Dome Formation of Panama Rock Banks Peninsula, New Zealand
Using Joint and Flow Banding Relationships
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Abstract
Panama Rock is trachytic dome located in Banks Peninsula, New Zealand in the extinct Akaroa Volcanic Complex. Lava domes come in many shapes and sizes but are generally defined as mounds of extruded igneous rock from a source vent. If the igneous material does not reach the surface the dome is classified as a cryptodome (Fink and Anderson, 2000). Using orientated samples collected on Panama Rock, thin sections were cut to describe the texture and figure out if Panama Rock’s joint structures are due to flow banding direction patterns to help improve previous research on classifying what type of dome Panama Rock is. The texture of the rocks showed Panama Rock is fine grained with no vesicle content, mostly composed of a trachytic groundmass and the occasional alkali feldspar phenocryst. Flow directions were not always present, and of the places where it was present the jointing was not always the result of flow. Using the textural aspects of Panama Rock and the flow and joint relationships it was concluded that Panama Rock is most likely a cryptodome, but more research needs to be undertaken to completely disprove other theories and solidify this argument.

Introduction

Background on Lava Domes
Lava domes are mounds of igneous rock extruded from a volcanic vent usually during an eruptive cycle that includes spurts of explosive behavior (Fink and Anderson 2000). Domes can be classified into four different types: Pelean/spiny (ie. Mount Pelée and Santiaguito), platy/endogenous (ie. Mount Merapi and Soufriere), lobate (ie. Mount Saint Helens, Katmai, Pinatubo), and axisymmetric (ie. Little Glass Mountain and Big Obsidian Flow). What differentiates one from another is based on morphology, surface texture, and eruptive style, including eruption rate, cooling rate, and yield strength of the lava (Fink and Anderson 2000). Cryptodomes, another variety of lava domes, is a dome whose lava never reaches the surface, typically the injected material lifts the overlying material, leaving a visible mound. The magmatic material under the surface eventually hardens into rock leaving a cryptodome (Fink
and Anderson 2000). An example of a cryptodome is the magmatic activity that preceded the 1980 eruption at Mount St. Helens.

Lava domes display two types of internal structure: flow bands and joints. These provide information about stresses and the flow interior of the dome. Flow bands are subparallel concentrations of crystals that develop in response to friction along the conduit walls and deform in reaction to changes in the flow (Fink and Anderson, 2000). Flow bands can either take an onion or fan like shape (Fink and Anderson, 2000). Joints reflect stresses associated with flow advance and cooling. Mapping the flow banding on Panama Rock can show where the rock experienced shear pressures and how the material spread out of the feeder dike.

Growth of lava domes is thought to be thought to be either endogenous or exogenous. When new lava is added to the outer surface it is classified as exogenous growth. If new lava is injected into the interior, the dome grows by inflation and the growth is endogenous. Most of the work done on domes is on exogenous domes, as exogenous growth is able to be seen and physically mapped. Whereas endogenous growth is all underground, or with minimal magmatic activity on the surface, and they usually erupt causing major disasters, an example being Mount St. Helens. This means not a lot is known about endogenous growth of lava domes, or cryptodomes. This is relevant to Panama Rock as it is believed that part of the dome formed under endogenous growth at some point.

Fink and Griffith (1998) used laboratory models to figure out the different constraints to form different types of exogenous lava domes. They found differences in eruption rates, water temperatures, or slurry temperatures cause the various types. While useful, they found a problem with their own work to classify domes. Natural domes have constant effusion rates or rheologic properties throughout effusion, making classifying a dome like Panama Rock harder if basing classification off their observations. Using Fink and Griffith’s (1998) models exogenous growth can be confirmed or ruled out.
Volcanic domes have the potential to be dangerous if part of the lava flow front collapses, causing an avalanche of hot pyroclastic material to surge down the slope. These flows, depending on the volume of collapsed content, have the potential to wreak havoc on down slope population centers. These flows at Montserrat, has made half the island unlivable and has killed countless people (Fink and Anderson 2000). On a closer to home front during the February Christchurch earthquake a dome collapsed on Banks Peninsula causing huge chunk to fall down the slope and onto nearby farmland (Local Account). Stressing the importance of completely research on domes.

