Experimental melting of a low grade pelitic schist from the Rangeley Formation, Massachusetts

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INTRODUCTION

The objective of this project is to characterize dehydration melting processes within aluminous crustal rocks by experimentally melting a low grade pelitic schist over a range of temperatures at constant pressure. By comparing the muscovite and biotite dehydration reactions observed in the experimental study to those predicted by theoretical models, it is possible to constrain the pressure-temperature paths of metamorphism in anatectic pelites. The chemical reactions predicted by Spear et al. (1998) to occur in rocks of this bulk composition are:

Muscovite + plagioclase + quartz = sillimanite + K-feldspar + melt
(discontinous in Ca-free system: T ~ 690° C @ 6 kb)

Biotite + sillimanite + quartz = garnet + K-feldspar + melt
(NaKFMASH continous)

Biotite + sillimanite + quartz = garnet + cordierite + K-feldspar + melt
(NaKFMASH discontinous: T ~ 780° C @ 6 kb)

Garnet + sillimanite = spinel + cordierite + quartz
(NaKFMASH discontinous: T ~ 950 ° C @ 6 kb)

In order to test the validity of these predictions, one sample from an outcrop west of Shoemet Lake (SLW) was experimentally melted and analyzed. The SLW sample is from the Rangeley Formation, a prograde sequence of pelitic schists located within the Merrimack Synclinorium of central Massachusetts. The metamorphism and intense deformation of Silurian sediments in the Merrimack belt results from convergence associated with the closing of Iapetus Ocean during the Acadian orogeny (Thomson et al., 1992).

MATERIALS AND METHODS

Sample SLW was chosen for analysis because it is a mica-rich low grade rock which does not appear to contain in-situ melt. It is a Sillimanite Zone pelitic schist which contains the equilibrium assemblage of garnet, sillimanite, biotite, muscovite, plagioclase, quartz, and ilmenite. Therefore, SLW can be experimentally heated to temperatures which produce the melting associated with the muscovite and biotite dehydration reactions.

Run Number	Temperature (^{0} C)	Pressure (kbar)	Duration
Melt 1	650	6	1 day
Melt 2	650	6	2 days
Melt 3	680	6	4 days
Melt 4	725	6	4 days
Melt 5	770	6	4 days
Melt 6	800	6	4 days
Melt 7	825	6	4 days

Figure 1. Experimental Conditions.

The sample was cut and polished to remove weathered edges, then pulverized with a tungsten carbide shatterbox to homogenize the rock. The resulting powder was then used in the experimental procedure. The experiment was performed using a 3/4 inch, end-loaded piston-cylinder device at constant 6 kb pressure and temperatures ranging from 650° C to 825° C. The powder was sealed in 2mm gold tubing within a nickel sample holder to prevent reaction

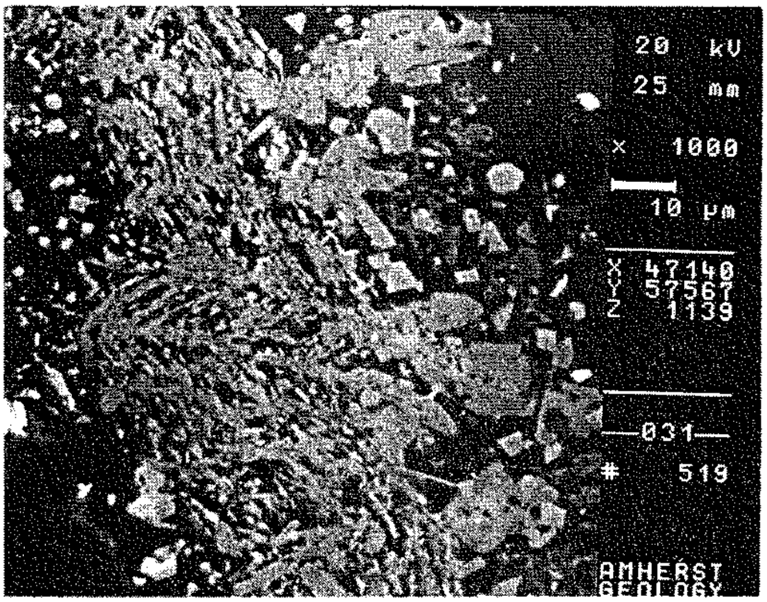

Figure 4. Backscattered electron image of 825°C experiment.

Mineral compositions in the samples vary with increasing temperature. For example, the rims of garnet that grow onto remnant garnet crystals are more magnesium-rich than the remnant crystals themselves. Melt composition becomes less aluminum-rich as aluminosilicate grows and takes up more of the aluminum, and the growth of K-feldspar rims onto remnant plagioclase decreases the amount of potassium in the melt.

