Scoria Cone Dimensional Analysis and Intrusive Body Interpretation at Pa Bay, Banks Peninsula, NZ

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June 12 2014

ABSTRACT

Banks Peninsula on the east coast of the South Island of New Zealand is a Miocene age volcanic region. This volcanic region features two major vent areas with numerous parasitic scoria cones and vent centers. One of these parasitic vent centers is located in the vicinity of Pa Bay on the east side of the peninsula. The vent site is composed of scoria deposits and an intrusive body. Using analysis and various calculations, the volume of the scoria cone is approximately 0.05 km^3 with a height of approximately 0.18 km. This classifies the cone as a small-scale monogenetic scoria cone that is decidedly monocyclic in activity. This area features many scoria deposits, lava flows, and an intrusive body. Using GIS and photographic evidence, the trends of joints in the intrusion can show the true nature of the emplacement of the intrusion. Through analysis of the intrusion's form and characteristics, it was determined that it is most likely a late-stage volcanic plug in the scoria cone's main magma conduit.

INTRODUCTION

Parasitic vents are the product of magma being erupted on the flanks of a larger volcano, and most have complicated magma conduit systems. These parasitic vents can manifest as fissures or point sources and accumulate material directly around the vent area itself. The magma ascends from its source area through systems of subsurface fractures and dikes (Wilson and Head, 1981; Lister and Kerr, 1991). Eruptions can be point or fissure sourced; point source eruptions form scoria cones (Bruce and Huppert, 1989). Small-volume basaltic volcanoes or cones are the most common subaerial volcanic landform on Earth and are usually exhibited as parasitic cones on larger volcanoes or in large fields of scoria cones (Wood, 1980a). Volcanoes and vents that erupt only once and are less that 0.1 km^3 in volume are referred to as monogenetic cones, and can be built up as a series of smaller eruptions that occur continuously for a short time (Kereszturi et al., 2010; Walker, 2000; Vespermann and Schminke, 2000).

These point source cones have shallow magma plumbing systems, and in some more heavily eroded cases, the plumbing systems of these cones may be visible at present surface levels (Valentine and Krogh, 2006; Keating et al., 2008). In many cases, the intrusive bodies found represent the remnants of a magma-filled conduit (Hintz and Valentine, 2012). It is thought that in many cases, as these volcanoes grow, the conduit system also widens and creates a flaring shape of the originally cylindrical magma conduit that fed the development of the scoria cone (Wilson and Head, 1981; Mitchell, 2005). The magma periodically fills the conduit and expands it near the surface. This type of intrusive structure has recently been classified as the “flower intrusive structure” based on its shape

(Tibaldi 2008). Tibaldi found that sheets and sills of magma were fed by multiple pulses of magma following radial paths which abruptly deflected outwards (2008). According to Keating et al., many intrusive bodies can be observed at depths of 250 m below the paleosurface and extend upwards and begin to flare outwards about 30 m below the paleosurface due to surface stresses (2008). Keating et al. also found that many of the cones studied show plug-like bodies of vertically-jointed, massive basalt (about 125 m wide) that represented the point at which scoria deposits started opposing in dips (2008). In these studies, this massive section of basalt plug represented magma that filled the magma conduit at the end of the eruptive phase and period of volcanic activity at that site (Keating et al., 2008).

According to Wood, many studies on volcanoes and scoria cones have the aim of determining the slope angles in order to determine the relative ages of monogenetic cones (1980a,b). A fresh scoria cone usually has a slope angle of 30°-33°, and this value decreases over time due to erosion (Wood, 1980b; Riedel et al., 2003). By determining the relative decrease in slope of scoria cones, the relative ages of scoria cones in a given field or parasitic vent area can be determined.

