MAGNESIOFERRITE FORMATION WITHIN LAVA TUBES

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ABSTRACT

Lava tubes on Earth have a unique mineralogy where a high-magnesium magnetite mineral, known as magnesioferrite, forms. The spectral signature of magnesioferrite may be useful in distinguishing between collapsed lava tubes and lava channels on Earth and other planets through remote sensing. Since magnesioferrite is thought to form only in oxygen-based atmospheres, it may provide evidence of oxygen-based atmospheres in the past if found in older rocks on other planets. The formation of magnesioferrite is believed to be related to a prolonged high temperature reaction of basalt melts and oxygen in the lava tube. The time-temperature relationship that occurs when basaltic glass is in transition to the formation of magnesioferrite is not clearly understood. In order to constrain the time-temperature relationship and get a better understanding of the stability of magnesioferrite several runs of 1 atmosphere experiments were conducted. First, using a high temperature furnace, a series of constant temperature experiments were conducted in order to determine when magnesioferrite began to form. Then a second variable temperature experiment was conducted to replicate the actual time-temperature relationship of a stationary position inside the walls of an active lava tube, to observe when the magnesioferrite formed. After these two experiments were completed, the spectral signature of the synthetic magnesioferrite, natural magnesioferrite and several other glassy basalts were taken and charted. Finally a thin section of the experimental magnesioferrite was made and an electron microprobe test was done to determine the mineralogy of the silver metallic coatings thought to be magnesioferrite.

INTRODUCTION

The purpose of this research is to constrain the time-temperature relationship in order to obtain a better understanding of the conditions under which magnesioferrite forms as well as the stability of magnesioferrite in lava tubes. Lava tubes are excellent thermal insulators allowing the lava to remain at high temperature (1050°C-1150°C) while traveling long distances and acts as an important emplacement mechanism. Heat from the tube allows easy detection through remote sensing, but this technique is only effective on active flows. Images from Mars Orbital Camera show collapsed lava tubes by inspection of their unique features, although it may not be clear in some images to distinguish between collapsed lava tubes from lava channels. Using the spectral signature of magnesioferrite in remote sensing the determination between collapsed tubes and channels could be distinguished. Magnesioferrite is also important because it only forms in oxygen-based atmospheres. The presence of magnesioferrite in older rocks on other planets may provide evidence of oxygen-based atmospheres in the past.

By using a high temperature furnace it is possible to replicate the same temperatures observed in natural lava tubes. Two experiments were established, one a constant temperature experiment, the second a variable temperature experiment. The constant temperature experiment was conducted to establish a temperature window of when a silver metallic coating, thought to be a synthetic magnesioferrite, began to crystallize on the surface of the charges. The variable temperature experiment was conducted in order to replicate the actual temperature at a stable location within the walls of the lava tube. Using real data from down cutting of the tube due to thermal erosion (Kauahikaua et al, 1998) a time-temperature path was established that followed the down cutting versus time path. Thin sections from the best samples from each experiment were made and polished for analysis using an electron microprobe located at the University of Hawaii-Hilo Geology Department. The spectral signature data of the lab produced magnesioferrite and natural magnesioferrite; in addition, several different basaltic glasses were collected. The data was then charted to show that magnesioferrite is distinguishable from other basaltic glasses, and for supporting evidence that the silver metallic coating on the samples made in the lab are magnesioferrite when compared to the spectral signature of natural magnesioferrite.

METHODS

Constant Temperature Experiment

The constant temperature experiment consisted of taking several small pieces of basalt (2x2x2 cm) and placing them in a furnace at set temperatures for prolonged periods. The temperatures ranged from 1040°C to 1120°C, and the time range lasted up to three weeks. One basalt piece was removed after one, three, seven, 10, 14, and 21 days at 1040, 1080, and 1120°C, respectively. Each piece was labeled, and observations recorded in a journal.

Variable Temperature Experiment

The variable temperature experiment was designed to replicate the varying temperatures observed in an active lava tube where the temperature will decrease with time. When the wall of the tube is in contact with the lava stream it will be at higher temperatures, and as the lava stream begins to erode downward (usually 2-3 days) the original wall temperature will decrease with time. The level of the lava in the tube will drop equally to the rate of down cutting (Kauahikaua et al., 1998). I modeled the experiment based on thermal erosion rates of down cutting from Kauahikaua's data (1998). One basalt piece was removed for observation and labeling after one, three, seven, 14, 21, and 28 days. The experiment started at a high temperature of 1120°C and ended at 1080°C. The temperature stayed stable at 1120°C for the first seven days then dropped an average of 3°C until 1080°C was reached and remained at this temperature for eight days and the experiment ended.

Spectral Reflectance of Synthetic Magnesioferrite

To obtain the spectral signature of the samples from the previous experiments; a glassy basalt was heated at 1100°C in the furnace for 14 days and removed. Using a handheld digital spectrometer five readings were taken from this sample at two different locations on the sample and plotted against natural pahoehoe lava (Fig. 1) using S. Shaw's data (1999). Spectral readings were also taken on several other naturally occurring minerals including magnesioferrite, and other basaltic glasses, and charted (Fig. 2).

