Inferring Scoria Cone Structure: A New Zealand Case Study

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Abstract

Structural and geochemical analyses provide an explanation for the types of facies associated with scoria cones. The Okains Bay region provides a unique opportunity to study previously unknown scoria deposits within the once active system of Akaroa Volcano. There are a number of scoria deposits on the flanks of Akaroa representing explosive activity away from the volcano's central eruptive region which give insight into the underlying magmatic system. The deposits within Little Okains Bay consist of lapilli to bomb sized material indicating a nearby eruptive source. Additionally, small dike-like structures (dikelets)which intrudeinto the scoria deposits suggesting post eruptive subsurface activity. Better preserved scoria cone facies are seen in the headwall immediately north of Okains Bay were also analyzed in order to make structural comparisons to the Little Okains scoria. This analysis adds to the preexisting knowledge of the Akaroa volcano system and the underlying magmatic system beneath the Okains Bay region.

Introduction

Scoria cones are often found as part of large volcano structures and can be used to locate the outer flanks of the parent volcano as they are linked by the system's internal plumbing (Hampton et al, 2009). This is because the scoria cones are usually fed by dikes radiating away from the main eruptive center (Shelley, 2011). Scoria cones are built up through Strombolian eruptions, which are highly explosive in nature due to the amount of gases released in each event (Martin and Nemeth, 2006; Parfitt, 2004). Scoria is basaltic to andesitic in composition and vesiculated due to this high gas content and explosivity (Polacci et al, 2006. The deposits usually range from lapilli to bomb sized material; fire fountaining may also occur.

Banks Peninsula is composed of two major basaltic volcanoes, Lyttelton and Akaroa, both of which formed in the Late Miocene, and both of which had flank eruptives - scoria cones. The larger and younger (9 – 7.5 Ma) Akaroa Volcano is mostly composed of hawaiitelava flows (Price and Taylor, 1980; Sewell, 1988).

One study conducted by Johnston et al (1997) that mapped and compared four preserved scoria cones on Akaroa Volcano (Pigeon Bay area) defined the evolution of scoria deposits as they extended away from their respective eruptive vent.This study looks at another area within Akaroa Volacano, the Okains Bay region, to extrapolate from the deposits information about the local volcanic activity and the system that fed it.

Geologic Setting

Banks Peninsula is located on the South Island of New Zealand, southeast of Christchurch. The peninsula is connected to the island by loose sediments indicating it may have been an unconnected island at one time (Sewell, 1988). The two main volcanoes, Akaroa and Lyttelton, while both heavily eroded, are clearly visible in aerial photographs. The area of Okains Bay is located on the northeastern side of Akaroa Volcano with Little Okains to the south and the headwall to the north (Figure 1).

Methods

Field work was conducted in the Lillte Okains Bay area on foot and by boat, in which the deposits were mapped and samples collected. Photo documentation was used as the primary data collection method for mapping inaccessible areas of the headland to the north of Okains Bay. These photos were then used to categorize the various sections of the headland and the cliff face in Little Okains Bay. This was done based on textural variances seen in the photographs, and trends within the visible structures.

The samples collected from Little Okains Bay (Figure 2) were examined in hand sample, and using thin section and geochemical analysis. On the larger scale, clast size and deformation supplemented the estimation of the explosive power, as well as relative distance from the scoria cone. This information is compared to the work done by Johnston et al (1997) to confirm estimations of the scoria cone facie in which the sample was found. As a study of scoria cones in Akaroa Volcano, their work should be analogous.In thin section, vesicle content were used to extrapolate eruptive style and the evolution of magma involved in the eruption (Polacci et al, 2006). The geochemical analysis was done using x-ray floresence to compare the composition of several samples taken from the lavas, scoria and dikelets to better understand the relationship between them.

Results

Little Okains Bay

Field mapping and photo analysis for Little Okains Bay provided four distinct deposit layers within the cliff face in addition to small dike intrusions. These are the basal lava which makes up the sea platform, the scoria, the massive lava-breccia system, and the massive over-topping lava. The basal lava is thickest at the most seaward section of the cliff face, and has been heavily weathered to a flat surface at the base of the cliff. It is also obscured in many areas by a large quantity of rubble, presumably from the platform and cliff face. There are also cowpat bombs visible in the exposed sections, though they are too weathered to be useful. The scoria deposits are thickest at the point and contain large round bombs. The size of bombs and thickness of deposit decreases toward the beach. The caves closer to the beach contain lapilli sized scoria that is weakly bedded with an apparent dip of approximately 10° to the west. The auto-brecciated lava section contains lavas which are all vertically jointed and have thicknesses on the meter scale, some of which form the roof of caves. The brecciated layers are generally thicker than the lavas they surround. The final, overtopping layer extends along the top of the exposed cliff face until it is lost in vegetation above and near the beach. It is dipping toward Little Okains Bay and to the east. In a section of the face near the point and between large caves, a part of the overtopping lava extends down to the rubble of the basal platform and is underlain by breccia. This section contains a curving, vertical pattern in addition to horizontal joints. The most prominent dikelets are located between two scoria filled caves near the beach and to the right of the downward extending piece of the over-topping massive lava. The cave dikelet is tan and composed of millimeter sized grains, extending up between the caves and forming part of the roof for both caves. It also extends out in front of the cave, vertically through the basal lava. The other is horizontal in scoria, but turns downward toward the base of the extending piece of overtopping lava and branches upward near vertical. This dikelet is also grainy in texture and platy. These features are more easily identified in Figure 2.

