

Measuring the Rates Between Cation Interdiffusion Between Dacite and Basalt

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Introduction

Almost every geologist has observed in the field a mafic pillow or pod located inside a felsic magma, and there always has been scientific curiosity concerning the interaction between magmas of different bulk compositions. The purpose of this study was to determine how dacite, a silica-rich magma, and basalt, a silica-poor magma, interact during magma mixing. The effects of cation interdiffusion between dacite and basalt also were studied. Several questions posed during the design of the project include (1) "what are the details of the magma mixing process between a felsic and mafic magma?" (2) "how does the diffusion rate differ under various temperature conditions for each constituent species?" There are many different geologic instances where various magmas come in contact with one another and combine, e.g. volcanic regions or any landscape where intrusions, dikes, and sills are present.

To answer the questions about the interactions among magmas of different bulk compositions, it is necessary to recall that magma can be mixed by mechanical processes, forcible injection and convection, or by chemical diffusion. These experiments were designed to try and minimize mechanical mixing by inserting the more dense magma in the capsule first and then placing the less dense magma on top. This helped to ensure that the different chemical composition readings collected would be a consequence of diffusion. It is also important to note that the melting and crystallization temperatures for each magma are dependent upon their chemical compositions. The final mixture is usually a combination of these processes occurring simultaneously.

I designed experiments to place dacite and basalt in contact at high temperatures (800°C - 1200°C) and 1.0 GPa of pressure in order to observe the reaction between them. Dacite and basalt were chosen for use in this study because both are common magmas but have different bulk chemical compositions. The major chemical factor which influences crystallization temperature is the percentage amount of silica in the magma. The dacite used contained 64 percent SiO₂ whereas the basalt contained 50 percent SiO₂. Because SiO₂ crystallizes at a lower temperature, it crystallizes out of the melt relatively early. When it crystallizes out, it is removed from interacting with the other chemical elements in the melt. Because of this, the amount of crystallization is an important factor in determining the final product of the background melt in magma mixing, or determining the diffusion rate.

As magmas can be molten at various temperatures, experiments are conducted at temperatures 800° C to 1200° C. In all experiments the temperature is low enough to allow the basalt to begin crystallizing before the dacite. At these experimental temperatures, the basalt became crystalline while the dacite was still above its liquidus. When this happens, the dacite is limited in its mixing with the basalt and diffusion occurs slowly. In order to address the question of how diffusive mixing differs under various temperature conditions, it is helpful to understand diffusion. Diffusion is defined by Dunn (1986, p.57) as "the movement of constituent species of the melt from point to point within the melt". Constituent species usually move from an area of higher concentration to an area of lower concentration in an attempt to achieve homogeneity. In order to verify a diffusive effect, it is necessary to minimize all other factors and avoid mechanical mixing. Diffusion is the idea that the species in the melt move because part of their total energy is kinetic. This kinetic energy causes random motions of the particles in the melt.

Experimental Procedure

To investigate how temperatures affect the rate of diffusion, five different experiments were conducted at temperatures varying from 800°C - 1200°C at intervals of 100°C. All experiments in this study were conducted at a constant pressure of 1.0 GPa. For each pressure-temperature pair, one sample had 0 percent water by weight, and a second sample had 6 percent water by weight. All five different temperature experiments were conducted for 24 hours to allow for measurable diffusion to occur. In addition to these five experiments, a four day experiment at 800°C and a zero-time experiment at 1000°C were conducted. The purpose of the four day experiments was to determine whether diffusion rates were what was actually being measured in the other samples. This verification could be accomplished by comparing data from the four-day run data with the 24-hour run data. For example, if the distance measured by diffusion was proportional to the time at 800°C, calculated using Fick's equation, and all other relevant factors were

Activation Energy

Activation energy is related to the log of diffusion coefficients and the inverse of temperature in degrees Kelvin by means of the Arrhenius relationship (Eq. 6). Activation energy is equal to $2.303R$ multiplied by the slope of a least squares fit on a plot of $\log D$ and $1/T^\circ K$. Figure 2 shows the least squares solution line and the value of its slope. The activation energy for An₂₀ Di₈₀ is 47.47 Kcal/mol. The value is comparable with activation energies for other similar systems.

