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Variations in Volatiles in Magma Bodies Based on
Studies of Melt Inclusions

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Date: December 13, 1989
Subject: Report of research project for sabbatical year, September 15, 1988 to June 15, 1989. Lawrence Livermore National Laboratory Contract No. 1304869. Michigan State University ORD No. 45643.

Title of Project: Variations in Volatiles in Magma Bodies Based on Studies of Melt Inclusions.

INTRODUCTION

The determination of volatile concentrations is fundamental to understanding the origin and evolution of magmas. Knowledge of volatile concentrations in magmas are also important in the prediction of explosive volcanism, and contribute to the understanding of the carbon dioxide budget of the atmosphere. Some important variables that are controlled by volatiles are: crystallization temperature of phases, composition of liquidus minimums, and viscosity. Volatiles are also catalysts for reactions that otherwise are sluggish. Carbon dioxide is so insoluble in silicate liquids, that the presence of small amounts (in the ppm range) requires that the liquid would be saturated with a vapor phase throughout much of its evolution. This has important implications for the degassing history of magmatic systems.

Because magmas degas as they reach the surface of the earth, little information on volatile content of magmas is based on direct measurements of volatiles in magmas. The determination of the volatile content in matrix glass of volcanics give only minimum estimates of these values. The estimation of the volatile contents of magmas are based primarily on experimental petrology and from theoretical modelling.

A better approach to estimating volatiles in magmas is to measure to measure the volatiles in glasses trapped as melt inclusions in crystals. Both H_2O and CO_2 concentration can be obtained from glass inclusions in minerals by infrared techniques. LLNL has a state of the art Fourier Transform IR spectrometer (FTIR) equipped with a microscope. With this instrument, melt inclusions as small as twenty-five microns in diameter can be measured. The concentration of individual water species (H_2O , OH^-) as well as carbon dioxide species can be determined with this technique.

The ability to determine the volatile content of the liquid at the time of entrapment by the growing crystal allows us, for the first time, to determine the pre-eruptive concentrations of volatiles in silicate liquids. Furthermore, by using the experimentally determined solubility of CO_2 and H_2O in silicate liquids at different temperatures and pressures, we can calculate the degassing history of the magma body from the volatile content of melt inclusions.

SAMPLES SELECTED FOR MEASUREMENT

For the past eight years we have been studying the large, chemically zoned ash-flow sheets in the southwestern Nevada Volcanic Field. These sheets represent an almost instantaneous eruption of part of a zoned magma body. Chemical and mineralogical zoning in these ash-flow sheets can be extreme. For example some bodies are zoned, from top to bottom, from 57% to 76% silica, 30 to 5% crystals, and inferred temperatures from 950 to 750° C. Reconstruction of the magma body would have the high-silica, low-crystallinity magma at the top of the body, whereas the lowest silica, high-crystallinity magma would occur at deeper levels. Volatile gradients have been inferred for the pre-eruptive magma bodies because crystallinity increases with increasing temperature and decreasing silica content. The best model to explain this situation is to have high water contents at the top of the magma body which would cause a suppression of the liquidus temperatures. It is for this reason that we selected to study melt inclusions in minerals from these zoned ash-flow sheets.

We have chosen four zoned ash-flow sheets to study the melt inclusion: the Rainer Mesa and Ammonia Tanks members of the Timber Mountain Tuff, the Topopah Spring member of the Paintbrush Tuff, and the Pahute Mesa - Trail Ridge Members (most likely one ash-flow sheet) of the Thirsty Canyon Tuffs.

SAMPLE PREPARATION

Preparation of samples is the most difficult part of this project, and much time was spent designing efficient sample preparation techniques. First, grains with melt inclusion have to be identified and separated from the sample. This requires examining each grain, in immersion oil with a transmitted light. Second, these individual grains are mounted in epoxy. Third, the grains are thinned and polished on both sides. Fourth, the thickness of the inclusion must be accurately determined. To do this it is best to have at least one surface of the inclusion exposed at one of the surfaces. About three months of work went into trial and error procedures before we developed preparation techniques that could be used on a regular basis. On the average, from start to finish, it takes about seven hours to prepare one crystal for analysis. Sixty-four crystals from two of the ash-flow sheets (Ammonia Tanks and Topopah Spring Members) were prepared by me at LLNL.

FTIR ANALYSES

Fifty-five separate crystals were studied in detail. From these we obtained 363 spectra from melt inclusions. Some of these are replicates of the same melt inclusion, or represent attempts to evaluate homogeneity within large inclusions. Because most of our

inclusions occur in feldspar, there is a tendency for the volatiles to leak out during decompression (because of the cleavages or defects present in feldspar crystals). Therefore many inclusion have to be measured from one sample in order to obtain the maximum volatile content at the time of entrapment.

PRELIMINARY RESULTS

We have only reduced the data from the Ammonia Tanks member, but even from this limited data set we can make some important conclusions. First, as predicted from the mineralogy and geochemistry, there are large differences in water content from the top of the magma body to deeper levels. The high-silica samples from the top of the body contains a maximum water content of 6.8 wt. % H_2O , whereas the lowest silica samples from deeper levels contain 2.9 wt. % H_2O . CO_2 contents range from 30 ppm to 119 ppm. The relationship between CO_2 and H_2O content suggests that the liquid was undergoing closed system decompression. However, it appears that the low-silica magma type and the higher-silica magma type started with different original CO_2 and H_2O concentrations, and thus followed different decompression paths. This is consistent with our previously collected chemical and mineralogical data that we have interpreted to indicate independent magma types for some of these ash-flow sheets. This fall we gave a report of these findings to the Annual Meetings of the Geological Society of America.

FUTURE WORK

During the past year we have received funding from the National Science Foundation to continue this work for the next two years.

We are continuing to reduce the spectra of inclusions previously collected from the Topopah Spring member and we should have results from this work by February of 1990. We have prepared thirty-four samples from the Rainer Mesa member for analyses. Samples from the Thirsty Canyon Tuff will be prepared early next year.

We are also working closely with researchers at Cal. Tech., the University of Chicago, and RPI to develop a better set of standards to use in FTIR studies of volatiles in glass.