DISCUSSION

The experimental results show changes with increasing temperature in our sample that are somewhat analogous to those observed in higher-grade rocks from granulite facies of south-central Massachusetts, which contain segregated, partial-melt patches of quartz-K-feldspar-sillimanite-garnet (Thomson et al., 1992). It seems that in light of the distribution of minerals in the samples and their compositions, each experiment probably achieved local equilibrium, in which muscovite and biotite break down and provide water for melting reactions to occur. These reactions produce aluminosilicate + melt. K-feldspar is present as both isolated crystals and as rims around remnant plagioclase. Garnet grows as rims around remnant garnet crystals. Although staurolite is present in the experiments as remnant crystals, it is likely that, in the natural granulite-facies rocks, staurolite also breaks down to provide water for melting reactions. The results indicate that the rocks of south-central Massachusetts may have undergone in situ dehydration reactions to produce partial melts.

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with non-SLW material. The sample holder was placed within a graphite furnace and surrounded by pyrex and NaCl tubing to equalize the pressure from all directions. A thermocouple inserted into the piston-cylinder was used to measure the temperature within the furnace. Runs were maintained at constant pressure and temperature for four days in an attempt to equilibrate the sample. At the end of four days they were rapidly quenched and the nickel sample holder was extracted. The sample holder was then cut to expose the rock within, mounted in epoxy, and carbon coated. Using the Zeiss Digital Scanning Electron Microscope (SEM) and the LINK Energy Dispersive Analytical System (EDS) at Amherst College, the minerals and melted areas of the sample were analyzed for chemical composition and mineral modes within the sample were determined by analysis of X-ray maps.

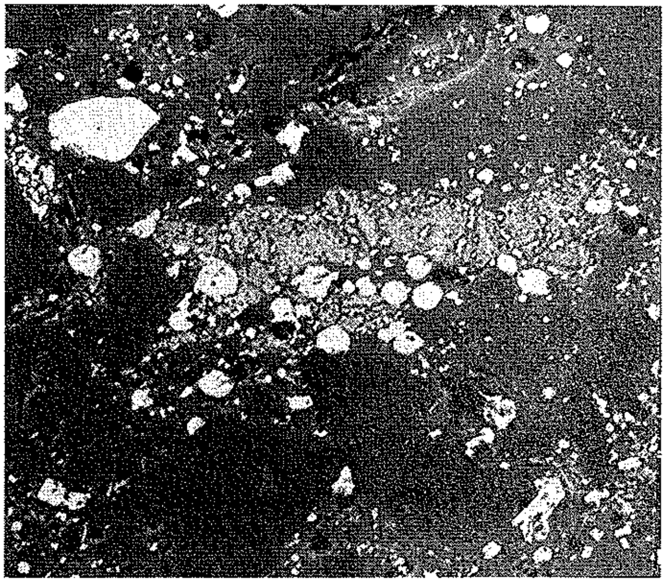
RESULTS AND DISCUSSION

Previous work by Tracy et al. (1976) characterized Shoemet Lake West as a Zone II or Lower Sillimanite Zone outcrop within the prograde metamorphic sequence of central Massachusetts. Typical Zone II pelites contain staurolite and muscovite, and an outcrop 0.5 miles away from the outcrop west of Shoemet Lake, called Shoemet Lake East (SLE), contains this assemblage. Because of the close proximity to Zone II schists, the lack of staurolite in outcrop SLW was believed to result from a more Mg-rich bulk composition. However, chemical data indicates that samples SLW and SLE have quite similar Fe/Mg ratios, and that SLW is more likely a higher grade schist than SLE. Therefore, SLW may be characterized as a Zone III assemblage containing garnet, biotite, sillimanite, plagioclase, quartz, and muscovite but no K-feldspar (Figure 6).

Reactions observed in SEM	Temperatures
muscovite + plagioclase + quartz = sillimanite + K-feldspar + melt	680°C - 725°C
biotite + sillimanite = garnet + K-feldspar + melt	700°C - 825°C
garnet + sillimanite = spinel + quartz	725°C - 825°C

The muscovite dehydration reaction is observed in sample SLW as predicted by Spear et al. (1998). The muscovite terminal stability is between 680° C and 725° C (Figure 4), and discrete grains of K-feldspar are observed in equilibrium with melt in higher temperature runs. The NaKFMASH continuous biotite dehydration reaction also occurs, in accordance with the model, from 700° C to 825° C (Figures 4, 7). Large biotite crystals are clearly breaking down, whereas small high-Mg, low-Mn garnets have grown near melt pods (Figure 2).