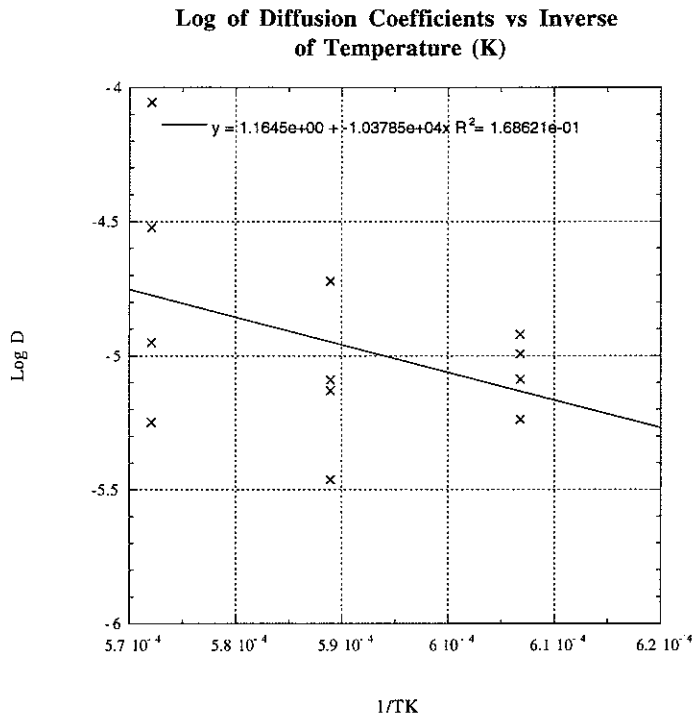


Figure 2. The log of each diffusion coefficient was plotted against the inverse of temperature (Kelvin). A linear curve was found and used to calculate diffusion coefficients. The slope of the line, 1.038×10^4 , is used to calculate activation energy for An₂₀ Di₈₀

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the same, then the differences in the data would be due to diffusion. The zero time experiment illustrates how much crystallization occurred by simply bringing the sample to the target temperature and then quenching it. This experiment was conducted to verify the sample's homogeneity, since if crystals are present, this is evidence of an uneven chemical distribution of elements throughout the sample.

The basalt and dacite utilized in this experiment were collected from the Mt. St. Helen's vicinity by Smith and Leeman (1987) and were obtained from Diane Smith in powder form. It was determined that five grams of dacite and four grams of basalt would be sufficient for all experiments. To eliminate any crystals each powder sample was melted and then quenched. After it was quenched it was set aside to cool and then ground into powder. This was repeated until no crystals could be identified in the powder.

The dacite sample was melted three separate times in a one-atmosphere bulk furnace, first for 15 minutes, then for 45 minutes at 1200°C, and finally for one hour at 1500°C. The dacite was melted in a platinum crucible because it was inert. Between each melting, the sample was quenched in 25°C to 30°C tap water, then allowed to sit at room temperature for approximately one hour. The dacite was removed from the crucible, then mixed with acetone, and ground into powder using a mortar and pestle. The basalt was prepared by melting in a graphite casing in a piston cylinder press at 1500°C, and 1.0 GPa for one hour. It was then ground in an automatic grinder with acetone until it was a fine powder.

After the samples were prepared, 0.025 grams of basalt, then 0.025 grams of dacite, were tamped down into a gold capsule. The gold capsule was placed inside a nickel plug. The gold capsule was then placed inside a graphite casing and was sealed by both a gold lid and then a graphite lid. Then the graphite assembly was inserted into a fired pyrophyllite container and lid. Then the pyrophyllite container was placed into the furnace assembly which was put into a 3/4" piston-cylinder press (see Figure 4.). This assembly provided a cold weld for the sample. The pressure kept any further mixing from occurring. The temperature of the sample was monitored by a W-Re thermocouple that was prepared beforehand and placed directly into the furnace assembly. This allowed the direct temperature of the sample to be monitored during heating.

The end load was added and the RAM pressure was raised to 1.0 GPa. The piston-cylinder press computer was programmed to increase temperature by 100°C/minute until the target temperature was reached. The samples were run for 24 hours and then quenched rapidly. Following quenching they were taken from the assembly and mounted vertically in epoxy. A cross sectional cut was needed in order to take spectra analysis readings along the specimen's axis. To accomplish a horizontal view, the samples were cut horizontally by a mini saw, then remounted in epoxy and polished using progressively smaller sandpaper grit and diamond paste mounted on a rotating disk. The samples were then carbon coated on a Pelco 9500 advanced coater for analysis on a scanning electron microscope.

