The Partial Melting of a Metapelite Under Wet and Dry Conditions

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Introduction

Most large-scale melting in the continental crust occurs near the level of the base of the crust at a depth roughly equivalent to a pressure of 10 kbar. For this reason, a large number of experiments have been performed on rocks of various compositions at the pressures and temperatures believed to exist in this region. The majority of these studies of partial melting in the lower crust emphasize the effects of water on the melting processes. However, it is now assumed that the majority of magmas in the lower crust are originally undersaturated with respect to water, indicating that the melting processes normally occur without water (Clemens,1984; Vielzuf and Holloway,1988). In order to further the understanding of this process, the experimental melting of a metapelite has been undertaken between 750-1050°C at 10 kbar under both wet and dry conditions. Similar studies done under vapor absent conditions have resulted in several models for the anatexis of pelitic rocks (Thompson,1982; Grant,1985; Vielzeuf and Holloway,1988). They did not, however, offer a comparison between melting with and without water.

The goals of the experiments of this study are to determine whether and to what extent melting occurs on the metapelite at various pressures and temperatures by studying the amount and nature of the melt which is generated along with the various mineral assemblages which remain. In order to do this, experiments were conducted using a piston-cylinder apparatus. The products of these experiments were studied via scanning electron microscope in order to determine the following: 1) The composition of the melt at different P-T conditions, 2) The mineralogic composition of the remaining rock, and 3) The proportion of melt as a function of temperature.

Normally experiments of this nature are run for several weeks in order to establish equilibrium. Due to time constraints, however, these experiments could only last for a few days each. Therefore, a series of experiments were conducted at 850°C for various lengths of time to determine whether or not it is reasonable to assume that equilibrium was established in the experiments.

Methods

The experiments were run at 10 kbar using a NaCl piston-cylinder assembly. Runs were conducted at 10 kbar for one to four days at temperatures ranging from 750°C to 1050°C. Each run consisted of both a water-saturated (10% water by weight) and a water-absent sample. Before the piston cylinder apparatus could be constructed, the sample had to be ground into powder. This was accomplished using a ball mixer. Once the sample had been ground, it was placed inside a sealed capsule. Gold capsules were used on all runs except those conducted at 1050°C. Silver-paladium capsules were used in the runs done at 1050°C since these were less likely to melt, thus helping to insure that contamination did not occur.

Once the capsules had been filled, the sample assembly was constructed. The sample assembly was then wrapped in lead foil and inserted into the piston-cylinder apparatus with a thermocouple wire which monitored temperature. The endload was employed and the pressure was brought up to 3 kbar at room temperature. The temperature was then brought up to the target temperature at a rate of 100°C/minute while the pressure was gradually increased to 10 kbar. Thus, the target pressure and target temperature were reached at approximately the same time.

At the end of each run, the sample assembly was removed from the pressure vessel and the surrounding material was broken off until the graphite sample container was completely exposed. The container was then mounted in epoxy and sawed in half. The exposed halves of the sample were then polished to 1 micron and covered with a thin film of carbon in preparation for analysis using a scanning electron microscope. All run products were analyzed on a Zeiss scanning electron microscope using a Link energy-dispersive analyser. Modal percents of minerals and liquids were determined via X-ray mapping techniques. The photographs were made in electron backscatter mode. Natural garnet crystals were used as standards and results were normalized to 100%.

Although steps were taken during each stage of the experiments and analyses to insure that the results were valid, erroneous analytical results may still have occurred. One possible source of error is contamination. This would most likely have occurred during the grinding of the rock when it could have been contaminated by previously prepared samples or by the grinding apparatus itself. Calibration could also lead to erroneous analyses as the accuracy of all analyses depends upon the accuracy of the standards used in calibration. Errors could occur relatively

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Vielzeuf and Holloway (1988) Experimental determination of fluid-absent melting relations in pelitic systems: Contrib Mineral Petrol, 98, 257-276