Geologic History- Banks Peninsula

Panama Rock is located on the South Island of New Zealand, Southeast of Christchurch in a region known as Banks Peninsula. The peninsula is dominated by the eroded features of two Miocene aged volcanic complexes: Lyttelton (11-9.7 Ma) and Akaroa (9.0-8.0 Ma) (Hampton, 2010). Akaroa deposited mafic lavas from picrite basalt to mugearite (Pincus, 2013). Volcanic activity was due to intraplate volcanism, a process where magma erupts at some location for an allotted amount of time but is not due to any relation with a magma source, as would a hotspot or a volcano at a subduction zone.

Panama Rock itself is located on the remnants of Akaroa, 3 km west of Le Bons Bay. It is approximately 250 m long by 150 m wide and intersected by a 4 m-thick dike (Curtin, 2012). An outer amphitheatre and an inner dome characterize the overall structure, where the feeder dike halts within the inner dome (Figure 1).

Previous Work on Panama Rock

Research was done on Panama Rock by Curtin and Lewis and Hampton in 2012, they described the overall structure of the dome and took strike and dip measurements over the accessible parts. They depicted Panama Rock as a dome between 20 and 30 m tall with an
elliptical shape, and its feeder dike oriented 240°E (Lewis and Hampton, 2012). The two domes are separated by a 20 m wide, 3 m deep depression. The inner dome was said to display “onion-skin” jointing, which occurs when new magmatic material pushes in though the source and pushes the older material away forming a concentric circle pattern (Lewis and Hampton, 2012). The oldest magma will be on the outside and the youngest in the center. The phenomenon is seen after cooling when the joint planes cool to solidify the concentric circle shape (Fink and Anderson, 2000). At Panama Rock, the onion layers are curved around a central point in an elliptical fashion (Lewis and Hampton, 2012). The exterior lava dome on the northwest and southern face have nearly vertical jointing, implying the dome hit some form of cooling surface to cause vertical jointing (Lewis and Hampton, 2012). The northern side slopes at an angle of 14° until it crosses Lavericks Ridge Road where the slope changes to 5°-10° (Lewis and Hampton, 2012). Lewis and Hampton (2012) believe this change in slope is due to a difference in viscosity of the lava because that area was the result of a different lava flow. Lewis and Hampton (2012) believe a scoria cone restricted flow to control formation and shape of Panama Rock. This scoria cone would have been the cooling surface that resulted in the vertical jointing (Lewis and Hampton, 2012).

Using all of this information Curtin and Lewis and Hampton (2012) attempted to classify what type of dome Panama Rock was. Curtin (2012) concluded due the lack of radial features and tall profile Panama Rock could not be any of the types described in Fink and Griffiths’ (1998) study and thus is either a cryptodome or was constrained by situations not accounted for in Fink and Griffiths’ (1998) study.

This research attempts to further the research on Panama Rock and help to solidify the events that lead to its formation by looking at the relationship of flow textures and jointing. By looking at the flow directions to see if they follow the jointing pattern it can be inferred if the jointing structure is related to flow or some other cooling process.

Methods
Methods for this research consisted of two components: field work and lab work.

Fieldwork consisted of collecting twelve oriented samples over the 5th to the 12th of February around the entire outer amphitheater of Panama Rock and the inner dome (Figure 2). The oriented samples were taken along prominent joint features (Figure 3). The lab component consisted of conducting geochemical analysis using XRF and cutting thin samples to find preferred orientation. All the thin sections were cut in the vertical plane. Thin section analysis consisted of describing the texture and finding any flow banding. Once the preferred orientation if any was found, the angle of it was recorded against the orientation of the joints to see if the joints were created by the flow or the result another process.

