PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2014
Mt. Holyoke College, South Hadley, MA

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ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
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Short Contributions— Martian Pāhoehoe Lava Project

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JAKE BLEACHER, NASA-GSFC
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Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Learning Science Through Research
Published by Keck Geology Consortium
Short Contributions
27th Annual Keck Symposium Volume
26 April, 2014
ISBN: 1528-7491

VERTICAL VARIATIONS WITHIN THE MCCARTYS FLOW: A PETROGRAPHIC AND GEOCHEMICAL ANALYSIS

MEGAN SWITZER, Colgate University
Research Advisor: Karen Harpp

INTRODUCTION

Volcanic eruptions are some of the most dynamic geologic processes on Earth. Unfortunately, owing to the rapid nature of eruptive events, it is difficult to understand the emplacement processes of individual flows within a volcanic field. In many cases, the best evidence of a past eruption is the cooled and hardened lava flow that it leaves behind. For this reason, it is imperative to understand exactly how a lava flow records physical, petrographic, and chemical changes that happened to the flow during the eruption.

Previous studies of the petrography and geochemistry of pahoehoe lava flows have mainly focused on how the composition of the flow varies horizontally (i.e., with distance along the flow from its vent). Conventional wisdom assumed that vertical variations in the composition of a flow are negligible and that the petrology and geochemical composition of the flow is homogeneous from the core to the crust in any given location (e.g., Garden and Laughlin, 1974). This study presents a petrographic and geochemical analysis of a vertical cross section of the McCartys flow, located near Grants, New Mexico, in an attempt to test this longstanding assumption and document potential compositional variations between the core and the crust of a pahoehoe lava flow. In particular, studies of lava flow emplacement indicate that pahoehoe flows experience significant amounts of inflation, involving injection of material into the core of the flow over the course of the eruption (e.g. Hon et al., 1994). Consequently, the assumption that vertical cross-sections of large flows such as the McCartys consist of material that emerged from the vent contemporaneously is likely to misrepresent reality.

GEOLOGIC SETTING

The McCartys flow, located in the Zuni-Bandera Volcanic Field in western New Mexico, offers an ideal opportunity to study physical and geochemical variations within a lava flow. The McCartys flow is composed primarily of basaltic pahoehoe lava. Some estimates suggest that the flow is 3900 years old (KellerLynn, 2012). Others propose that the flow was emplaced between 2500 and 3200 years before present (Laughlin et. al., 1993). The size of the flow provides for numerous opportunities to study physical and chemical features. At 43 kilometers long, the McCartys flow is one of the longest lava flows in the world (Fig. 1). Near the vent, the flow reaches up to 100 meters high, and even the distal parts of the flow have heights of up to several meters (Nichols, 1946). For these reasons, the McCartys flow and the entire flow field to which it belongs have been the subject of numerous studies over the past several decades (Nichols, 1946; Garden and Laughlin, 1974; Laughlin et al., 2993; KellerLynn, 2012).

The McCartys flow shows strong evidence of growth by inflation (Nichols, 1946). As a pahoehoe flow cools, the crust becomes rigid and develops strength. Eventually, the strength of the crust prevents the liquid core from continuing its forward movement. There comes a point where it is easier for the flow to grow upward (vertically) instead of forward (horizontally). Sustained lava injection into the core increases the hydrostatic head of the flow and leads to uplift of the entire flow sheet (Hon et. al., 1994). Observations of petrography, vesicularity, and crack depths indicate that inflation of the McCartys flow occurred over a