<u>Geologic Setting</u>

Banks Peninsula is on the east coast of the South Island of New Zealand (Figure 1). It represents the remains of two major extinct Miocene volcanic complexes (Hampton and Cole, 2009). There were two major vent areas; Akaroa Volcano (9.3-8.0 Ma) and Lyttelton Volcano (11-9.7 Ma). Each complex has many parasitic cones and lava domes as well as lava flows. Akaroa Volcano itself is a large strato-shield volcano. Scoria cones, lava domes, and lava flows are the most common landforms and rock types on Banks Peninsula. Several scoria cones have been identified on the east side of Banks Peninsula in previous years by Frontiers Abroad students.

Pa Bay Geologic Setting and Background:

Pa Bay, a bay on the east side of Banks Peninsula and south of Okains Bay (Figure 2), is a small bay which features an intrusive body, scoria deposits, fissure deposits, and many lava flows up the valley of the bay. Previous unit and rock study by Burgi have shown the southern side of the bay to be made of single-source scoria deposits, indicating a scoria cone (2013). The north side of the bay is composed of fissure deposits. Geochemical analysis by Anne Fulton shows the scoria deposits on the south side and the intrusive body in the mouth of the bay to be basaltic in composition (2014). The three sampled lava flows up the valley are geochemically mugearite (lower flow) and hawaiite (upper flows). Fulton also found the fissure deposits on the northern side of the bay to be basaltic in composition. Pa Bay has a scoria cone and an intrusion, which are of similar composition, but quite different in geochemical composition from the lava flows in the valley.

METHODS

Field Observations and Data Collection

Several types of data were collected at Pa Bay. Strikes and dips of the fissure deposits were taken, GPS-referenced field descriptions were recorded, and photographic evidence were collected in the field. Photographic evidence was collected for rock descriptions and contact behavior as well as dip information for the southern scoria deposits for use in computer modeling.

Computer Modeling

After the field observations and data collection, the information was georeferenced into the GIS program ArcMap 10.2. GPS-correlated strikes and dips, field waypoints, and intrusive joint trends were georeferenced onto a basemap of the Pay Bay area. After these points were correctly oriented and in place with geochemical data in mind, shapefiles were drawn to show the units of the Pa Bay area geology. Scoria deposits, the intrusive body, fissure deposits, and the lava flows up the valley were shown on the map with approximate contacts. I then used ArcMap 10.2 to determine the distances between the edge of the scoria and the intrusive body. I used CorelDRAW X6 to draw on a probable scoria cone and its crater extent for the southern scoria deposits. This helps create a visual for the extent of the cone for use in correlating to other deposit and vent types in the area.

Cone Dimensional Analysis

Photographic evidence for the scoria deposits on the south side of Pa Bay allowed me to approximate the slope of the scoria cone.

After using GIS to determine the radius of the scoria cone, I used a calculation determined by Porter for scoria cones to calculate the approximate height of the scoria cone (1972).

$$Height_{cone}=0.18 \times Diameter_{cone}$$

After determining the approximate height of the cone at this time, I calculated the approximate volume of the scoria cone in Pa Bay by using the equation below.

$$V_{cone} = \frac{\pi r^2 h}{3} \qquad r = \text{radius},\ h = \text{height}$$

RESULTS

Using field photographs and ArcMap 10.2, I was able to create a map of the geology and units in the Pa Bay area (*Figure 3*). This map represents the units in the area based on waypoint unit descriptions and visual clues. The scoria unit was constrained in the valley by the lava flows, which have distinctly different geochemical composition from the scoria deposit (Figure 4,5). Using this figure and the ground length measure function on ArcMap 10.2, I was able to estimate that the distance between the end of the scoria deposits in the valley and the intrusive body/locus of opposing scoria deposit dip. The radius of the cone was 0.5 km, so the height came out to be approximately 0.18 x 1.0 km≈0.18 km. Using photographic evidence, I found the dips of the scoria deposits to consistently be 22°. This means that the cone in half a cross-section formed a right triangle with a side angle of 22° and a base length of 0.5 km with a height of 0.18 km (Figure 5). Using this information, I was able to calculate the volume of the scoria cone to be approximately 0.05 km^3. According to Kereszturi and Németh's diagram, the crater is approximately one-third the diameter of the cone (Figure 7). This and the extent of the cone are shown in Figures 8 and 9.

