments that acquire more precise and accurate data.

1. Introduction

A previous study by Coburn showed biotite grains within a hand sample of rock, with both no titanium and trace amounts of titanium[4]. This was of significance because of titanium's role in substitution of iron and magnesium in biotite at certain temperatures and pressures. There is a point when pressure increases and the amount of titanium within biotite starts to decrease[5]. Biotite has different end member compositions within the group, phlogopite is the magnesium end member and annite is the iron end member. The amount of magnesium has a vital role in titanium's substitution in biotite; when there is more magnesium there is a lower substitution of titanium[5]. Another factor for titanium substitution is the grade of the biotite; a high-grade biotite will allow more titanium to substitute compared to a low-grade biotite[5]. Therefore investigating the titanium within biotite samples will provide a better understanding of the temperature and pressure during the formation of the biotite. Locating both biotite compositions with and without titanium is a major goal of this research in order to constrain the temperature and pressure during formation. Determining biotite's relationship to other minerals such as titanium oxides within the samples can show how biotite is acquiring titanium.

2. Methods

Samples were collected at Mount Mitchell from four separate locations, one within the same rock outcrop Coburn sampled at the top of the peak, termed Slant Rock, and from three outcrops along the Balsam Nature Trail, which winds along the same side of Mount Mitchell as the first outcrop. Samples were prepared as grain mounts, a powdered sample on a glass slide within a refractive index (RI) liquid, the middle of the RI range for the biotite series. Biotite grains containing more titanium would have a different RI than the other biotite grains, allowing for a quick selection of samples to focus chemical analyses. Samples were trimmed into billets and prepared as polished thin sections by Spectrum Petrographic for optical analysis by polarized light microscope (PLM) and compositional analysis by energy dispersive spectroscopy (EDS) with a scanning electron microscope (SEM). The PLM is used primarily for optical identification of minerals and to look around the thin section in order to identify which areas to focus on in the SEM for EDS chemical analysis. EDS identifies the elements present and their relative amounts by detecting characteristic energies of x-rays created with the interaction of the electron beam and the sample. The EDS was used to identify biotite grains with titanium and without titanium as well as confirming other minerals within the samples such as kyanite, sillimanite, rutile, and ilmenite.

3. Results and discussion

The grain mounts of the sample from Slant Rock (SR1 & SR2) showed becke lines moving into the refractive index liquid as well as becke lines moving into a biotite grain, showing there are biotites with different refractive indices, possibly due to the presence of titanium in the grains of lower RI. Thin sections of SR1 contained rutile, a titanium oxide, within the same sample that the becke lines were observed (Figure 1). The rutile appears to be breaking down into ilmenite, the titanium in rutile is substituting for iron in biotite thus the rutile degrades to ilmenite (Figure 2 & 3). This observation of rutile altering to ilmenite was not made in the previous study by Coburn[4]. All of the Slant Rock thin sections (SR1, SR2, & SR3) contained both kyanite and sillimanite indicating the medium-high temperature and pressure ranges as well as outlining that the PT path must fall along the kyanite and sillimanite interface (Figures 6 & 7).

