Lateral Geochemical Variation Within Banks Peninsula Lava Flows

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Abstract

Research being conducted in Banks Peninsula by the University of Canterbury and the Frontiers Abroad program has been relying on single hand samples to represent an entire flow in their studies. Previous research investigating flow homogeneity, however, has only investigated flow homogeneity with a minimum of only 300m sampling intervals. This distance is much larger than most exposures in banks peninsula due to erosion and coverage by plants and soil. In order to investigate the homogeneity of the lava flows on a smaller scale, samples were taken from a continuous crystal rich lava flow and crystal poor lava flow on the banks of Lyttelton Harbor. Through analysis of the phenocryst content in thin sections and geochemical analysis from an XRF it was determined that the lava flows in Banks Peninsula are homogenous due to lack of variation within both the major oxide percent compositions and the phenocryst percent compositions. This means that previous sampling methods of using a single sample to represent an entire flow will be accurate as long as there is not an unusually high amount of phenocrysts within the sample taken.

Introduction

Current work by the University of Canterbury and the Frontiers Abroad program has long relied upon single hand samples taken from lava flows on Banks Peninsula to represent the entirety of the flow. This is necessary because of the lack of exposure of the lava flows due to erosion and soil cover. However due to possible heterogeneity of the lava flows being sampled, it is currently unknown how representative the samples taken are of their parent flows.

To date there have only been three significant studies looking at lateral geochemical homogeneity of a lava flow. A study by Rhodes (1983) found significant homogeneity in the Mauna Loan flow that was studied. The samples were collected in vertical sections at the head and tail of the flow. These two areas displayed nearly identical geochemical composition indicating significant homogeneity over the entirety of the flow. However, due to no samples being taken from anywhere between the head and tail of the flow, it is unknown whether there was any small-scale heterogeneity within the flow between the head and tail.

A study of the McCartys Basalt in Valencia County, New Mexico offers contrast to Rhodes's study by sampling a heterogeneous flow (Garden & Laughlin, 1974). In this study the group collected samples over a distance of about 30km to analyze the longitudinal differentiation of geochemistry of the basalt. The group discovered that there are two geochemically distinct parts of the flow, one olivine-normative composition close to the vent and a plagioclase-normative composition further from the vent. The study had a variable sampling interval with the smallest interval being about 200m, however most other intervals were tens to hundreds of meters larger. This large sampling interval left the researchers unable to determine whether the two distinct geochemical signatures that were identified were due to the heterogeneity of the flow or due to the researchers accidentally sampling a different flow without realizing the change.

A final study by a group of geologists took multiple samples over 30 km of the Borgarhraun flow in Iceland (Maclennan et al., 2003). What they found was that differences in rare earth elements can be attributed to incomplete mixing of fractional melts. They also found that lack of homogeneity of major elements is attributed to fractional crystallization separating the elements so that they are erupted at different stages. The study, however, failed to identify a length over which homogeneity or heterogeneity can be assumed due to their sampling interval of over 300m being too large.

By sampling along a continuous flow in Banks Peninsula with a smaller sampling interval than used in previous studies, we can gain insight into the scale on which homogeneity exists within these lava flows. From this it will be possible to conclude whether current sampling procedures currently being used in Banks Peninsula are giving accurate representations of the flows, or if they need to be modified.

Geologic Setting

The volcanism that created Banks Peninsula began in the Miocene when plate tectonics caused compression, creating the Kaikoura Orogeny and causing an increase in volcanism in Banks Peninsula and other areas around the south island. In Banks Peninsula the volcanism had two different magma sources, one in the northeast and the other in the south-east. These two magma sources generated the Lyttelton and Akaroa volcanic systems. The volcanism eventually ceased when the tectonics of the area switched from strike-slip to compressional. Once the volcanism ceased, erosion began occurring. The combination of the elements along with rivers and a large influence from the ocean eventually formed Lyttelton habor. While this was occurring, rivers flowing from the Southern Alps were also depositing sediment creating alluvial fans that eventually reached out far enough to connect Banks Peninsula to the mainland (Hampton and Cole, 2009).

Methods

Samples were taken from 2 independent exposed lava flows located in the Port Hills above Lyttelton Harbor (Figure 2 and 3). The samples were taken every 50m along the flow from the middle of the exposed flow. The samples were then taken back to the lab and cut into billets for thin sections. The rest of the sample was cut to get rid of weathered material and dried at 105°C for 24 hours. This dried sample was then crushed with a hydraulic press and a ring grinder to create a powder for XRF. The powder was then used with a Philips PW 2400 Sequential wavelength dispersive X-ray fluorescence 63 spectrometer at the University of Canterbury to obtain major oxide percent compositions.