Electron Microprobing

Three samples from 1080 at 600 hours, 1120 for three days, and the 21 day sample from the variable temperature experiment were thin-sectioned and polished for microprobing. The purpose of microprobing the samples are to confirm or refute the formation of magnesioferrite in a laboratory setting.

RESULTS

Results from the constant temperature experiment were very encouraging. The 1080°C experiment produced the most interesting result. I observed that a small amount of partial melting was taking place inside of the sample pieces. Using a binocular microscope, observations of small bubbles and metallic patches, of what is presumed to be magnesioferrite, formed. The bubbles and metallic patches formed more readily at higher temperatures, from observation of two short one day runs at 1130°C and 1140°C, where the bubbles that formed where larger and more prominent. This has led me to believe that small amounts of water vesiculating inside the samples have been forcing the partially melted glass inside the sample to the surface in the shape of bubbles. The partial melt is reacting with oxygen and forms what is presumed to be a magnesioferrite coating. At temperatures higher then 1140°C the water inside the sample simply remains in the melt as the sample begins to reach the liquidus.

The variable temperature experiment produced similar results to the sample pieces as the constant temperature experiments. Bubbles and metallic patches were observed throughout the entire sequence of the experiment. These bubbles are important in that they may represent what is happening in a natural lava tube in the formation of stalactite drips and "soda straw" features from the roofs of the tube. Observations under the binocular microscope show light brown transparent bubbles extruding from the surface of the samples, and other bubbles that have extruded earlier from the surface of the sample have a metallic coating consistent with magnesioferrite.

High end temperatures of the experiment showed abundant bubbles and the bubble were much more prominent because of the larger size compared to the bubbles formed at the 1080°C constant temperature experiment. The higher temperature samples did not show any oxidation surfaces until temperatures below 1100°C. At the low end of the temperature phase of the experiment, 1080°C, oxidized reddish to rust color surface was observed readily. This oxidizing layer lay in the background from the metallic patches, and is consistent to observations on roofs of natural lava tubes. To confirm what is believed to be happening in the lava tube another experiment of up to two to three months could be conducted to better replicate the time-temperature path of a thermally eroding lava tube.

After the variable temperature experiment was completed thin sections were made and polished. Inspection of the thin sections under a microscope showed an opaque edge around the vesicle rings inside the sample. The opaque edge is believed to be magnesioferrite, and is consistent with a thin section of natural magnesioferrite. In addition, the thin sections also showed needles of titanium oxide and globules of partially melted glass, also consistent with thin sections of natural magnesioferrite.

The spectral signature of natural magnesioferrite is distinctly different that other basaltic glasses (Fig. 2). When comparing the natural magnesioferrite to synthetic magnesioferrite there is a clear difference (Fig. 1). This is most likely due to the hasty experiment to produce a magnesioferrite coating on a basaltic glass. The basaltic glass used in the experiment was surface basalt, a condition that natural magnesioferrite does not form under. In this experiment for my research purposes I needed a broad flat surface in order to get a spectral reading and this particular basalt suited these needs, and is likely why the spectral signature of the synthetic magnesioferrite is so much different than the spectral signature of natural magnesioferrite.

CONCLUSION

It is very likely that magnesioferrite can be produced in a laboratory setting. Electron microprobing of samples from experiments will verify this conclusion. The onset of the formation of magnesioferrite in a natural setting seems to begin at a high temperature of approximately 1130°C ~1120°C, at a time shortly after the tube begins to thermally erode. Magnesioferrite will continue to form under these conditions for prolonged periods which results in the formation of the stalactites and other lava tube roof features, as the high magnesium rich melt reacts with oxygen in the tube. This will continue until the tube empties and begins the cool down. During cooling of the lava tube the walls can expand due to the temperature change and release of pressure of the lava stream. During the time of lower temperatures below 1080°C it is likely that a reddish oxidation occurs on the wall of the tube, similar to what is observed on the surface of the samples from the constant temperature experiment from the 1040°C set.

When comparing the spectral signature of natural magnesioferrite to other basaltic glasses, the natural magnesioferrite is distinguishable. This could be very useful in distinguishing collapsed lava tubes through remote sensing, as well as remote place on earth.

Further work on the formation of magnesioferrite in lava tubes will help in the knowledge of the dynamics of lava tubes and their presence on earth and other planets. By learning how lava tubes work will let us also learn how to coexist with volcanoes near populated regions on Hawaii and other areas on Earth.