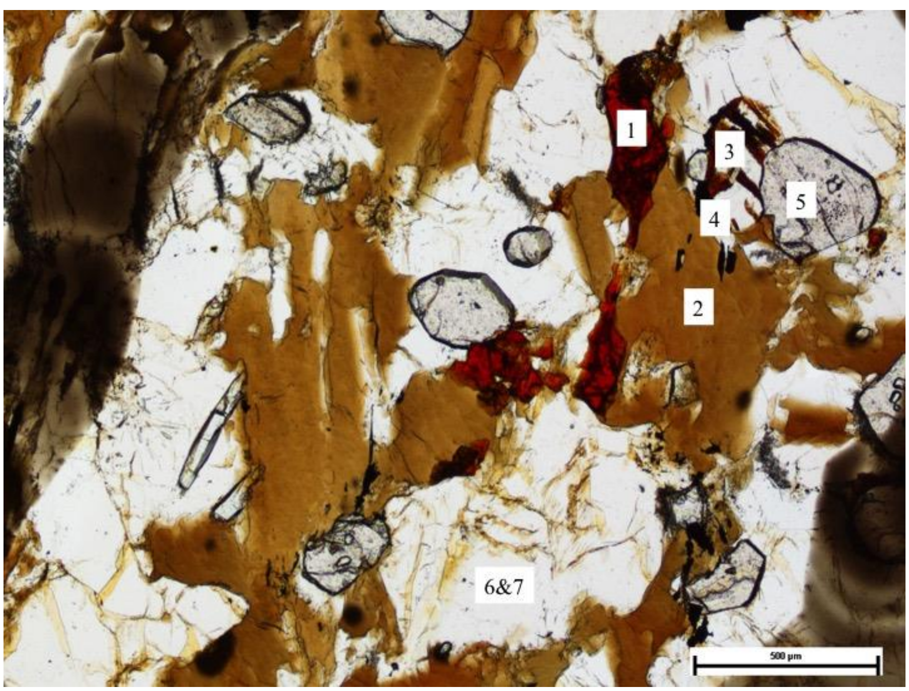

Figure 1. Rutile, Biotite, Apatite, and Ilmenite found in SR1

Figure 1. Photomicrograph of thin section SR1 in plane polarized light (PPL) showing rutile (1) along with biotite (2), apatite (3), and ilmenite (4, small black crystals). Garnet (5) as well as quartz and feldspar (6 & 7) were also present.

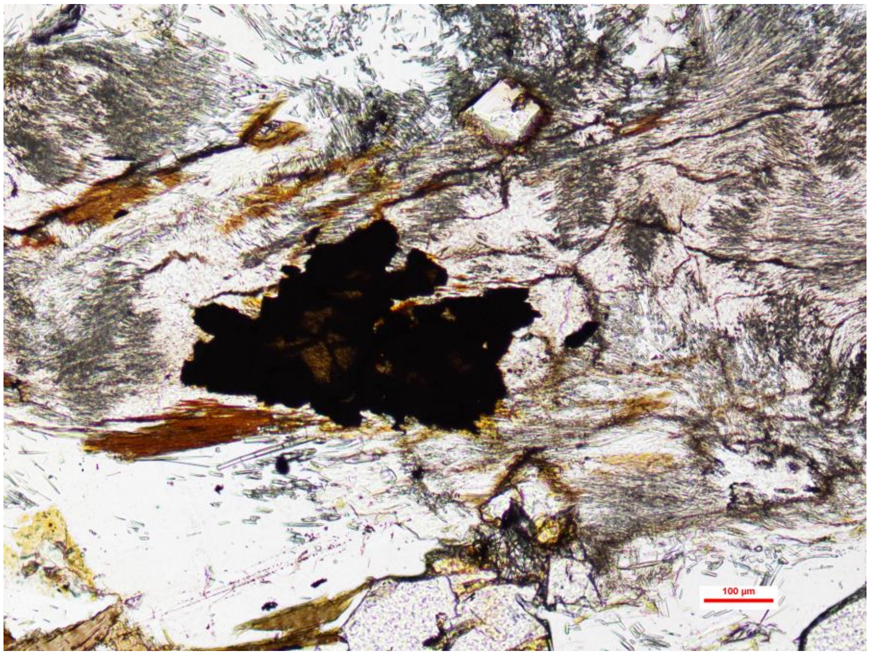

Figure 2. Rutile and ilmenite

Figure 2. Photomicrograph of thin section SR3 showing the golden center of rutile altering into the outer rind of the black ilmenite.