All samples were analyzed on a scanning electron microscope model JOEL JSM-6400. The electron beam was brought to saturation at 20 kV and viewed at a magnification of 2000X from a working distance of 39 mm. For actual chemical analysis, the Kevex Analyst 8000 computer was used. The Kevex super dry advanced performance detector was deployed while the probe current was brought down to 0.375 nanoamps. All spectra were collected by the Quantex VI program and compared against mineral and glass standards collected earlier by John Brady on the Quantex VI program (personal communication). Spectra data yielded weight percents of each element. Back scattered imaging pictures were then taken at a working distance of 8 mm by a Polaroid camera model 545 to document the contact between the magmas.

Results

If diffusion occurred during any experiment, it should be evident in the changed weight percents of all elements over the cross sectional distance of the sample. The four elements that contributed the largest amount of weight percents to both magmas, and the elements examined most carefully in this study, are: silica, aluminum, calcium, and potassium. The weight percents obtained from the experiments produced values that vary slightly from the original separate melt data.

This study focuses on mixing processes for the dry sample, but describes content and appearance of both the dry and wet samples. It is important to note that in the zero-time run, tiny crystals identified as plagioclase, pyroxene, augite, and magnetite had already begun to form in the basalt (see Fig. 1 and 2). Eighty-five percent of the dry basalt sample and 15-40 percent of the dry dacite sample are crystallized. Diffusion data was not calculated because of the impossibility of analyzing the background melt separately from the crystals. Because of the large amount of crystals, a line mode analysis was used over a 500 μ m distance. This combined the crystals and the melt into the analysis. Because the dacite sample was mostly all glass, dacite observed readings are more accurate.

The graphs show "jumps" in element weight percent near the physical boundaries. This "jump" originates from the original weight percent differences. But when more spectra are taken over a shorter

distance close to the contact on the dacite end, there is a sharp slope connecting the lines. This is evidence for diffusion.

Both dry and wet samples were photographed displaying the physical point of contact between melts (see Fig. 2 and 3), the crystal sizes, and the crystal amounts. Overall, the dry samples contain more crystals in the final melts than of the wet samples (see Fig. 2 and 3). Both pictures are of the same sample containing different amounts of water. The addition of water lowered the temperature at which the magmas melted. This explains the glass that is present in the wet samples. There are crystals interspersed throughout the glass with no visual line of contact between the two magmas. There is also crystal zoning present in the wet zero time sample. Sample six, the dry sample, had a pocket of coarser plagioclase crystals located between the two magmas (see Fig. 2). This is probably due to the higher temperature conditions.

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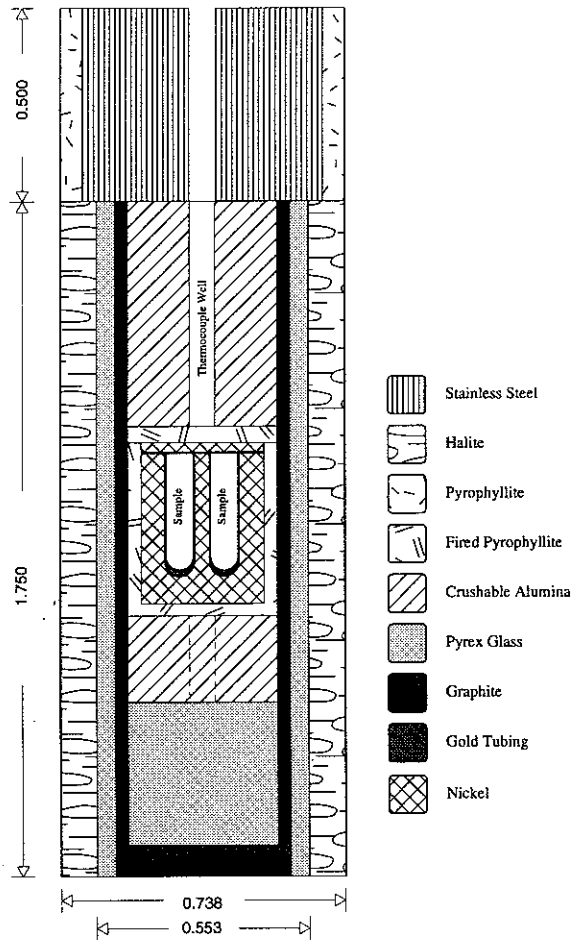


Figure 4. The sample assembly used in experiments.