The orientations of the joint trends in the intrusive body are shown on the map of the Pa Bay units (Figure 10). These orientations show the cooling joint pattern of the intrusive. These orientations show a roughly flared pattern of the joints (Figures 10, 11). This information about the cooling of the intrusive indicates its position in the scoria cone plumbing.

DISCUSSION

Pa Bay exhibits scoria deposits and an intrusive body that appears to coincide with the middle of the scoria cone. Using geochemistry to determine similarities in vent source, the valley lava flows provided a constraint for the scoria cone in the south part of Pa Bay. These lava flows are geochemically mugearite (lower flow) and hawaiite (upper flows). This lava geochemistry does not match the scoria deposits and the intrusion; which are both basaltic. This difference shows that the lava flows were from a different source vent and may have “pooled” against an existing scoria cone. This provides a constraint for the size of the scoria cone on the south side of the bay. The intrusive body is situated where the dips of the scoria deposits begin to oppose each other, indicating the crater rim and middle of the scoria cone. Using this information, the diameter and volume of the scoria cone are determined. The volume of the cone of approximately 0.05 km^3 ensures that it is in fact classified as a monogenetic basaltic scoria cone according to Walker (2000). The scoria deposits indicate a cone slope of approximately 22°. This is slightly less than indicated by Wood for fresh scoria cones (1980b). This is most likely due to the fact that this scoria cone has experienced significant erosion since it developed approximately 8 million years ago. The original slope may have been closer to the 30°-33° that is common of most fresh scoria cones (Wood, 1980b). The dimensions of this cone are similar to most monogenetic cones around the world, though this cone is slightly larger than others found in the vicinity of Pa Bay and Banks Peninsula. The fresh scoria cone may have had a steeper angle of repose and slightly larger volume at the time of eruptive activity since it has experience significant erosion.

The intrusive body in Pa Bay appears to be more circular than linear in map view (Figure 4). This initial observation indicates that it is more likely to be some sort of round intrusive body that filled a void rather than a dike; which are usually more linear in map view. The geochemistry of the intrusive body matches the basaltic composition of the scoria deposits, indicating that they are from the same source. Further, the trends of the cooling joints in the intrusive body exhibit a flared pattern. This pattern is shown in many other examples (Wilson and Head, 1981; Mitchell, 2005) and shows that the intrusive body is most likely a type of volcanic plug that formed as the cone's activity came to an end. The surface stresses and expanding magma conduit system would have caused the magma in the chamber to expand outwards near the surface. The conduit widens with pulses of magma injection near the top where it is not as vertically constrained. The fact that the intrusive body appears at the point where the scoria deposit dips start to oppose each other indicates that it is near the crater rim and therefore middle of the cone.

CONCLUSION

The scoria cone in Pa Bay is constrained by geochemically different lava flows in the valley and the presence of an intrusive body at the site of opposing scoria deposit dips. These constraints allow for the calculation of the cone's volume, which verifies the type of cone as monogenetic basaltic. Further the intrusive body is determined to be some sort of late-stage volcanic plug of the same scoria cone. This plug exhibits the previous documented flared shape, as indicated by cooling joints.

ACKNOWLEDGMENTS

I would like to thank Dr. Sam Hampton and Dr. Darren Gravley for their research support and help. I could not have done this project without them and the Frontiers Abroad Study Programme. I would also like to thank Anne Fulton for geochemical analysis as well as field data collection. Additional thanks to Lily Gaddis, CC Connard, and Matt Sumner for helping collect data in the field.