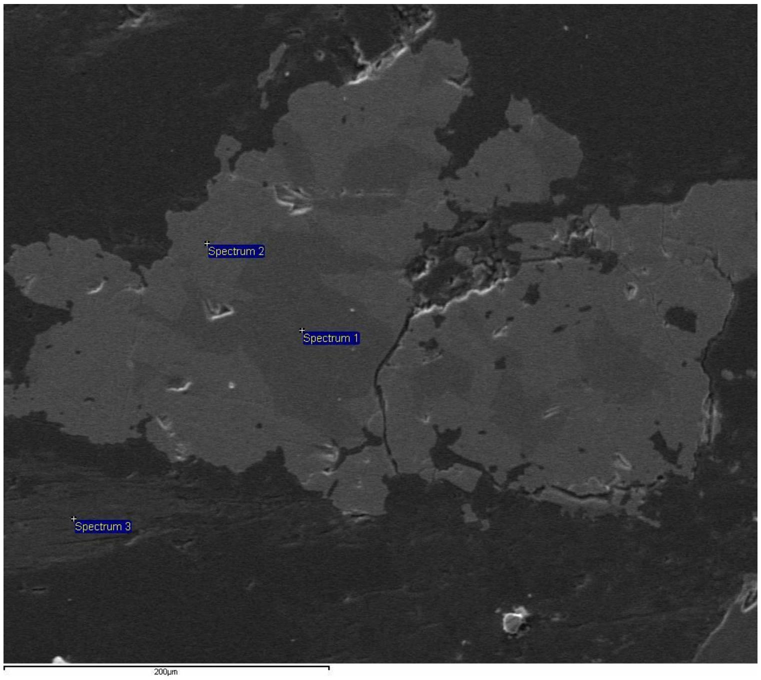

Figure 3. Rutile and Ilmenite in SR3

Figure 3. Secondary electron (SE) image of the rutile in Figure 2 breaking down to ilmenite, showing an alteration from the darker zones of rutile (spectrum 1) to the lighter zones of ilmenite (spectrum 2). A grain of biotite is located just below the rutile and ilmenite (spectrum 3).

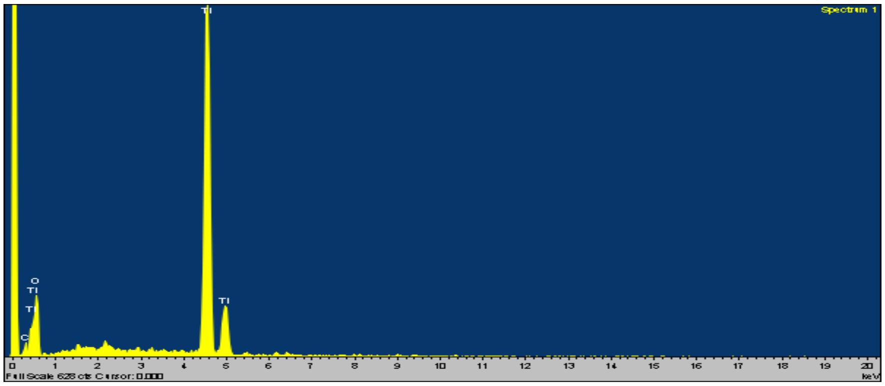

Figure 4. EDS spectrum 1 from Figure 3

Figure 4. The EDS spectrum 1 is identifying that the darker core is made up of rutile (TiO_2).

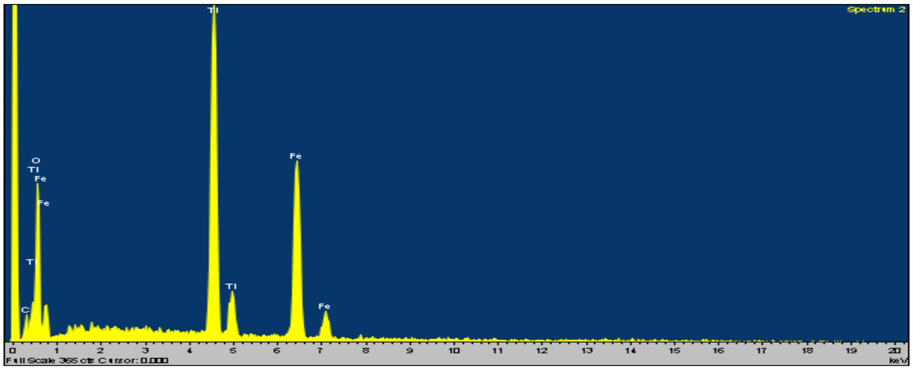

Figure 5. EDS spectrum 2 from figure 3

Figure 5. Spectrum 2 from Figure 3 shows the chemical composition is of the lighter grey is ilmenite ($Fe^{3+}TiO_3$) and it has altered from the rutile (spectrum 1, darker grey).

