Structural and Geochemical Characterization of a Trachy-Andesitic Cryptodome: View Hill, Banks Peninsula, New Zealand

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ABSTRACT

Structural and geochemical studies of cryptodomes can provide insight into their origin and method of formation. Little is known about cryptodome formation, particularly in the case of mafic domes. In this study, an exposed cryptodome located on the Banks Peninsula of New Zealand was characterized using geochemical and structural methods. It was found to have risen through an area covered in earlier basaltic lava flows. Strong flow banding shows that magma movement was a significant factor in the emplacement of the dome. Further study is needed to better understand injection sources and their significance; however, this study proposes a possible model of emplacement and later activity.

INTRODUCTION

Cryptodome formation is currently a poorly understood process. Stewart and McPhie (2003) note that they are commonly inaccessible, forming in subaqueous environments, buried by the land underneath which they form; or mistaken for lava domes due to similarities in shape and geochemical composition. However, cryptodomes and their better-studied cousins, lava domes, represent a major part of the eruptive and post-eruptive history of a volcano. The presence of a dome can act as an indicator of a pending eruption, as was the case at Mt. St. Helens, or a destabilizing force that could cause other volcanic hazards such as landslides and sector collapses (Riggs and Carrasco-Nunez, 2003; Fink and Anderson, 2000). Study of how these domes form can give clues as to the potential for collapse, eruption, and other types of hazard that they hold.

Historically, lava domes and cryptodomes are associated with felsic magma compositions (Fink and Anderson, 2000). The mafic nature of the View Hill dome makes it an unusual example and raises a host of questions concerning the processes by which it formed. This study utilizes whole rock geochemistry, as well as micro and macro scale structural analysis, to reconstruct the method of emplacement of the View Hill dome. View Hill is an excellent location for this study because overlying material has been fully eroded, allowing for easy mapping of the entire dome. It is the goal of this study to structurally and geochemically characterize the View Hill dome, and to determine what, if any, correlation exists between flow textures and intrusive dome structure. Field relationships, flow patterns, and mineralogy all provide insight into the origin of the dome and the mechanics of its emplacement.

GEOLOGIC BACKGROUND

View Hill is located in the midst of a volcanic complex on Banks Peninsula, New Zealand. The dome forms part of the Akaroa volcanic complex, which was active from 9.0 - 8.0 Ma (Hampton and Cole, 2009). Two competing models, both published within the last 5 years, claim different methods of the complex's formation. Timm (2009, 2010) uses a geochemistry-based approach to argue that Akaroa was a complex shield volcano. In his model, eruptive activity took place in two main stages. The first was the formation of a basaltic shield, during which the majority of eruptive material was emplaced. This was then followed by small, late-stage eruptions that continued for several million years after the main period of volcanic activity ended (Timm et. al., 2009). By contrast Hobbs (2012) used structural data and remote sensing to model Akaroa as a composite cone volcano with many different eruptive centers. According to this hypothesis, eruptive activity was ongoing throughout the volcano's active period (Johnson, 2012; Hartung, 2011).

Both of these hypotheses have corresponding models that explain the formation and injection patterns of the magma. The formation of Akaroa Volcano cannot be correlated to either a mantle plume or extensional tectonics; therefore it is considered an intraplate volcano. Timm (2009) has attributed melt formation to localized lithospheric detachment brought on by an unusually dense lower lithosphere and stresses related to continental break-up. This model explains how upwelling of a large volume of melt could have occurred over a relatively short time period, and is consistent with the Si-undersaturated, mafic rich rocks that are most commonly observed in Banks Peninsula. In Hobbs' (2012) version of events, magma injection need not occur all at once. Hartung (2011) and an abstract published by Johnson (2012) utilize a similar model of lithospheric detachment to explain the mafic nature of the melts, but argue that injection occurred in small bursts, between which extensive crystal fractionation took place. This model, they argue, better explains why rocks in the Akaroa complex tend to be either basaltic / gabbroic or trachytic / syenitic, with very little evidence of intermediate stages.

METHODOLOGY

Strike and dip measurements of platy cleavage planes were taken in 36 locations across the western side of the dome, as outcroppings and accessibility permitted (Figure 1). Five samples were taken: three from the northern and southwestern sides of the dome, and one each from what appear to be small intrusions located in the south and center part of the dome (Figure 1). Three of these were oriented; two dome samples and one from the center intrusion. The whole-rock geochemistry of one dome sample and both intrusion samples was analyzed using X-Ray Fluorescence on the Philips PW2400 Sequential Wavelength Dispersive X-ray Fluorescence

Spectrometer at the University of Canterbury. Oriented thin sections were prepared from samples 1, 2 (dome) and 5 (centrally located intrusion).