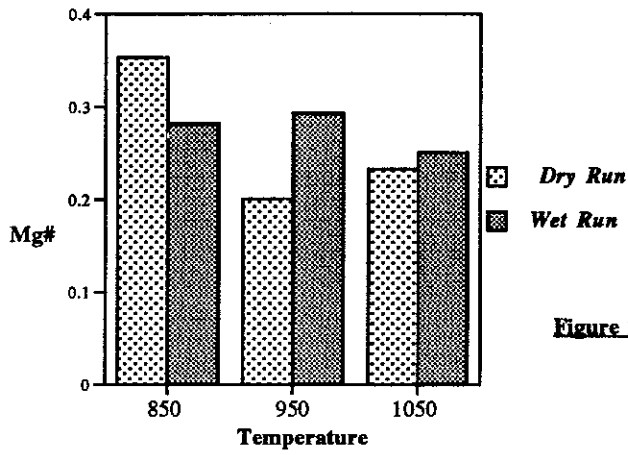**Figure 1: Average Liquid Mg # by Temperature**

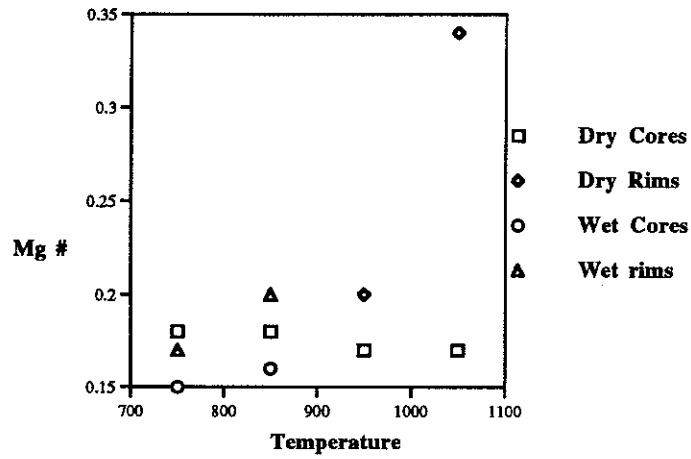

Figure 2: Average Garnet Rim and Core Mg # by Temperature

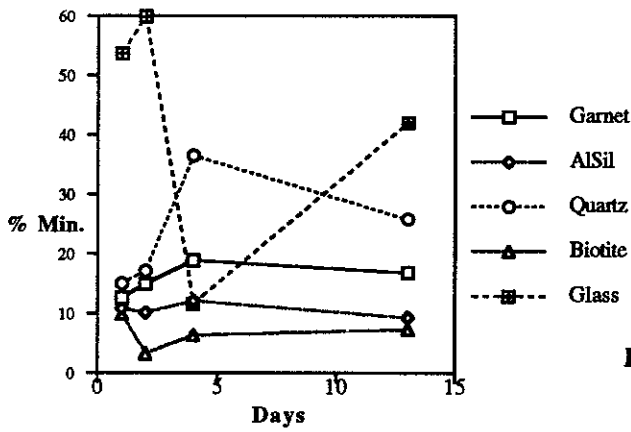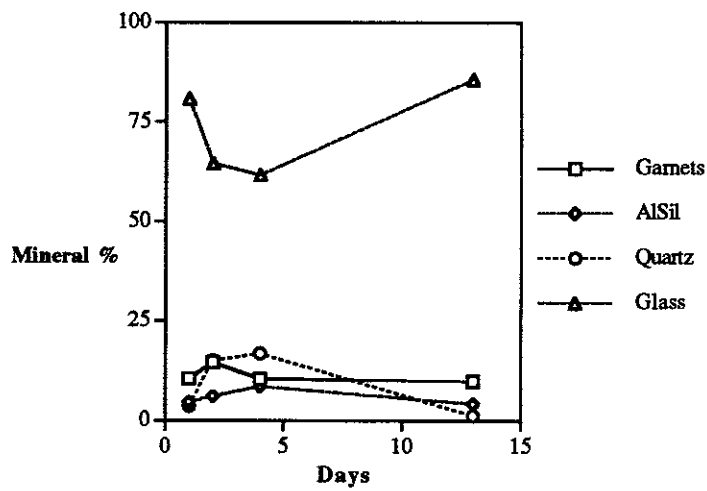**Figure 3: Mode Percent Minerals at 850 C Dry**

Figure 4: Mode Percent Minerals at 850 C Wet

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easily during this stage. Finally there is the possibilty that interference of spectral lines could occur during the analyses, thus increasing the value measured for a particular element.