Results

Textural Observations

In hand sample Panama Rock is gray and extremely fine grained with the occasional feldspar phenocryst. No texture or preferred orientation can be seen in hand sample (Figure 4). Chemistry showed Panama Rock is trachytic in composition. In thin section, samples were dominated by >95% groundmass of trachytic texture made up of potassium feldspar crystals with the occasional alkali feldspar phenocryst (Figure 5). Phenocrysts were tabular with rounded edges and displayed 90° cleavages (Figure 5). No vesicles or volcanic glass were found.

Preferred orientation was found in ten of the twelve thin sections (Figure 5). The degree of preferred orientation ranged from thin section to thin section. Thin sections P9, P10, and P11 had almost perfect alignment with all the crystals going in the same direction (Figure 5). The rest of the thin sections had less obvious orientation, with kinking flows and crystals in every direction. The feldspar phenocrysts were not always aligned with flow banding, although P10’s phenocrysts were aligned with the flow (Figure 5).
Angles of Flow Direction Against the Jointing

The angles created from the direction of the preferred orientation ranged from directly along the jointing to up to 50° off from the joint plane (Table 1). This angles are all subject to human error that could have happened while drawing the horizontal on the rock, and/or during the cutting process as the rocks could not have been cut perfectly perpendicular every time.

Discussion

Panama Rock Texture and Composition

The trachytic composition of Panama Rock points to a more evolved magma that underwent fractional crystallization to produce a melt composed of incompatible elements. Through this process, compatible ions would crystallize out first to form some type of mafic rock, as compatible ions want to be in solid state. After compatible ions crystallized out the melt is predominantly composed of the incompatible ions to make feldspars: potassium, and silica dioxide. Fractional crystallization obviously takes some time to occur, and compared to deposits from Akaroa, which range from picrite basalt to mugearite, the melt injected into the flank of Akaroa had more time to evolve or had an influx of silicic material from the country rock.

Textural analysis of the thin sections also showed a distinct lack of any vesicle textures. Fink and Anderson (2000) described two vesicular textures extrusive domes display; both models assume most of the magmatic gas content is already lost. But, Panama Rock shows no vesicles. This texture is extremely similar to the description of the Mount St. Helens’ cryptodome (Fink and Anderson, 2000). To form the Mount St. Helens cryptodome, Fink and Anderson (2000) implied a more substantial degassing process occurred prior to emergence. One theory is that Mount St. Helens’ taller dome and thicker crust created a cooling environment that inhibited magma extrusion allowing for further degassing to happen underneath the surface (Fink and Anderson, 2000). This theory for Mount St. Helens’ degassing could be applied to Panama Rock as it too has no vesicles.
Crystal Alignment, Shearing, and Joints

Not all of the thin sections displayed crystal alignment; thin sections P3, and P4 did not display any orientation. Thin sections 3 and 4 both came from the inner dome; this could mean the shearing forces put upon the inner dome where not in the vertical plane but in the horizontal plane, or the shearing directions where so multifaceted there was not one concrete direction for crystal to align in.

Of the thin sections that did show flow banding, P6 and P7 were perfectly aligned with the jointing features at an almost $0^\circ$ angle. Thin sections taken from the exterior dome on the northeaster side all showed angles close to alignment with the jointing features. They became less aligned the farther northwest and farther south the samples came from. This means flow controlled formation of the joining on the southern portion of the exterior dome and played less of a role as you move outward in either direction.

Lewis and Hampton’s (2012) and Hobden’s (1990) strike and dip relationships in the areas of P6 and P7 show almost vertical orientation of the dips the joints matching the vertical orientation of the cutting (Figure 6). So in this area the jointing must be related to the way in which the rocks flowed. For the rest of the samples the angle did not always match the strike and dip relationships. Where P12 was taken the strike and dips in the area are around $65-88^\circ$ but the crystal alignment orientation is $125^\circ$ when you would expect something closer to $0$ or $90^\circ$. It seems in places the jointing is related to the flow regime but in other places it did not place as significant a role. Jointing at locations P6, P7, P9, and P10, and possibly P5 and P11 are most likely the result of flow regime.