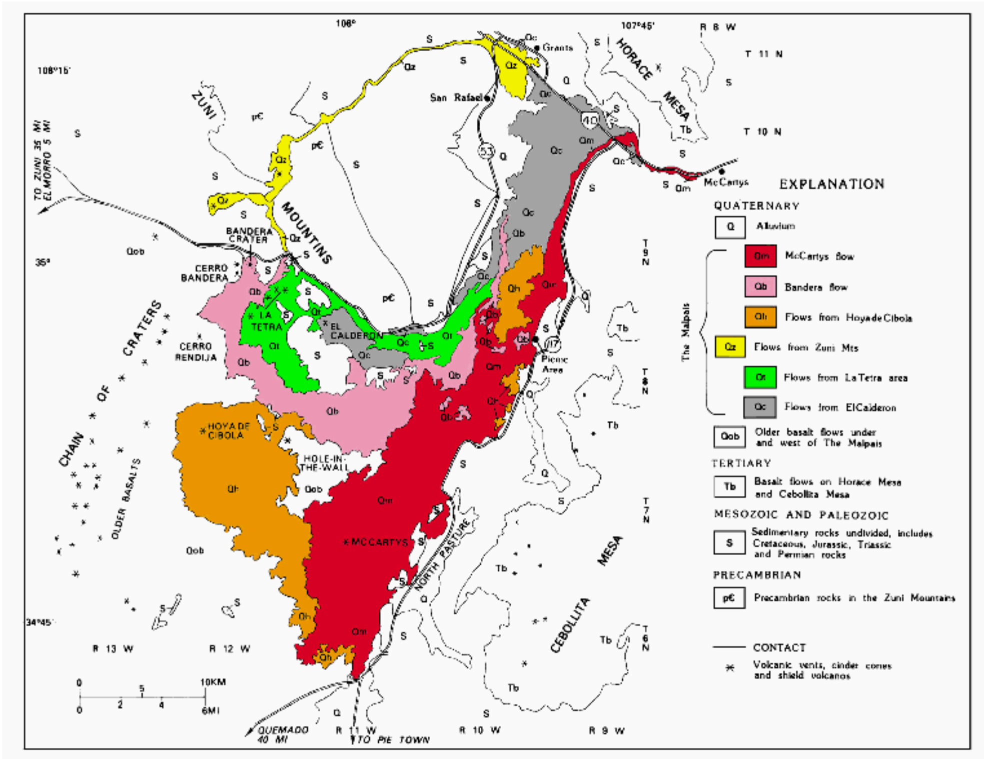

Figure 1. Map of the Zuni Bandera flow field. The red region indicates the extent of the McCartys flow. From New Mexico Bureau of Geology and Mineralogical Resources.

	McCartys	Twin Craters	Bandera
SiO2	51.48	48.86	44.47
TiO2	1.41	1.44	3.04
Al2O3	15.18	14.84	15.22
Fe2O3	11.87	12.48	4.39
MnO	0.16	0.17	0.15
MgO	8.29	9.15	9.3
CaO	9.11	8.87	8.8
Na2O	2.78	2.81	3.38
K2O	0.69	0.74	1.6
P2O5	0.19	0.22	0.58

Table 1. Major element geochemical data for the McCartys flow, the Twin Craters Flow, and the Bandera Flow. All flows are located within the Zuni-Bandera Volcanic Field. The values indicate the weight % major element in each flow. Data from (Laughlin et al., 1993.

period of several months. Considering the length of time during which lava was being injected into the flow, it is possible that changes in lava composition may be reflected in the petrography and geochemistry of the inflated lava here.

The McCartys flow has a specific geochemical signature that distinguishes it from the other flows in the Zuni Bandera Volcanic Field (Table 1). Previous studies have identified lateral variations in geochemistry across the 40 km length of the flow (Garden and Laughlin 1974). Magnesium concentrations vary the most, from ~5 to 8 wt. %. Concentrations of the rest of the major elements differ by only a maximum of 2 wt. %. For this reason, it has been assumed that a sample taken from anywhere in the McCartys flow is representative of the geochemistry of the entire flow (Garden and Laughlin 1974).

METHODS

Field Work

In this study, a total of 26 samples were collected from a vertical section of the McCartys flow in Grants, NM. The section is located about 40 km from the vent. At this location, a 6-meter high cross section of the flow extending from the core to the crust is exposed. Samples were taken every 10-40 cm in a vertical profile (Fig. 2). Observations of vesicular textures across the profile were recorded in the field. Furthermore, observations of mineralogical and vesicular features were documented for each of the 26 hand samples.