Commented [DM1]: include the crystal rich crystal poor stuff

The major oxide percentages from the XRF analysis were first adjusted to normalize for LOI before being put into Igpet to classify the two flows. The major oxide values then were plotted against the distance from the sample closest to the vent (samples 5 and 11 for flows 1 and 2 respectively). Doing this shows how the element concentrations change laterally along the flow. These element compositions were also put into the statistical program R and smoothing splines were fit to each element's percent composition over the length of each flow.

The thin sections were photographed under cross-polarized light to determine phenocryst percent composition. To do this the photographs were put into CorelDraw where the phenocrysts were colored by mineral type and the groundmass was also colored (Figure 1). Using ImageJ these edited photographs were then analyzed and the percent composition by phenocryst type was recorded.

Results

Thin Sections

The images put through ImageJ show that flow1 contains consistent amounts of feldspar phenocrysts and olivine phenocrysts. In flow 1 the change in feldspar phenocrysts over the entire length of the 210m sampled flow was 4 percent with the largest change in composition being a 5 percent change between samples 1 and 2. The olivine crystal percent changes by less than that, with only a 0.4 percent by volume decrease over the 210m of flow and maximum change of 0.5 percent change between samples 4 and 5. There are no observed pyroxene crystals in the thin sections from flow 1.

Flow 2 also has consistent mineral content with only a 2 percent change in feldspar over the 250m of flow, which is also the largest difference in feldspar percent composition in flow 2. Olivine percentages also remain consistent with a change of about 2.4 percent over the entire 250m of the flow and the largest difference in percent composition being about 1.8 percent difference between samples eight and nine. Pyroxene is the most variable of all the phenocrysts with only about a 1 percent change between the two ends of the flow, however between this the pyroxene content seems to oscillate by half a percent to 1.5 percent. This still is a small percentage to change by and despite the small oscillations is still relatively consistent (Table 1).

Geochemistry

When plugged into igpet the geochemistry of Flow 1 shows it is a crystal rich trachyandesite that is transitionary between tholeitic and calc-alkaline. Flow 2 is crystal poor and consists of an alkaline basalt that is between a mugearite and hawaiite.

When the percent composition of the oxides was plotted for each flow in figures 4 and 5, the bars representing the oxide percents maintained a uniform thickness. This indicates little change in major oxide composition over the length of either flow. In Flow 1 there is a small but noticeable increase in silica and a less noticeable increase in manganese at a distance of 160m (sample 2). At this point there is also another small but noticeable decrease in iron. In Flow 2 there is a very slight increase in iron at 50m (sample 10), but it decreases back to its previous percentage past 50m. At this distance magnesium experiences a slight decrease in percent but, like iron, returns to its previous percentage past 50m.

Statistical Analysis

Figure 6 displays the smoothing spline analysis applied to the geochemical data. The results yielded all linear regressions most of which were close to horizontal as is shown by the Fe_2O_3 (other oxides with this spline pattern include TiO_2, K_2O, P_2O_5, SiO_2, CaO, and MnO). However there were a few with positive slopes such as the Al_2O3 and the Na_2O of Flow 1 (MnO in flow 1 also had a positive slope). However MgO was the only one with a negative slope.

Discussion

The lack of change in the major elements (Figure 5), the mineral compositions (Table 1), and the flat linear smoothing splines for most of the major elements (Figure 6) indicate that both flows are homogenous. The highest variation observed within the oxide percent composition data set was at sample two, with increases in silica and manganese and decreases in iron. The thin section for sample two also varied from the rest of the samples. The difference in percent composition of feldspar phenocrysts between samples one and two is the largest difference than between any other two samples for any mineral type.

The albite twinning of the phenocrysts supports that the feldspar could be plagioclase, an increase of which would account for the increase in manganese and silica composition. This is supported by the findings of Lindstrom and Haskin (1981) who found that significant geochemical differences that were present within the tholeiitic Icelandic flow being studied were attributed to segregation of the melt and phenocrysts. While the phenocrysts in this flow do not cause as large a change in the bulk geochemistry as the change observed in the study by Lindstrom and Haskin, the idea that differences in phenocryst content cause differences in the major elements is still relevant.