Results

An important factor in determining the melting relationships in the experiments is the liquid composition at the various temperatures. Liquid phases were observed in most of the experiments, but in several it was difficult to separate the liquid from the crystals surrrounding it. These samples included the runs done at 750°C and a few of the water-absent runs done at 850°C. In these samples, it is unlikely that any analyses of the liquid composition will be possible. The samples that were analyzed are listed, along with their average liquid compositions, in Table1.

The liquid compositions for the water-absent samples show several trends worth mentioning. From low to high temperatures, SiO_2 increases until 1050°C is reached. At this point, it decreases sharply. While Al_2O_3 and MgO remain relatively constant, FeO shows an abrupt increase at 1050°C. This increase most likely corresponds to the reversal of the Fe-Mg partitioning between the glass and the garnets (Vielzeuf and Holloway, 1988). The trends in the magnesium number (MgO/MgO+FeO) of the liquids are also interesting (Figure 1). The magnesium number starts out relatively high at 850°C, then drops sharply at 950°C and remains constant through 1050°C. This can most likely be explained by the fact that a significant amount of garnet disappears between 850°C and 950°C while the amount of garnet remains relatively constant between 950°C and 1050°C.

The magnesium numbers for garnet rims and cores are helpful in a different way (Figure 2) When compared to the magnesium numbers for liquids at the same temperatures, these values can aid in determining whether or not equilibrium was establihed. In general, the closer the values for the garnets' and the liquids' magnesium numbers, the more likely it is that equilibrium was reached. It is clear from the diagram that the garnets were not in equilibrium with the liquid at 850°C. As the temperature increases, the values for the garnet rims become closer to those of the liquids, suggesting that the higher temperature runs came closer to establishing equilibrium.

The liquid compositions for the water-saturated experiments are in many ways similar to those in the water-absent experiments (Table 1). The amount of SiO_2 decreases at 1050°C, as before, while Al_2O_3 and MgO again remain relatively constant. There are some key differences, however. The amount of FeO begins to increase at 950°C rather than at 1050°C, as the garnets are dissolved earlier due to the buffering effect that the water has on the melting reactions. This effect can also be seen in the magnesium numbers of both the water-saturated liquids as there is little change in these values between 950°C and 1050°C.

The mineralogic composition of the rock which did not melt (or which did melt and then recrystallized) can also aid in understanding the melting relationships. The modal percents of the minerals present have been determined for the series of time experiments which were done at 850°C. The mapping for the remainder of the experiments has not yet been completed, and the modal percents at these temperatures are therefore unknown. In the water-absent runs at 850°C, there is significant disparity between the values for the modal percents in the different samples (Figure 3). In general, the runs which lasted for greater amounts of time displayed more pronounced differences in the amounts of the various minerals present. More work must be done with the composition of the starting material in oredr to determine whether or not this is a sign that the longer runs were closer to reaching equilibrium than the runs of shorter duration. The water-saturated runs at 850°C more closely resemble one another as the amounts of the various minerals remain relatively constant as the duration of the runs increases (Figure 4). The only exception is the amount of liquid, which drops sharply as the runs are extended to 2 and 4 days, and then increases dramatically as the runs are extended to 13 days. This would seem to suggest that the 13 day runs were closer to reaching equilibrium than the shorter runs.

Unfortunately, the runs done at 850°C are the only runs for which we have information as to the proportion of liquid to crystal. Further study of these proportions at the other temperatures, and further study of the compositions of the remnant rock, should aid in understanding exactly how the melt is behaving and what reactions may be controlling this behavior.

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Table 1: Average Liquid Compositions for Results

Dry Runs	850 C	850 C	950 C	1050 C	
	1 day	*4 day*			
Wt % oxide					
SiO2	70.71	66.30	77.90	64.38	
Al2O3	12.14	16.60	13.61	13.26	
TiO2	0.48	0.95	0.57	2.16	
MgO	0.85	1.59	0.56	1.52	
FeO	2.26	2.92	2.23	5.01	
MnO	0.00	0.00	0.02	0.51	
CaO	0.10	0.00	0.06	0.75	
Na2O	0.82	1.11	0.43	1.00	
K2O	5.47	9.91	4.25	6.07	
Wet Runs	850 C	850 C	850 C	950 C	1050 C
	1 day	*4 day*	*13 day*		
Wt % oxide					
SiO2	64.62	68.54	68.74	67.26	63.27
Al2O3	12.65	12.38	11.99	12.94	14.14
TiO2	0.26	0.42	0.42	0.65	1.00
MgO	2.62	1.33	1.52	2.21	2.55
FeO	5.53	3.38	3.47	5.33	7.59
MnO	0.08	0.03	0.05	0.17	0.11
CaO	0.11	0.10	0.14	0.21	0.19
Na2O	0.30	0.24	0.32	0.45	0.65
K2O	3.10	4.15	3.92	2.85	2.24