Figure 2. Biotite breaks down; growth of new garnets.



However, no cordierite occurred in the higher temperature experimental runs. This differs from the prediction that cordierite would be produced in the NaKFMASH discontinous biotite dehydration reactions at higher temperatures. Moreover, higher grade Zone VI pelitic schists within the Rangeley sequence, which were metamorphosed at ~750° C, contain cordierite + K-feldspar assemblages (Thomson et al., 1992).

There are several explanations for the lack of cordierite in experimentally heated samples. The bulk composition of SLW may be such that modes of cordierite are negligible. Models by Carrington et al. (1995) predict that cordierite will not be produced until 860° C at 6 kb. The cordierite-forming reaction may indeed occur at temperatures greater than 825° C (the implication being that Zone VI Rangeley rocks were heated to temperatures above 825° C.) It is also possible that cordierite was present, but was consumed during the terminal spinel-forming reaction, as Carrington et al. (1995) have theorized, rather than created in the non-terminal reaction proposed in the Spear model. Whether the reaction is terminal or non-terminal depends on the relative ratios of Fe/Mg in spinel and garnet.

Another anomalous result is the relatively large amount of spinel in the 770° C, 800° C, and 825° C (Figure 4). Because the bulk composition of SLW plots on the garnet-sillimanite tie line of an AFM diagram, the spinel seems to be forming degenerately from the reaction garnet + sillimanite = spinel + quartz, with cordierite neither consumed nor created (Figure 7). Interestingly, the Spear model predicts the formation of spinel at temperatures around 950° C.

Its presence in mineral assemblages down to 770° C may indicate that the run had not been maintained long enough to reach chemical equilibrium. It is possible that the spinel has been concentrated in disequilibrium low-silica pockets and thereby stabilized to lower temperatures. Alternatively, Fe^{3+} may stabilize spinel to lower temperatures.

Pods of partially melted material begin to form at temperatures around 675° C as the mica dehydration reactions proceed (Figure 4). Melts are similar in chemical composition to average granites although less potassic, and early melts are more K-rich than later ones. With increasing temperature, melts become more mafic and increase in Fe relative to Mg: 770° melt has an Fe/Mg ratio of 4.3 whereas at 825°, melt has a ratio of 6.3 (Figure 5). Melt is generally associated with the growth of new garnets, spinel, sillimanite, and K-feldspar. Modes of melt increase as temperature increases, with melt forming 30-40% of high temperature runs.

CONCLUSIONS

Our study of an experimentally melted low grade pelitic schist indicates that dehydration melting of muscovite and biotite can yield substantial partial melting at temperatures which range from 770° C to 825° C. The mica dehydration reactions which were observed in SLW appear to qualitatively match the predictions of Spear et al. (1998), although the absence of new cordierite is problematic. The occurrence of spinel at lower temperatures than in field sequences creates doubt as to whether the experimental runs had completely equilibrated. Further experiments are necessary to ensure that chemical equilibration has been reached.

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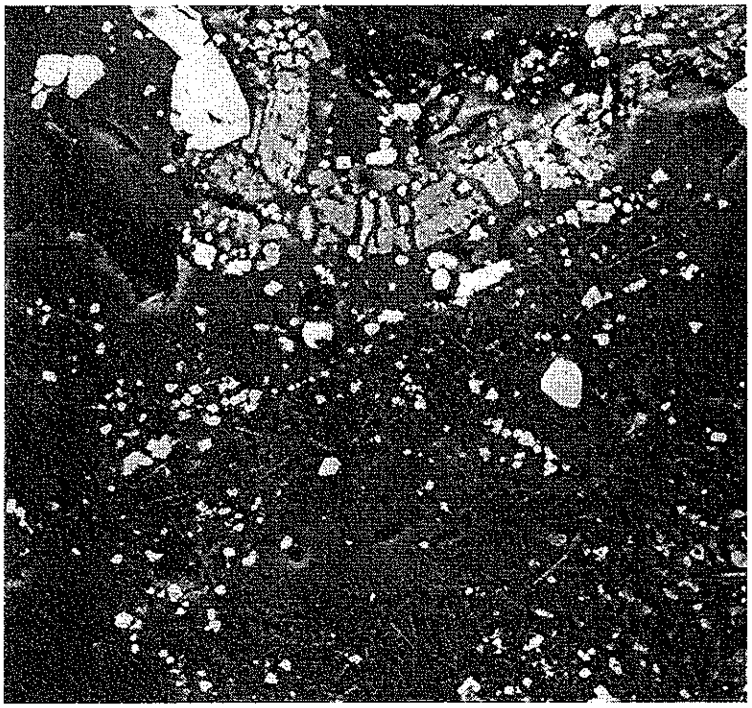

Figure 3. Most of the dehydration reactions predicted by Spear et al. (1998) are visible in this SEM photo. Muscovite has broken down, and sillimanite is replacing it parallel to the orientation of the biotite grain. Biotite is no longer stable, and spinel as well as new, high-Mg garnets are growing in association with pods of melt.