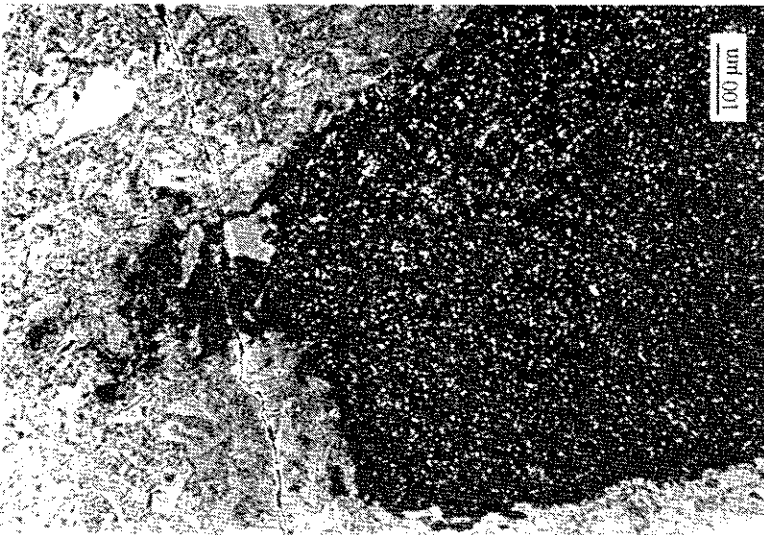


Figure 1.

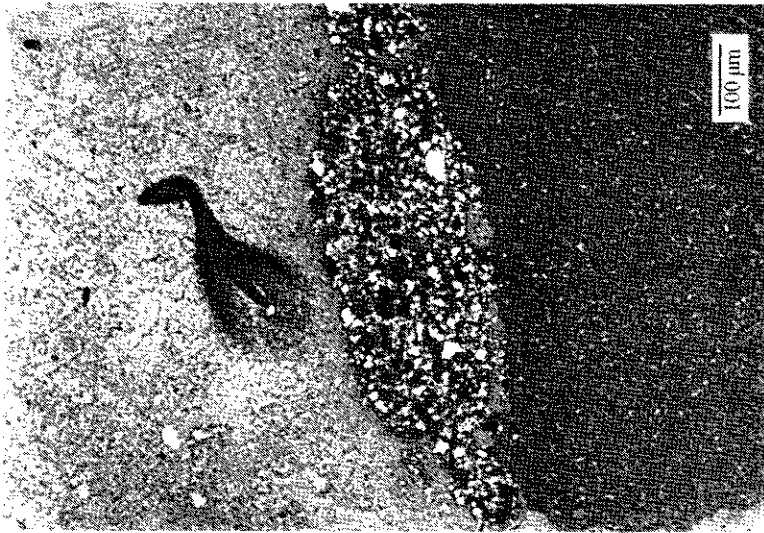


Figure 2.

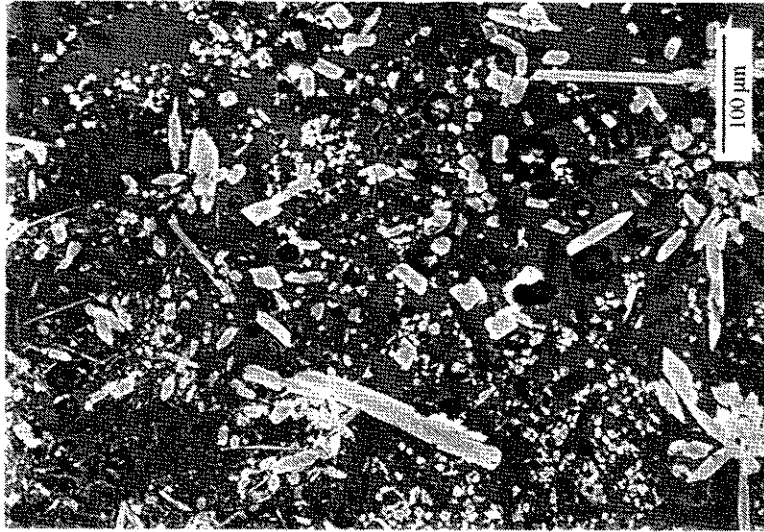


Figure 3.

Figure 1. Backscattered electron image of sample #2 (800°C, 1.0 GPa, 24 hrs, dry). Both the basalt (bottom) and dacite (top) are highly crystallized. The irregularity of the interface is probably due to uneven packing of the glasses when preparing the sample. Magnification: 80x.

Figure 2. Backscattered electron image of sample #6 (1000°C, 1.0 GPa, 24 hrs, dry). Notice the hybrid zone located between the basalt (bottom) and dacite (top). Small crystals are present in both the basalt and the dacite. Magnification: 75x.

Figure 3. Backscattered electron image of sample #6 (1000°C, 1.0 GPa, 24hrs, wet). Although the magnification (150x) is greater, crystals have clearly grown much larger in the wet sample. This is a closeup of a hybrid zone between the two melts.

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