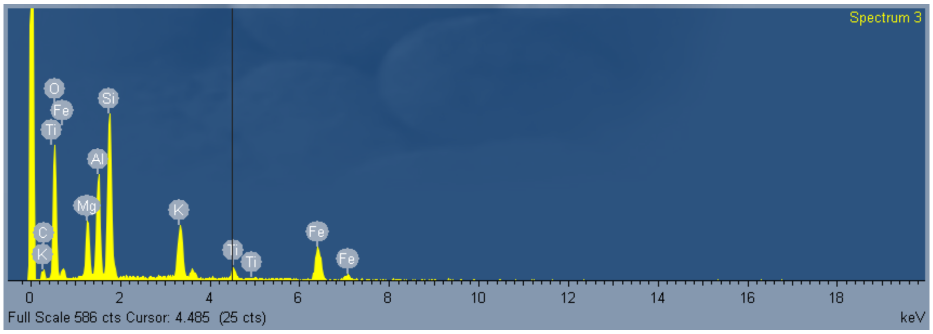

Figure 6. EDS of spectrum 3

Figure 6. EDS spectrum 3 of biotite from figure 3 and contains titanium.

The three EDS spectra from Figure 3 show the chemical changes that took place during deformation within SR3 (Fig. 4-6). Figure 4 and Figure 6 show the chemical alteration of rutile into ilmenite (respectively), which can also be seen in secondary electron (SE) image in Figure 3 by the color change from a darker grey to lighter grey. The SE detector in the SEM uses electrons to detect changes in topography across a sample, however there is no topography in these thin sections as they are polished. Instead, the varying shades of grey are reflective of the composition of the phases present. There are more electrons within the Fe and Ti rich phase of ilmenite for the electron beam to interact with, so the signal is brighter. The lack of Fe in rutile provides fewer electrons to interact with the beam, resulting in a darker shade of grey. Titanium within a grain of biotite was identified in spectrum 3 right next to the alteration of rutile into ilmenite. The biotite exchanged iron for titanium while the rutile exchanged titanium for iron causing the alteration from rutile into ilmenite and the inclusion of titanium in biotite. This reaction did not affect the entire grain, leaving a core of rutile within a rind of ilmenite.