RESULTS

Geochemistry and Texture

The three samples collected from the dome are all categorized as trachy-andesites based on their total alkali to total silica ratio (Le Bas et al, 1986) (Figure 2). They display typical trachytic texture as outlined by Smith (2002). All samples are visibly crystalline at the hand sample scale, and petrographic analysis confirms interlocking crystalline texture and a pronounced lack of glassy groundmass. Samples 1 and 2 show equigranular textures and are mineralogically composed of >90% k-feldspar, with scattered green and brown skeletal clinopyroxenes and amphiboles, as well as weathering-related opaque minerals, making up the remainder of the crystals. Sample 5 has the same mineralogical composition, but differs texturally. In this sample strong flow texture is visible in the k-feldspars, while clinopyroxenes and amphiboles are phenocrystic and display euhedral forms. Ellipsoidal vesicles are interspersed throughout the sample, although there is still no glass in evidence. Percentage of aligned feldspars varies in the samples, with sample 2 showing >90% aligned feldspars and samples 1 and 5 showing 80-90% aligned feldspars. All samples analyzed show that the preferred orientation of k-feldspars is distinctly parallel to cleavage.

Structure

The View Hill dome measures approximately 500 meters in length, and is 300 meters across. Cross-cutting relationships based on satellite images of the dome indicate that it is younger than the basaltic lava flows that surround it (Portner, in prep). A fissure extends to the southwest of the dome, however its relationship to the dome is uncertain (Figure 3). Macroscale structures observed on the dome include platy cleavages, columnar jointing, and irregular jointing. Platy cleavage is present in almost all measured outcroppings of trachy-andesite. Jointing varying from columnar to irregular is present in almost all measured trachy-andesite outcrops as well. Injections are defined by significant and abrupt changes in the direction of cleavage and jointing. The central injection shows no platy cleavage and is defined by its strong jointing, vesicles, and porphyritic texture.

DISCUSSION

Dome Structure

The View Hill dome is similar in texture and composition to Akaroa's late phase trachytes (Hartung, 2011). These are compositionally the most mature of the Akaroa volcanics. Interlocking crystal textures and an absence of glass in the samples indicate that the dome is intrusive, although vesicular textures found in one area may indicate that a late phase eruption occurred after the cooling and hardening of the cryptodome.

The lack of vesicles and glassy groundmass in the majority of the dome rule out exogenous models of dome formation. Because no models exist for cryptodome formation, the nature of the View Hill dome was determined by comparing data to Fink and Griffiths' (1998) models of endogenous dome formation. While not true cryptodomes, endogenous domes may have similar flow orientations because the center of the dome is not exposed to the surface. Fink and Griffiths (1998) model two types of endogenous dome: spiny and axisymmetric. Spiny domes have steep, conical profiles and are defined by single spines that arise from the vent. On View Hill, the outcroppings of the vesicular injection appear to be in the correct location for it to have been a spine, but petrography indicates that the injection was a later stage eruption. Had it been a spine, it would have formed at the same time as the dome itself. This, as well as the flat profile of View Hill rules out a spiny dome model. An axisymmetric model better fits the low profile of View Hill. However, these domes are characterized by their blocky surface and talus apron, of which View Hill has neither. It is possible that both have been eroded away in the time since the dome's emplacement, however it is difficult to believe that everything disappeared without a trace.

Analysis of oriented thin sections shows that cleavage may be used as a proxy for flow banding in the View Hill dome. Strike and dip measurements of the platy cleavages at View Hill (Figure 1) do not support an endogenous dome model of formation. In an endogenous dome, flow banding should dip away from the vent source. The flow banding at View Hill is chaotic, and does not show any prevailing direction of magma flow. Since only the western half of the dome was mapped, it is possible that an area with more orderly flow banding went unnoticed. However, with the western side of the dome being uniformly chaotic, it is unlikely mapping of flow banding on the eastern side would yield significantly different results. The lack of patterns in the collected strike and dip measurements seems to coincide with an intrusive model of dome formation, in which magma was flowing freely within the dome at the time of crystallization. Areas where abrupt changes in the cleavage and jointing (referred to in this paper as injections) occur seem to indicate a violent change in flow direction. Such a change could have been brought on by a second injection of magma after the majority of the dome was mostly cooled. This model of formation does not correspond to any published accounts of cryptodome formation, and therefore must be further investigated before it can be verified.