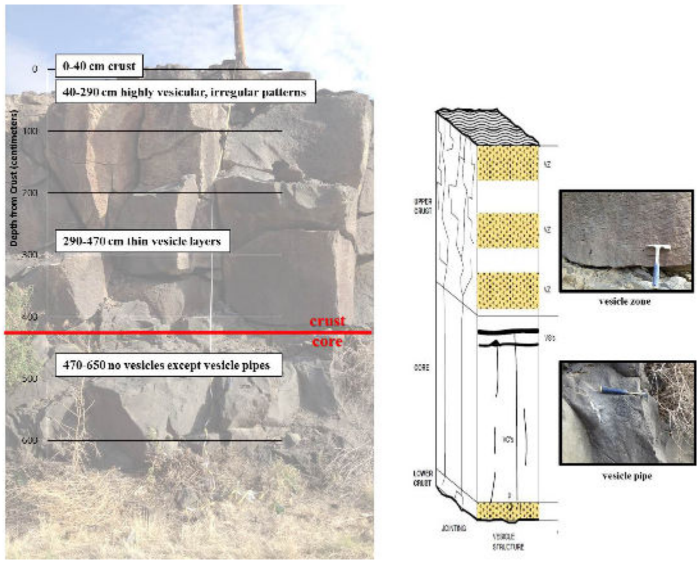

Figure 2. The vesicle patterns visible in the flow profile are consistent with with patterns identified by Self and Thordarson in (1998) (image in center borrowed from this paper.)

Sample Preparation

Thin Sections. Using a rock saw at Franklin and Marshall College, the hand samples were cut into blocks to be mounted on thin sections. The thin sections were prepared by Spectrum Petrographics, Inc.

XRF Analysis. Hand samples were prepared for XRF analysis at Colgate University. The samples were ground into a fine powder using a Balacor Shatterbox assembly. The powder was heated to 450°C during a standard loss on ignition procedure using a Barnstead 2000 Thermolyne furnace. Glass disks including 0.5000 g of each sample mixed with 4.5 g lithium tetraborate were made using a Claisse Fluxy fluxer. The disks were analyzed for major element geochemistry using a Philips PW2404 X-Ray Fluorescence Spectrometer.

RESULTS

Vesicularity

Outer Crust: The vesicular textures displayed in the vertical profile are typical of inflated basaltic lava flows (Fig. 2). The samples from the 40 cm thick crust typically have maximum vesicle sizes of approximately 5mm in diameter and tend to be tube shaped.

Upper Crust: Moving progressively down the profile, the next 250 cm have vesicles that are rounded and irregular in shape and have maximum sizes of 20 mm. This section of the flow corresponds to the vesicle zone, as defined by Self et al. (1998). Vesicle zones form while inflation is still occurring as a result of sudden changes in pressure of the liquid core (Self et al., 1998).

Upper Core: The next section extends from 290 cm to 490 cm. It is dominated by thin layers of vesicles that are often less than a millimeter across. The layers themselves are 1-3 mm thick and are 2-5 cm apart from each other. This kind of texture is called a vesicle sheet (Self et al., 1998). Vesicle sheets form when inflation has ended and the cooling core is slowly releasing gases (Self et al., 1998)

Inner Core: The final section that extends from 270 cm to 650 cm has few vesicles; this is the core of the flow. Where there are vesicles, they are located in isolated “pipe” structures. These pipes emerged after inflation ended when the core was cooling (Self et al., 1998).

Petrology and Geochemistry

Petrology: The mineralogy of the hand samples does not appear to vary. Examination of the thin sections reveals that crystal sizes are mainly 0.5 mm to 1.0 mm in diameter and the distribution of mineral types in each sample is indistinguishable from sample to sample. The hand samples are dominated by olivine phenocrysts and the second most common mineral is plagioclase.