Dome Classification

Curtin (2012) classified Panama Rock as either a cryptodome or an extrusive lava dome created under parameters not considered by Fink and Griffiths (1998). Lewis and Hampton (2012) implied Panama Rock was an extrusive lava dome as they detailed how when the lava was extruded a scoria cone already in place controlled its morphology. This study agrees with
Curtin (2012), Panama Rock lacks the radial features of an extrusive dome as detailed by Finks and Griffiths (1998); but if there were a scoria cone than it would have inhibited any radial features from forming. It is difficult to tell if Panama Rock is a cryptodome due to the fact that erosion has taken away the material above the dome that could show bulging or extruded material. Flow directions that go along with the jointing could have come from the shearing that was created underground or from ramping up against the scoria cone. An interesting feature Panama Rock does not display is vesicle texture extrusive domes exhibit as described by Fink and Anderson (2000), while it exhibits the vesicle texture of the Mount St. Helens cryptodome. Furthermore, other fieldwork conducted in the Panama Rock area during the fieldwork for this research shows no evidence of a scoria cone.

Conclusion

Domes are bodies of magmatic material which when extrusive are classified as lava domes and when the magmatic material never reaches the surface they are classified as cryptodomes. Extrusive lava domes have many types and what differentiates them are differences in morphology, surface texture, and eruptive style, including eruption rate, cooling rate, and yield strength of the lava (Fink and Anderson 2000). Of the two types of domes extrusive domes are studied more in depth due to the fact they are not underground, development can be documented over time, and cryptodomes usually erupt destroying most of the evidence. This study looked a dome’s flow banding to figure out if the jointing was the result of the flow regime or some other mechanism.

Past work done on Panama Rock classified the dome as either a cryptodome or some type of extrusive lava dome formed under conditions not considered by Fink and Anderson (2000). By looking at the flow banding under microscope it was found that in certain places Panama Rock’s jointing was the result of flow. Due to the lack of a scoria cone feature, and similar vesicular texture to a known cryptodome this study believes Panama Rock is most likely a cryptodome but there are still some anomalies not yet researched to create some doubt onto this classification.
Future Research

Future research on this dome should be done to map the direction of flow. This was originally the plan for this research but not enough field data was undertaken leaving some missing information. In the future, strike and dips measurements should be taken at the locations where oriented samples are taken so the orientation of the rock is space is known and can be mapped on any mapping program. Also oriented samples taken in the regions where no preferred orientation was found could be cut in the horizontal plane to see if flow directions are found in that plane. Once the flow directions of the Panama Rock are found a greater understanding can be reached about formation and development of the feature. Also more research should be done on the degassing that could have taken place to create a texture without any vesicles in it. The Mount St. Helens cryptodome did not have any vesicles and it would be interesting to research other known cryptodomes and see what their vesicle content is like. Lastly, geologists in the future should look into the presence of a scoria cone to either prove or disprove Lewis and Hampton’s (2012) interpretation of Panama Rock’s growth.

Acknowledgements

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Resources


Figure 1: Structure of Panama Rock with arrows pointing to the prominent features: the inner dome, the exterior dome and the feeder dike.
Figure 2: Locations of the oriented samples taken in the field.
Figure 3: An example of an oriented sample taken in the field.
Figure 4: Photograph of hand samples from Panama Rock showing the lack of any textural features and fine-grained nature.

Figure 5: Thin section photographs of the trachytic texture with arrows showing the direction of flow banding, if any. A) A photograph from thin section P1, B) a photograph from thin section P6, C) a photograph from P4 showing no orientation, and D) a photograph showing the thin
section with the best, most consistent flow banding and the phenocryst that is aligned with it in thin section P10. All photos were taken at a 4x magnification and a scale bar showing the distance representing 500 micrometers.

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<th>Thin Section</th>
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<td>P4</td>
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<td>P13</td>
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Table 1: The angle of the preferred orientation of the feldspar crystal against the orientation of the joint features on Panama Rock.

Figure 6: The strike and dips measured by Lewis (2012) and Hobden (1990) on Panama Rock.