Emplacement and Later-Phase Activity

View Hill was likely emplaced through a single injection of magma into the shallow crust, followed by several smaller scale injections. Samples taken from the main dome and from a suspected later phase injection are geochemically and mineralogically identical, indicating that both early and late-phase injections are from the same magma chamber. Low magma viscosity in the original injection would have allowed for the chaotic flow banding that characterizes the dome. Later-phase injections may have been more crystalline, for they form sharply bounded areas with flow banding that cross-cuts the prevailing flow direction in the area. Cooling and hardening of the main dome at the time of the injection would also explain the sharp boundaries and dike-like appearance of the injections.

One of the injections observed at View Hill is vesicular, although mineralogically and geochemically identical to the other rocks. This injection, seen in several outcroppings in the center of the dome and trailing off to the northeast, may indicate an extremely late extrusive eruption that occurred once the rest of the dome was emplaced. There are several reasons for this theory. First, petrography indicates that two phases of cooling occurred in this injection. Amphiboles and clinopyroxenes in the injection rock are euhedral and phenocrystic. Larger euhedral crystals are a product of a more developed magma, which means that the injection magma had more time in the magma chamber than the dome magma did before injection. Second, vesicles in the injection are numerous and indicate an extrusive source. However, thin section analysis of a sample taken from the central part of the injection does not show any glassy groundmass, which indicates that the lava cooled very slowly and was likely not in contact with the outside air. This leads to the inference that the eruption formed a viscous blob of lava on top of the dome. The analyzed thin section represents the inner portion of the lava, which was insulated by the lava on top of it and the dome underneath it, and thus could cool slowly and form no glassy groundmass. Although high viscosity lavas are unusual in Si-undersaturated conditions, the extended period of crystal growth that took place in the magma chamber allowed the erupted lava to be crystalline and viscous.

The strong flow texture observed in thin sections is unusual in a dome setting because non-erupted magma is assumed to be relatively stagnant. While more study is necessary to understand the origin of the flow banding at View Hill, flow texture models published by Murphy and Marsh (1993) and Smith (2002) may be helpful in correlating flow texture to location on the dome. Based on their work, strong feldspar alignment texture is most likely to be seen at the injection source and around the edges of the dome. At View Hill samples 1 and 2 are roughly equidistant from the dome edge (Figure 1) yet have differing percentages of aligned feldspars, making Smith's model difficult to apply. Further data is needed to determine if a correlation between location and flow band strength exists in the View Hill cryptodome.

FUTURE RESEARCH

Further research in this area would focus on mapping the eastern side of the View Hill dome in order to completely characterize flow orientations across the dome. These measurements could be compared to flow banding in other known cryptodomes and possibly kaolin-PEG models as per Fink and Griffiths (1998). It would be interesting to know if there are any flow orientations characteristic of cryptodomes, or if the chaotic system presented in this paper is characteristic in and of itself. To this end, if more oriented thin sections were cut at regular intervals across the dome it might be possible to determine a relationship between position on the dome and strength of flow banding. This information could be compared to the data presented in Murphy and Marsh (1993) and Smith (2002) to see if similar models apply to cryptodomes.