Major Element Chemistry: The major element components of each sample in the profile define two distinct trends. The concentrations of each element are constant or slightly changing only slightly for the entire profile until 640 cm; at this depth, the concentrations of the major elements either sharply increase or sharply decrease (Fig. 3). Concentrations of silica, titanium, iron, sodium, potassium, and sulfur tend to decrease down from the upper crust and then sharply increase at 640 cm. Concentrations of aluminum, calcium, and magnesium slightly increase with depth and then sharply decrease at 640 cm.

The silica and calcium components exhibit an additional pattern with depth. Samples from 0 cm and 30 cm depth have an increased silica component and a decreased calcium component. The concentrations of silica and calcium in these samples are similar to the concentrations of these elements at 640 cm depth.

The concentrations of major elements vary systematically with the amount of magnesium in the sample. The concentrations of titanium, sodium, and potassium all increase as magnesium increases. Aluminum content decreases as magnesium goes

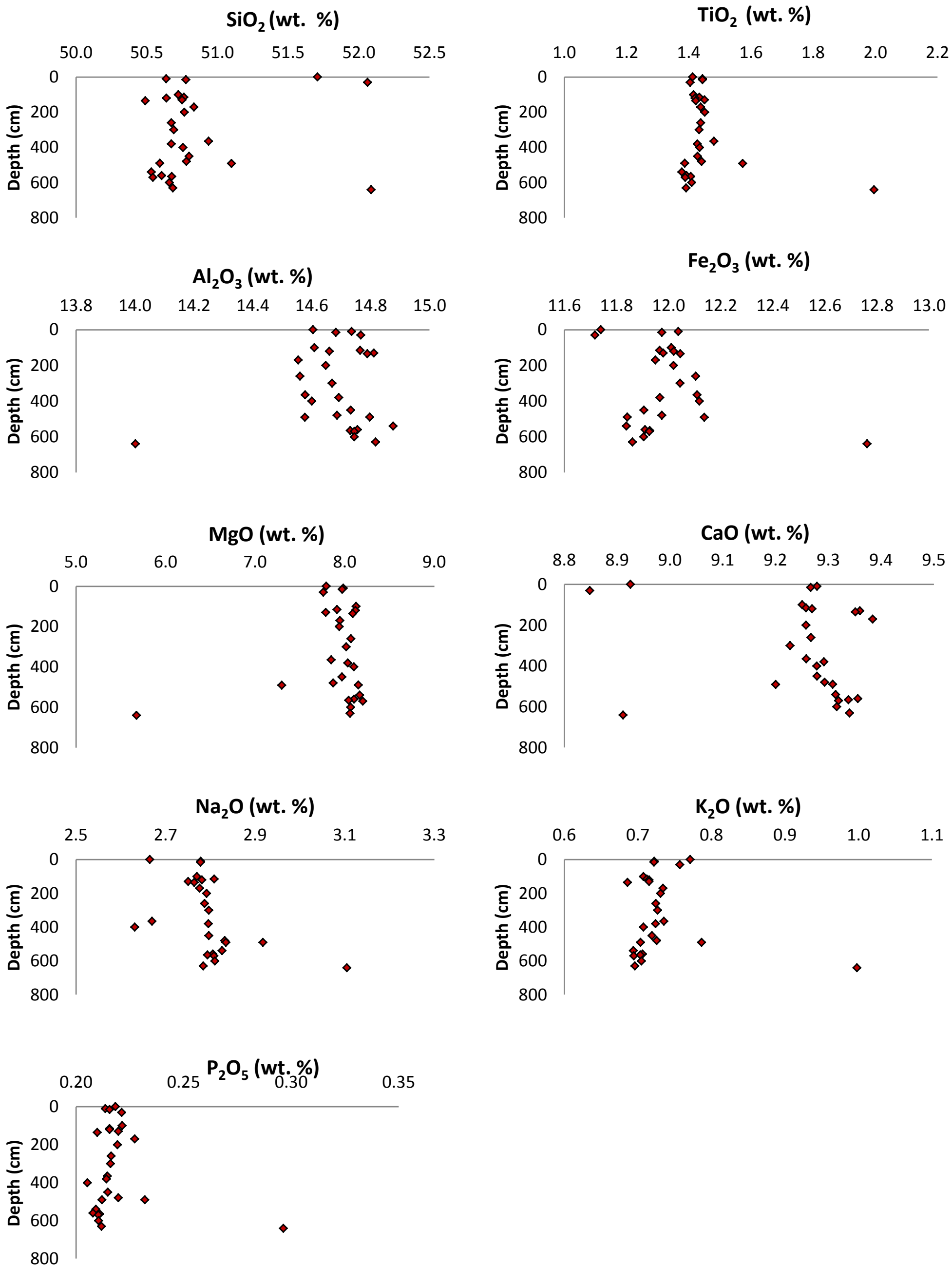

Figure 3. Major element compositions with depth from the surface.

down. However, iron and calcium components do not correlate directly with the amount of magnesium in the sample (Fig. 4).

DISCUSSION AND CONCLUSIONS

The vesicle textures at the sampling location are nearly identical to features of a typical pahoehoe flow as described by Self et al. (1998). The bottom crust is inaccessible at this outcrop, but the core through outer crust sections are clearly defined by vesicle structures; these structures include pipes and vesicle sheets in the core and vesicle zones in the upper crust. The consistency of these features suggests that the vertical profile studied here is all part of a single flow.

Analysis of major elements reveals that there are slight changes in chemistry between the core and the crust of this flow, with outliers at 640 cm (the deepest sample into the core) and 0 and 30 cm (upper crust). One explanation for the outliers is that they were derived from a separate flow with a distinct chemical signature. The variation in vesicularity of this site, however, suggests that only a single flow is represented here (e.g., Self et al. 1998).