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FIGURES

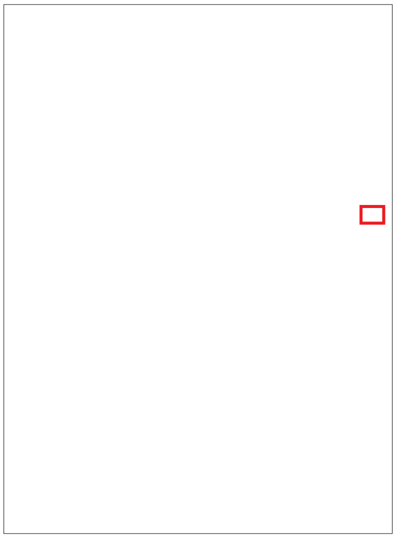


Figure 1: Banks Peninsula situated on the east coast of the South Island of New Zealand. The study area Pa Bay is outlined in red on the east flank of Akaroa Volcanic complex (Google Earth).

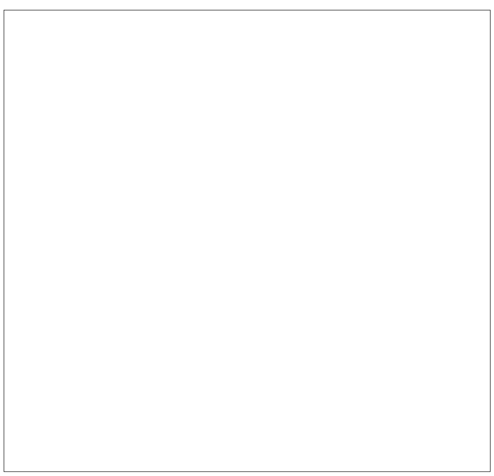


Figure 2: Inset aerial photograph of the study area of Pa Bay on Banks Peninsula (Google Earth).

Figure 3: Geologic map of the Pa Bay study area. Bedding orientations and joint trends are shown as well as geologic units. The “v-ing” nature of the lava flows in the valley allowed the contacts to be estimated in the valley.

Figure 4: Scoria deposits and hawaiite lava flows in the valley west of Pa Bay. This contact represents a constraint on the edge of the scoria cone using geochemical differences. The lava flows "pooled" against this scoria cone.

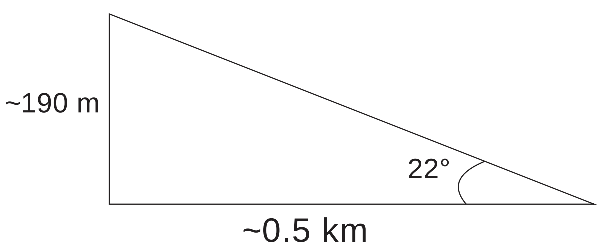
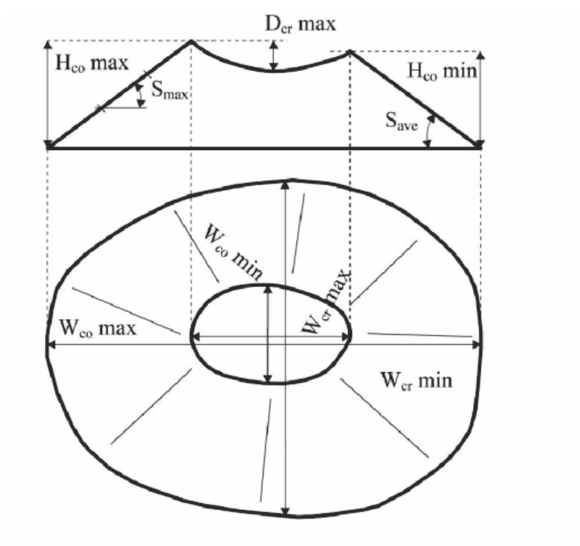


Figure 5: Right triangle with dimensions representing a cross-section of the scoria cone in south Pa Bay.

Figure 6: Contact between south-east scoria deposits and intrusive body. The dip of the scoria deposits is inferred to be ~22° from this photographic evidence and is shown on the left side of the figure.