Experimental Partial Melting of a Pelitic Schist

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Introduction

A natural meta-pelite has been partially melted under both fluid-present and fluid-absent conditions. In vapor saturated environments, water facilitates melting at relatively low temperatures. In vapor absent environments, dehydration reactions must occur in muscovite and biotite to create a hydrous phase; hence, melting should occur at a relatively higher temperature. The sample melted is an upper sillimanite zone schist from Puzzle Mountain, ME (sample A53). The initial mineralogy of the pelite is muscovite (17.5% Pg), biotite (.44 Mg/Mg+Fe), garnet (~9% pyrope & 10% spessertine), plagioclase, quartz, sillimanite, and ilmenite.

Methods

Experimental runs were performed in a 3/4", end-loaded piston cylinder device at 10 kbar pressure and temperatures ranging from 750° C to 1050° C. In order to determine the effect of experiment duration on the phase assemblages and compositions of the phases, a time series study (1, 2, 4, and 14 days) was conducted at 850° C (Skjerlie, Patino Douce, and Johnston 1993).

All experiments utilized an NaCl + pyrex glass solid media assembly surrounding a graphite furnace with a graphite plug at the bottom. Within the graphite furnace a nickel sample holder (9mm long, 8mm in diameter) containing 2mm diameter Au tubing was seated in a pyrophyllite cup with lid. This cup was bordered above and below by corundum plugs. After the runs, samples were mounted in epoxy, polished, and carbon coated.

The compositions of each mineral phase in each sample were determined using the Zeiss Digital Scanning Electron Microscope/Energy Dispersive System and the LINK analytical system at Amherst College. The modes of phases in each sample are currently being calculated by collecting and averaging SEM X-Ray maps. The bulk composition of the original schist was determined using X-Ray Fluorescence analysis at University of Massachussets.

Results

Results obtained on the SEM show that wet and dry runs at 850°C for one day, two days, four days, and two weeks all exhibit some degree of melting; the same is true for wet and dry runs at 950°C for two days and at 1050°C for one day. In each pair of runs, the water absent one produced less melt than the water saturated one. All glasses are silicious with compositions ranging from 60-73 wt.% SiO_2.

The four day, 750°C, wet run contains euhedral garnet, biotite, muscovite, aluminosilicate, and ilmenite, anhedral quartz, and glass. The corresponding dry run has the same assemblage plus euhedral staurolite. Interestingly, the garnets in the 750°C runs display little to no zoning. Most of the garnets, in fact, have no rims; these garnets reflect the core compositions of zoned garnets analyzed in subsequent runs.

The two week, four day, and two day, 850°C, wet and dry runs all contain euhedral garnet, biotite, aluminosilicate, spinel, and ilmenite, anhedral quartz, and glass. The 850°C one day runs display similar assemblages except that the wet run contains corundum, and the dry run contains muscovite. Curiously, the 850°C, one day ,wet run does not contain garnet.

The two day, 950°C runs display the same assemblage as the two week, four day, and two day, 850°C runs with the exception of biotite. The 1050°C, one day, wet run contains a great deal of melt and some spinel and ilmenite; the corresponding dry run contains less melt and some spinel, quartz, and aluminosilicate.

The garnet crystals produced in the various runs (with the exception of the 750°C garnets) are zoned with high magnesium rims (~30% Py,~5% Sp,~1% Gr).

A mineral summary table is included indicating the phases present in each sample. Two SEM photos are also included: one shows the presence of almost all mineral phases in the 850°C, one day, dry run, and one shows the presence of only spinel, ilmenite, and liquid in the 1050°C, one day, wet run.