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FIGURES

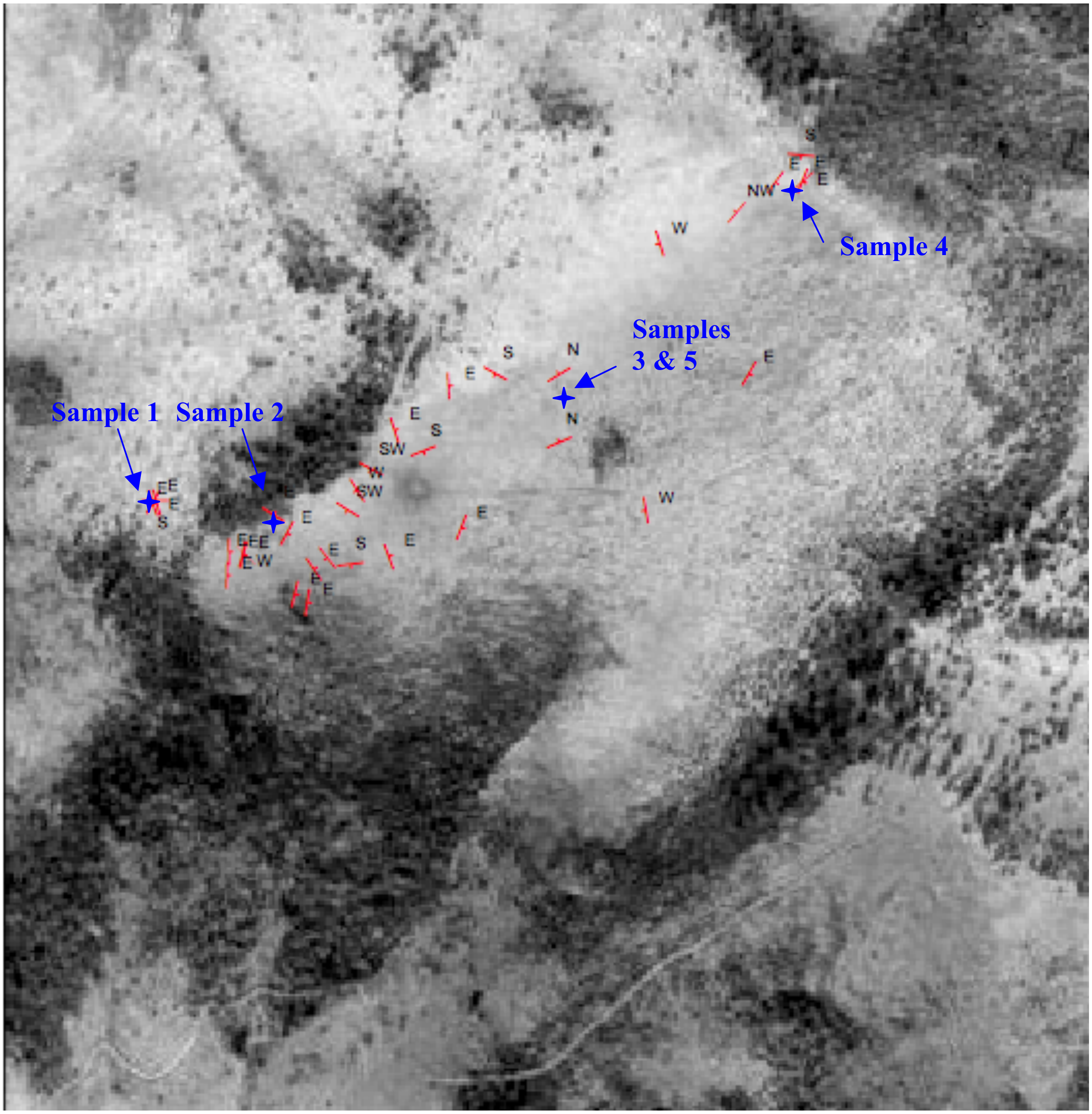

Figure 1: GIS image of View Hill showing strikes and dips of cleavage planes. Sample numbers and locations are marked by blue stars.