260 Definitions of traditional morphometric parameters of a scoria cone.

Figure 7: Kereszturi and Németh's diagram of scoria cone dimensions which shows the crater as approximately one-third of the cone diameter and fairly shallow (2012).

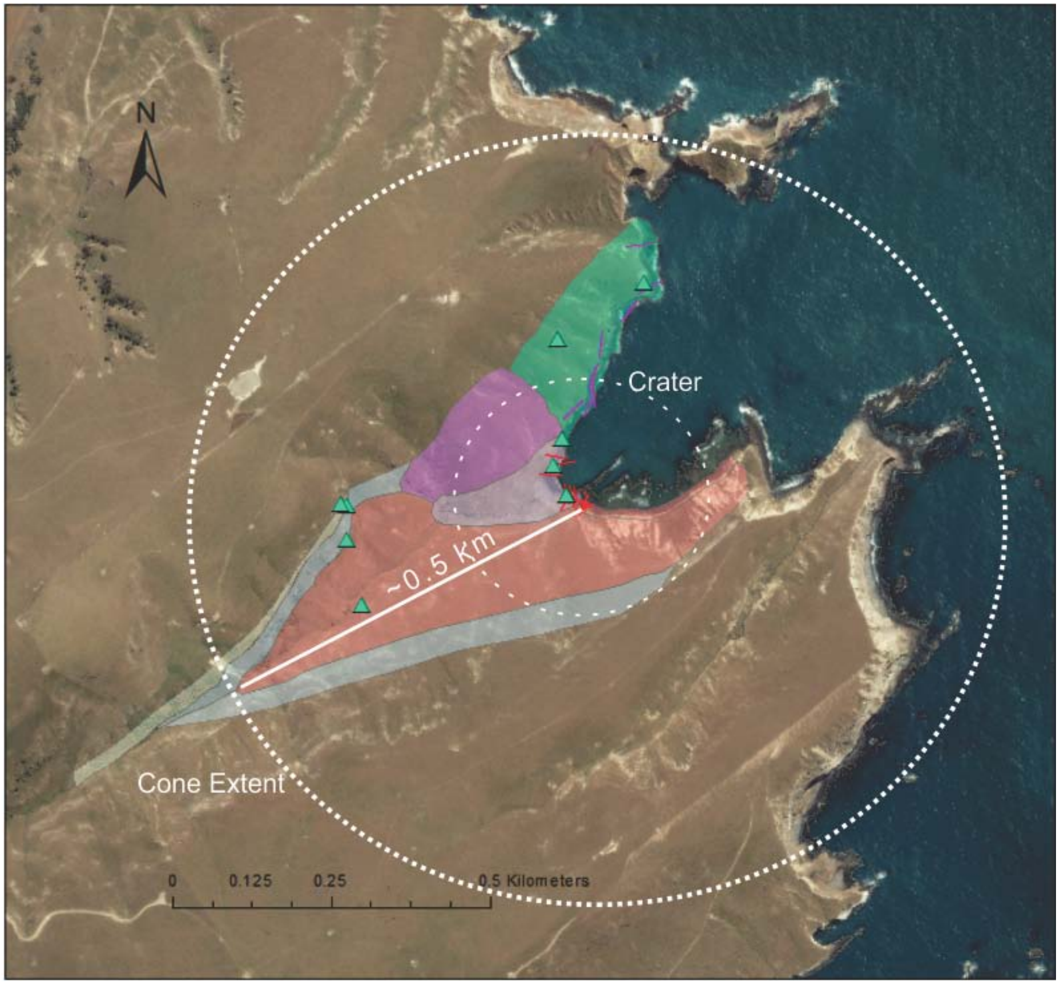


Figure 8: Geologic map of Pa Bay area showing geologic units and the proposed scoria cone extent and its crater extent. The radius of the scoria cone is inferred from and informs this figure. This represents the possible area that the scoria cone may have deposited material at the eruptive time. Since this time, many other vents and deposited have changed this scene to not be a complete circle on the north side of the bay.