The total sampling length for this study of 250m and 210m comes close to the 300m sampling interval of the study by Garden and Laughlin (1974). In their study Garden and Laughlin observed heterogeneity over the length of 300m. The fact that no heterogeneity was observed over a length close to the one used in the Garden and Laughlin study indicates that large-scale homogeneity throughout the length of the flow is highly likely. This large-scale homogeneity means these Banks Peninsula flows are similar to the one studied by Rhodes (1983) in which there is also large-scale homogeneity. This similarity of homogeneity between Banks Peninsula and Hawaii along with their similar tectonic settings indicates there could be a link between the tectonic setting of a volcano and the homogeneity of its lava flows.

Conclusion

The data collected along with previous studies indicates that the lava flows remain homogenous over the 210m and 250m sampled. This indicates that the sampling methods used on Banks Peninsula are properly representing the flows being sampled, because no matter where the sample is taken from within the flow, the sample will maintain the same chemical composition. However future studies should take care to avoid any large conglomerates of phenocrysts when sampling, as the conglomerates will cause misrepresentative geochemical data.

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Works Cited

Garden JR, Laughlin AW. Petrochemical Variations within the McCartys Basalt Flow, Valencia County, New Mexico. *GSA Bull*. 1974;85(9):1479-1484.

Hampton SJ, Cole JW. Lyttelton Volcano, Banks Peninsula, New Zealand: Primary volcanic landforms and eruptive centre identification. *Geomorphology*. 2009;104(3-4):284-298. doi:10.1016/j.geomorph.2008.09.005.

Katz MG, Cashman K V. Hawaiian lava flows in the third dimension: Identification and interpretation of pahoehoe and a'a' distribution in the KP-1 and SOH-4 cores. *Geochemistry, Geophys Geosystems*. 2003;4(2). doi:10.1029/2001GC000209.

Lindstrom M, Haskin L. Compositional inhomogeneities in a single Icelandic tholeiite flow. *Geochim Cosmochim Acta*. 1981;45(1):15-31.

Maclennan J, McKenzie D, Hilton F, Gronvold K, Shimizu. Geochemical variability in a single flow from northern Iceland. *J Geophys Res*. 2003;108(B1):1-21. doi:10.1029/2000JB000142.

Rhodes JM. Homogeneity of lava flows - Chemical data for historic Mauna Loan eruptions. *J Geophys Res*. 1983;88:A869-A879. doi:10.1029/JB088iS02p0A869.

Rhodes JM. Geochemical stratigraphy of lava flows sampled by the Hawaii Scientific Drilling Project. *J Geophys Res*. 1996;101(B5):11729. doi:10.1029/95JB03704.

Rhodes JM, Vollinger MJ. Composition of basaltic lavas sampled by phase-2 of the Hawaii Scientific Drilling Project: Geochemical stratigraphy and magma types. *Geochemistry, Geophys Geosystems*. 2004;5(3). doi:10.1029/2002GC000434.

Shorttle O, Maclennan J. Compositional trends of Icelandic basalts: Implications for short-length scale lithological heterogeneity in mantle plumes. *Geochemistry, Geophys Geosystems*. 2011;12(11). doi:10.1029/2011GC003748.

Stracke A, Bourdon B. The importance of melt extraction for tracing mantle heterogeneity. *Geochim Cosmochim Acta*. 2009;73(1):218-238. doi:10.1016/j.gca.2008.10.015.

White RS, McKenzie D, O'Nions RK. Oceanic crustal thickness from seismic measurements and rare earth element inversions. *J Geophys Res*. 1992;97(B13):19683. doi:10.1029/92JB01749.

Tables

sample#	feldspar %	olivine %	pyroxene %
1	4.796	1.969	0
2	10.662	1.793	0
3	7.713	0.835	0
4	9.946	2.078	0
5	9.98	1.503	0
6	6.145	1.764	0.936
7	6.94	1.712	1.457
8	8.024	2.814	0.589
9	8.12	1.829	2.375
10	7.183	1.594	0.943
11	10.213	2.94	2.391

Table 1. The samples and their respective phenocryst percent composition by mineral