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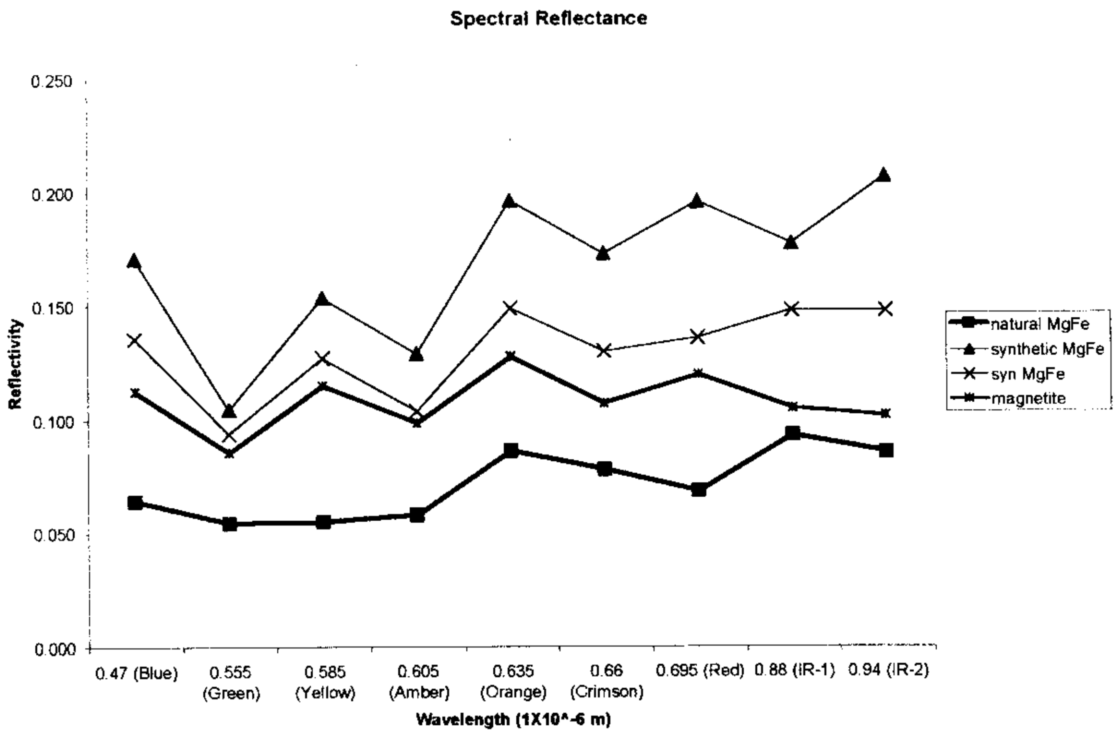

Fig. 1. This chart shows the comparison of natural magnesioferrite to a magnetite sample, and the two synthetic magnesioferrite produced in the lab.

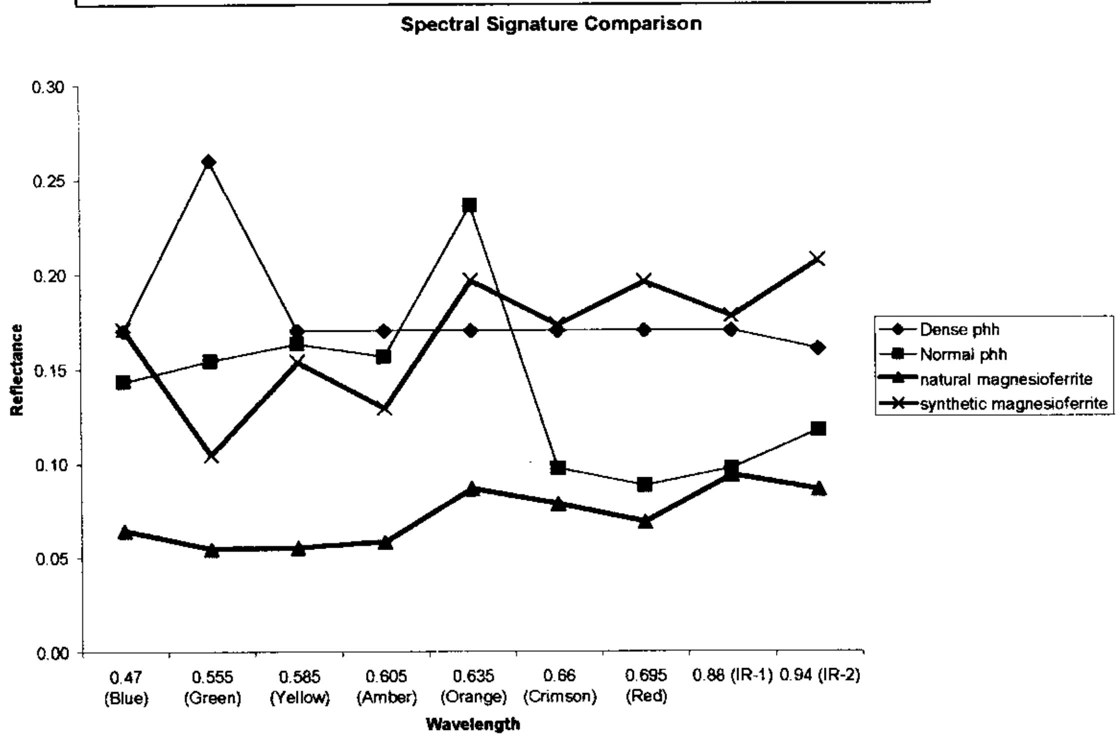

Fig. 2. This chart shows the spectral comparison of natural magnesioferrite to the synthetic magnesioferrite produced in the lab and to a dense pahoehoe and normal pahoehoe.

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