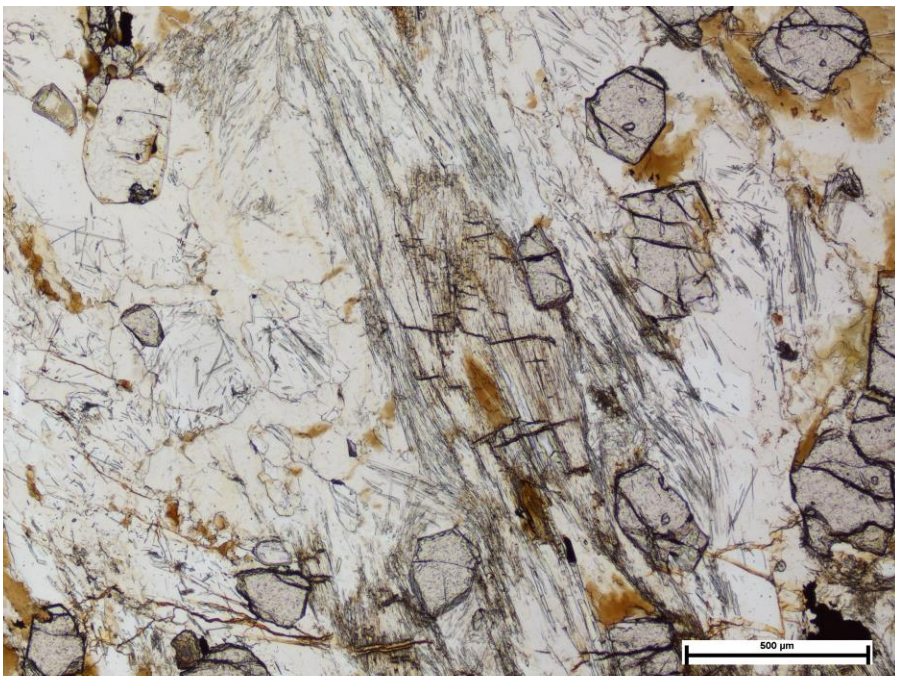

Figure 7. Kyanite and sillimanite intergrowth in SR1

Figure 7. Photomicrograph of thin section SR1 in PPL showing kyanite in the center underwent prograde metamorphism into the needle-like sillimanite crystals.

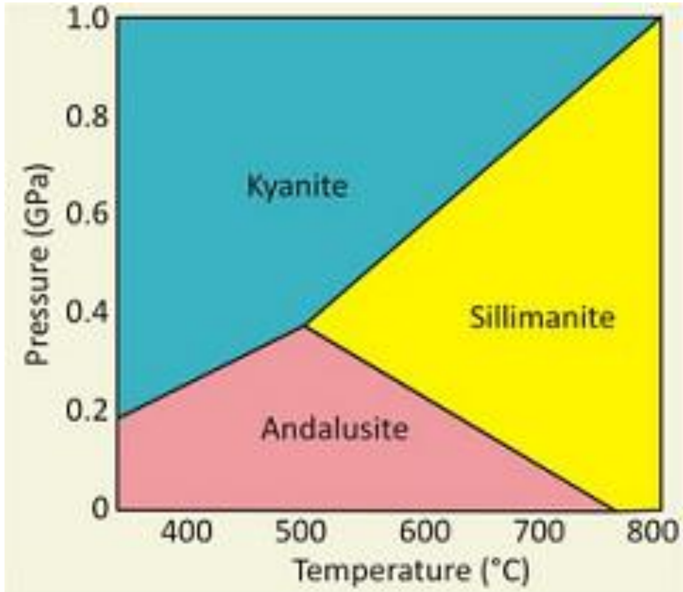

Figure 8. Triple point of aluminosilicate formation

Figure 8. The triple point illustrates the temperature and pressure region required to have both kyanite and sillimanite (figure adapted from [6]).

Since Figure 7 shows kyanite and sillimanite growing together in SR1 and no andalusite was seen across all samples, the environment during formation of the kyanite and sillimanite must be along the interface above 500^o C and .4 GPa (Figure 8).

4. Conclusion

Biotites of varying compositions within the same sample were suspected by refractive index analysis with the PLM, but not confirmed by compositional analysis in the SEM. A temperature and pressure range for the Slant Rock samples can be inferred based on the observations of kyanite and sillimanite intergrowth. Finding biotite containing titanium in close proximity to rutile altering into ilmenite explains how biotite acquires the titanium. Future research would include precise chemical analysis of biotite as well as rutile-ilmenite interaction boundaries within the layers of Slant Rock and outcrops from along the ridge. Analyzing the precise chemical composition wavelength dispersive spectroscopy (WDS) with an electron microprobe is more precise than EDS and would allow for a quantitative comparison of biotite and associated minerals within the samples. WDS analysis should reflect if there is a relationship between Ti in biotite and it's proximity to rutile/ ilmenite and if there are differing stages of these reactions occurring throughout the outcrop. Furthering understanding the role Ti plays in these minerals can help constrain the varying temperature conditions experience across the ridge.

5. Acknowledgments

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6. References

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