Figures

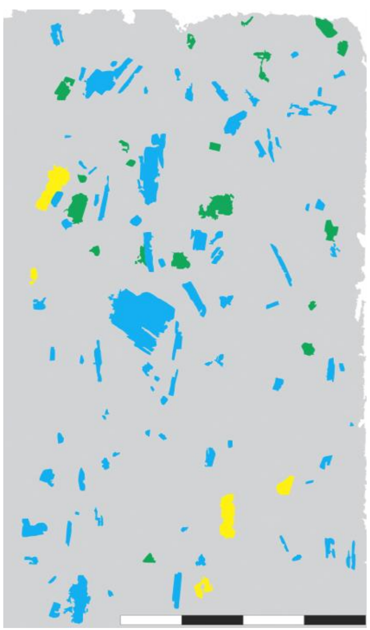

Figure 1. edited thin sections from sample 10, Feldspar is highlighted in blue, olivine in green, pyroxene in yellow and groundmass in grey. The scale is in 0.4cm increments

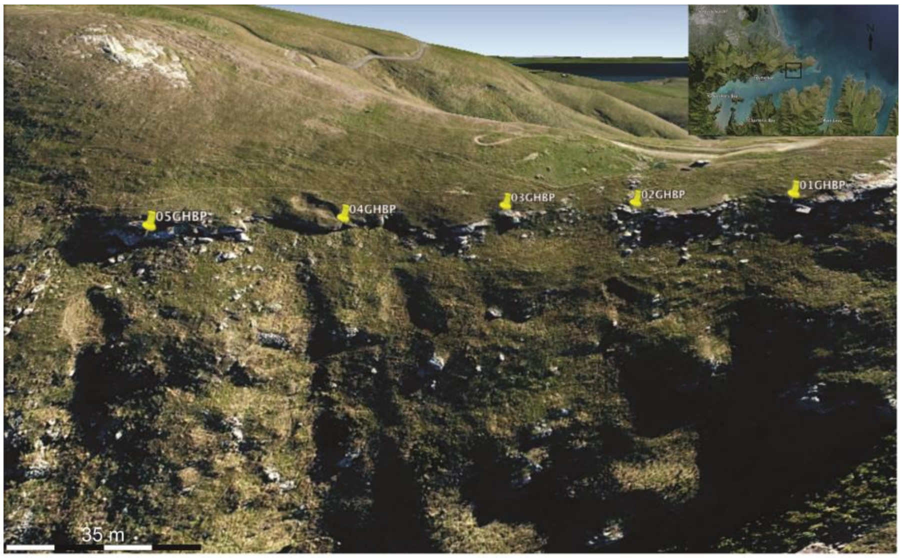

Figure 1. Flow1 with each sample location marked and labeled (adapted from Google Images 2015)

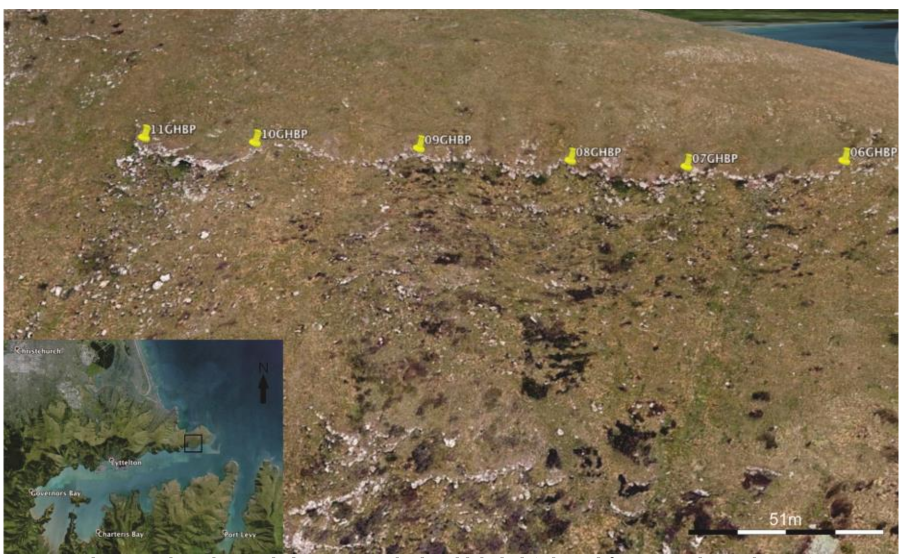

Figure 3. Flow 2 with each sample location marked and labeled (adapted from Google Earth 2015)