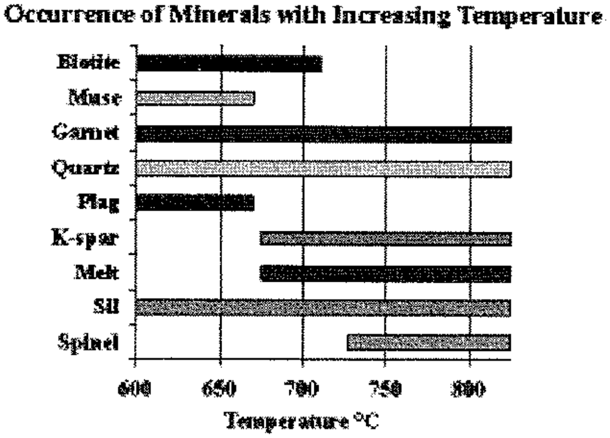

Figure 4. Fish plot showing mineral stabilities with increasing temperature. Note the breakdown of muscovite, biotite, and plagioclase, as well as the growth of K-feldspar and spinel.

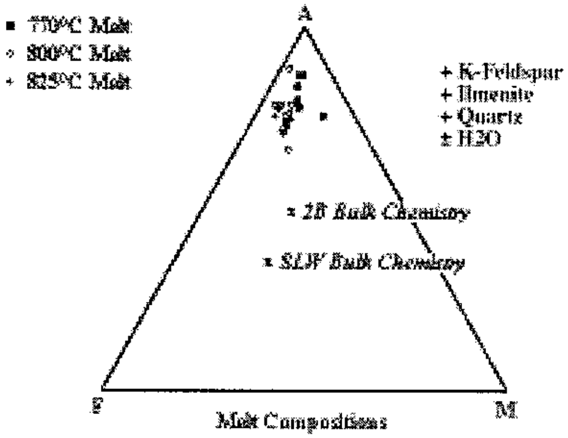

Figure 5. AFM diagram showing increasing Fe/Mg ratios in higher temperature melts.

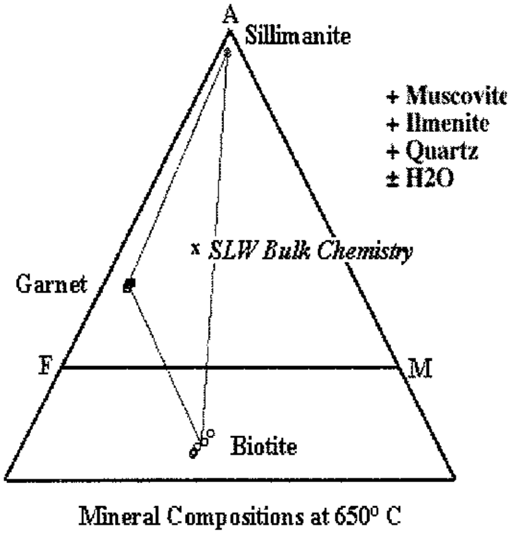

Figure 6. Equilibrium AFM assemblage for sample SLW prior to melting.

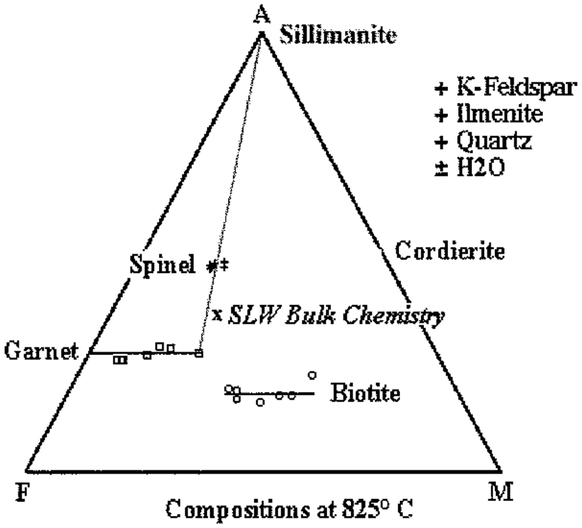

Figure 7. New mineral assemblages as biotite dehydration reactions proceed.

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