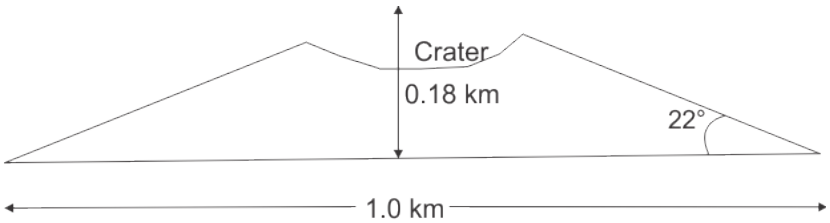


Figure 9: Model of the cross-section of the scoria cone in south Pa Bay with possible height, diameter, and slope angle.

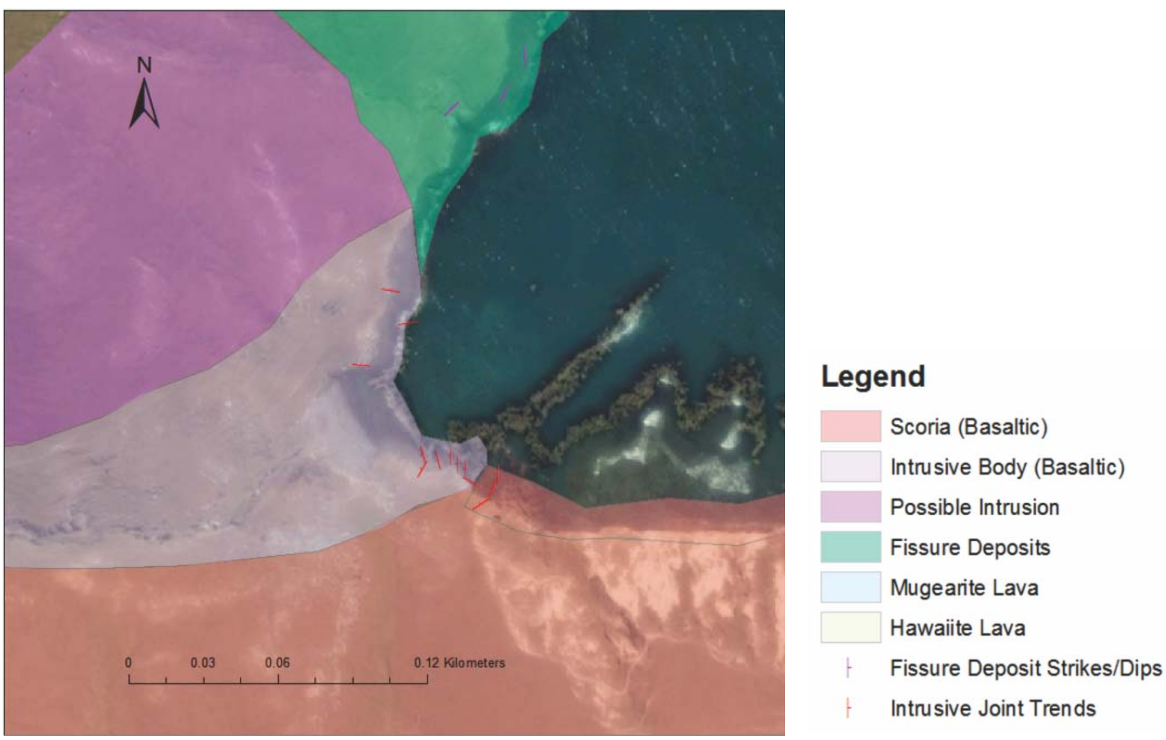


Figure 10: GIS-created figure of joint trends in the intrusive body of Pa Bay. The joint trends show the "flared" pattern which is common in volcanic plugs.

Figure 11: Intrusive body on the south side of Pa Bay. The joint trends show the well-documented "flared" structure that is common in volcanic plugs. The pulses of magma and decreased stress at the surface cause the magma to "flower" outwards at this point.