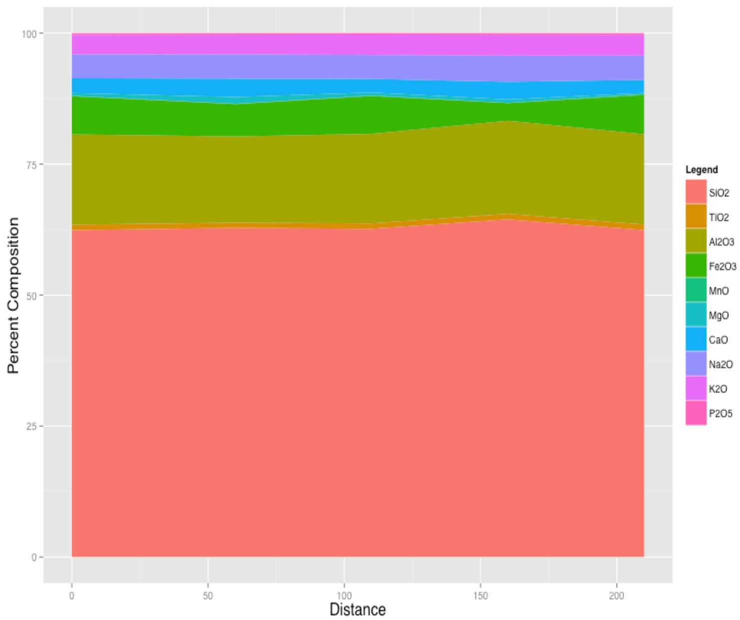

Figure 4. The percent composition of each major oxide from the XRF analysis for Flow 1

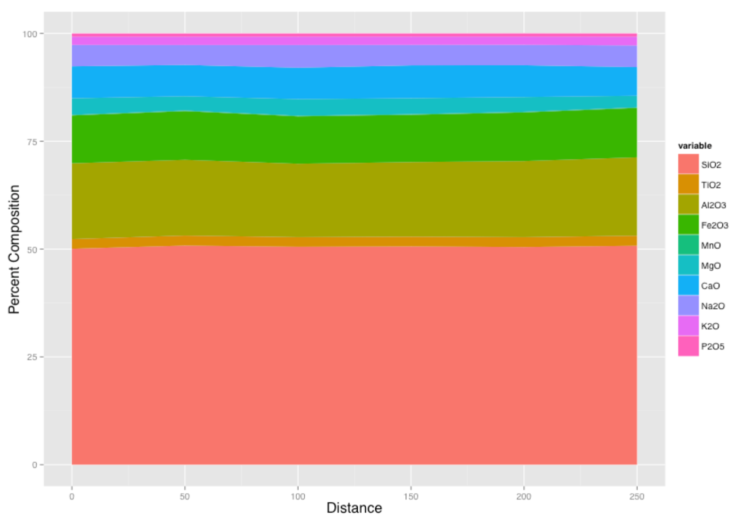

Figure 5. The percent composition of each major oxide from the XRF analysis for Flow 2

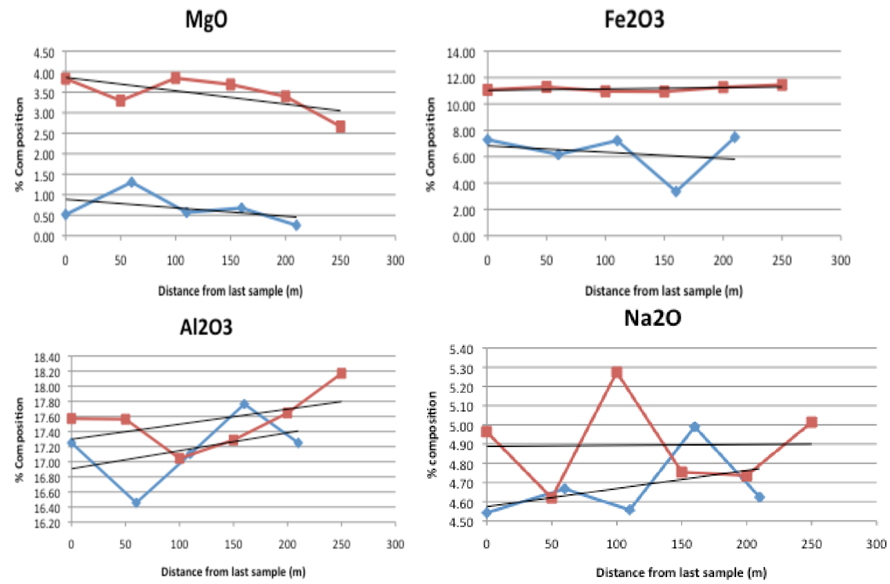

Figure 6. The change in percent composition over distance and the smoothing splines fit to each flow. (Flow 1 in blue and Flow 2 in red)