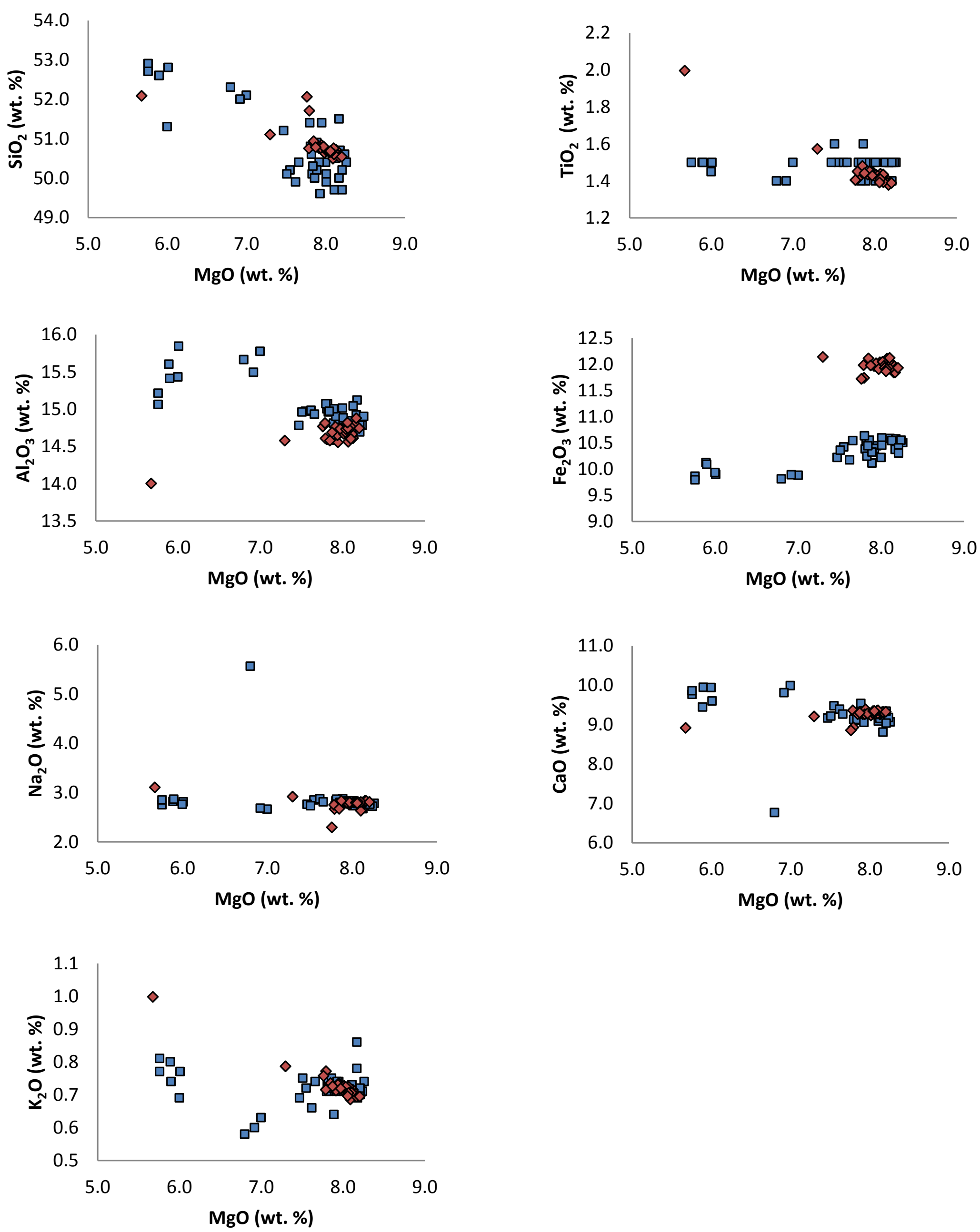

Figure. 4 Variations in MgO with other major elements within the flow. The blue symbols represent the chemistry of the entire lateral extent of the flow (this data is taken from Garden and Laughlin, 1974). The red data-points represent the vertical chemistry (this study).

Alternatively, chemical variations throughout the profile may be the result of variable degrees of fractional crystallization in the magma chamber prior to emplacement. Major element variations in the profile define coherent liquid lines of descent, which indicate that all the samples from the profile were derived from a single parental magma.

The sample from 640 cm with irregular chemical components has a lower magnesium concentration than the other samples in the series, which suggests that this sample underwent a greater degree of cooling than the rest of the magma prior to emplacement. One possibility is that this sample represents the youngest material in the flow since it appears to be located in the core; the implication of this theory is that it is possible to halt and then remobilize the injection of lava into a single flow after an additional degree of cooling has occurred. However, this is an unlikely scenario because the difference in fractionation in this series would have taken thousands of years to develop (Cashman, 1993).

The best explanation for the irregularity of the sample from 640 cm is that it actually represents the lower crust of the flow, which was presumably buried by dirt at the site. According to the inflation growth mechanism, the composition of the lower crust ought to be identical to the composition of the upper crust because they were emplaced at exactly the same time (Hon et al., 1998). The composition of the 640 cm sample is nearly identical to the samples from 0 cm and 30 cm with respect to silica and calcium; this similarity supports the hypothesis that the 640 cm sample represents the lower crust.

Similar patterns in major element compositions have been observed in a study of basalts from the 2005 eruption of Sierra Negra volcano in Galapagos, Ecuador (Geist et al., 2005). Material that erupted early in the 2005 event has experienced significantly more cooling than the Main Stage material, produced during the rest of the eruption. Early-erupted magma lost magnesium-rich olivine through fractional crystallization (Geist et al. 2005). Geist et al. (2005) further propose that the first magma erupted had been stored in the magma sill for longer than the subsequently erupted material, and as a result, experienced greater extents of cooling. I propose that a similar mechanism may have caused chemical variations in the McCartys flow; different degrees of cooling in the magma chamber produced lavas with different compositions.

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