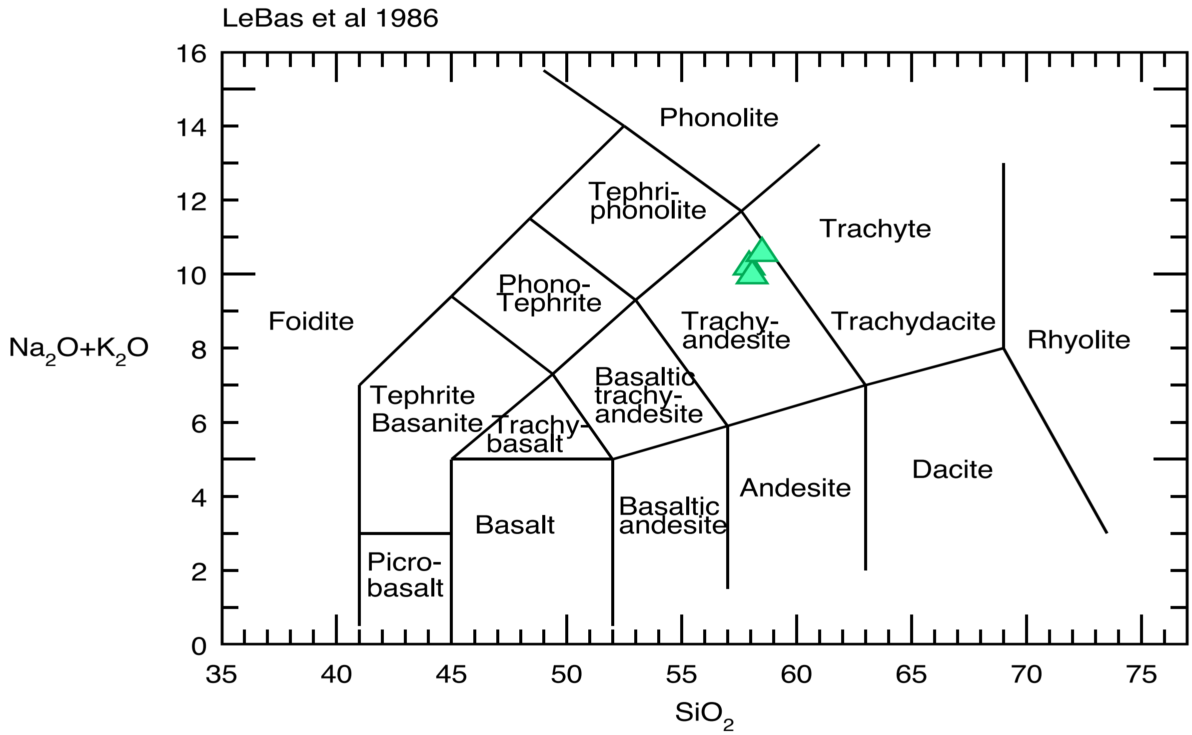

Figure 2: Green triangles represent three samples from View Hill dome and intrusions.

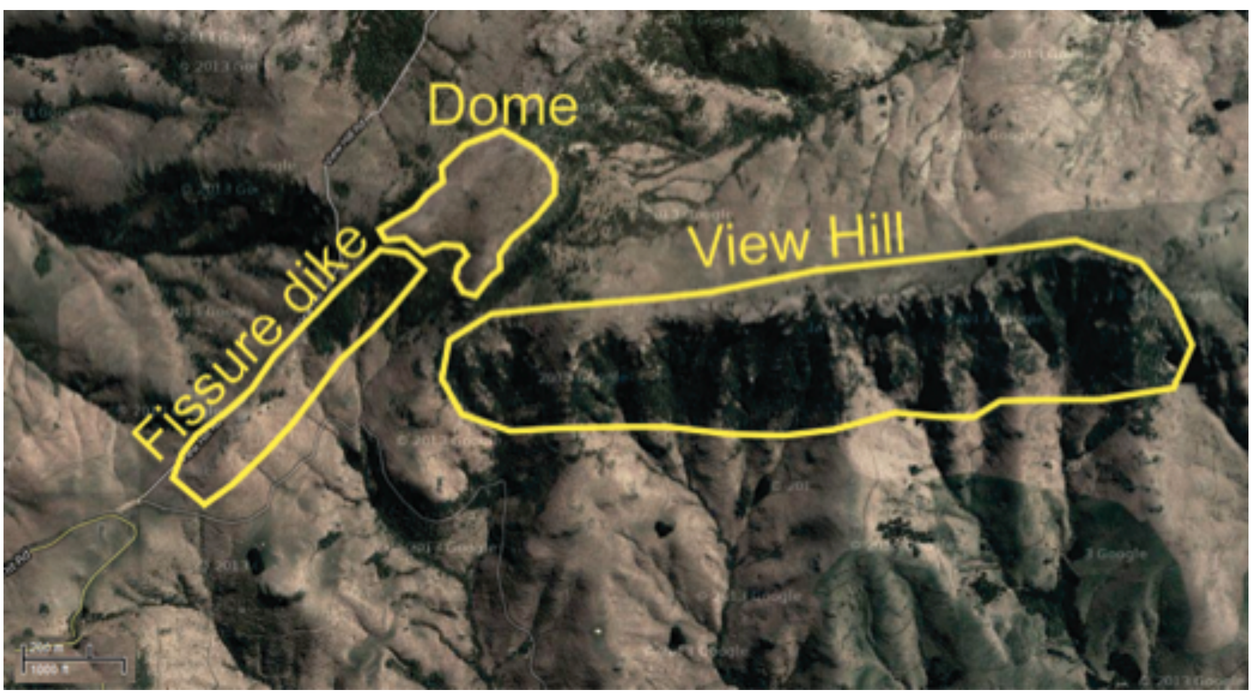

Figure 3: Satellite map showing the locations of the dome, lava flows, and fissure dike on View Hill. Figure courtesy of Portner (in prep).