The geochemical analysis of select samples from the basal lava, scoria from one of the caves adjacent the dikelet, from the dikelet, and from the downward extending piece of massive overtopping lava (See Figure 2 for locations) is shown in Table 1. The sample of the dikelet was not viable, however, being too weathered to be of use. The other samples were useful, and were identified as hawaiiate for the overtopping lava, and benmorite for both the scoria and basal lava (Figure 3).

The thin sections from samples of scoria, including lapilli sized clasts and a bomb, showed vesicles on the millimeter scale, in densities of 40-50% (Figure 4). The vesicles are round or elongate, though some are large (cm scale) and irregularly shaped. The bomb sample shows signs of deformation on impact, and in thin section has banding alternating between groundmass with 10% millimeter sized vesicles and 50% centimeter sized vesicles.

Headwall

Within the more northern headwall we see jointed lavas along the basal section on the far right. These continue along the base of the headwall, gradually disappearing from view as they dip to the southeast. There are three clear paleosol/ash layers visible within the lavas, one of which can be clearly followed across the whole of the headland. Above this layer, for the majority of the headwall is a massive, vertically jointed lava. Again on the far right, above this lava, is another paleosol/ash layer overlain by another vertically jointed lava. Above both of these is a heavily jointed lava that drapes across in a 'v'-shape, the left side of which is directly over the extensive vertically jointed lava. This 'v' is filled by sediments to create a flat surface. Moving to the left is a horizontally jointed dike cross cutting both the basal lavas and the massive. The middle section of the headwall is fairly uniform consisting of the basal lavas, paleosol/ash layer, and massive lava, though near the center the massive lava extends down as a lobe, to the left of which begins another paleosol/ash layer. This leads to the left side of the headwall in which the paleosol/ash layers are overlain by scoria deposits. Sections of the massive lava are located within the scoria and at the left edge of the headwall. In the center of the scoria deposits is a dike (See Figures 4 and 5 for clarification)

Discussion

Little Okains Bay

Based on the stratigraphy the succession of emplacement in the exposed cliff face begins with the basal lava, then the scoria, the auto-brecciated lavas and finally the overtopping lava. It is unclear whether the dikelets intruded before or after the auto-brecciated lavas. They intrude through both the basal lava and scoria, and appear to follow along the contact between the scoria and auto-brecciated lava near the caves, but next to the extruding piece of overtopping lava, the dikelet is only seen in the scoria section, without an origin point. The shapes of the dikelets are typical of scoria deposits and can be seen as part of the scoria source system (Mathieu et al, 2008).

Basal Lava

The basal lava is of similar composition to the scoria and also thickens toward the point. Cowpat bombs in the basal lava could have been erupted at the same time as the earliest scoria deposits were being emplaced, or the whole basal lava section could have resulted from an earlier eruption from the scoria source vent that has welded and eroded. Too little data was collected from the small portions of exposed basal lava to provide a definitive interpretation of its origin and significance within the Little Okains scoria cone.

Scoria

Within the scoria deposits, the clast vesicles are irregular in shape, showing evidence for coalescence (Polacci, 2006). Vesicle content, combined with the fact that much of the material is lapilli sized is evidence of a highly explosive eruptive event, most likely of Strombolian style (Head and Wilson, 1989; Pioli et al, 2008; Pioli et al, 2009). The scoria deposits are all distal deposits based on the lack of welding in most of the deposits and the well-formed bombs that have little deformation from impact (Johnston et al, 1997).The weak bedding structures are indicative of an early stage in cone formation, in which the cone is still relatively flat (Houghton and Schmincke, 1989; Houghton and Gonnermann, 2008; Valentine et al, 2005). The small amount of bedding and presence of large bombs near the point would suggest a source vent somewhere farther out in the bay. Additionally, the geochemical data clearly marks the scoria as being from a separate source than the overtopping lava. This source, if connected to the Akaroa system, is most likely a smaller more evolved chamber that is an off shoot from the source of the Akaroa lavas.

Auto-Brecciated Lava

The auto-brecciated lavas between the scoria and overtopping lava are possibly related to the overtopping lava, but data was not taken from these to provide conclusive evidence. The jointed lavas do, however, form the roof to many of the caves in the cliff face, and could be integral to cave formation.

Overtopping Lava

The overtopping lava has come from somewhere to the northwest, based on its dip and the piece extending down to the basal lava platform. This piece is likely the result of the lava filling in a channel that eroded through the underlying scoria. Based on the jointing, the lava flowed down into the channel somewhere behind the present surface and out toward the bay, gradually filling in the channel.

Headwall

East Side

The eastern side of the headwall is dominated by the massive lava and scoriaceous material. The last episode of scoria deposition and the massive lava occurred at the same time since part of the massive lava is surrounded by scoriaceous material. The dike is a later stage feature as it cross cuts both paleosol/ash layers, most likely radiating from the scoria source vent (Figure 6; Mathieu et al, 2008). The source vent must have been farther out to sea; otherwise the massive lava would have flowed with more scoria materials intermixed rather than being uniform. There were at least two episodes of eruption from this vent as there are two paleosol/ash layers within the deposits.

West Side

The right side of the headwall shows younger volcanic activity from the lava separated from the massive by a paleosol/ash layer. Atop this is another lava that occurred after a period of erosion that cut through the massive lava, creating a valley. This thinner lava was sourced from a vent to the west, flowed down into the valley and thinned as it went up the other side. This is evidenced by the vertical jointing in the eroded portion on the right side of the valley, and the thinner, more radially jointed parts near the top of the left side (Figure 5). Because the lava is thin and fairly uniform throughout the valley, the lava flowed into the valley and continued flowing outward toward the sea. The horizontally bedded deposits within the 'v' of this lava are most likely sediments from a water channel that continued to flow and erode through the young lava until the water source became inactive or was diverted.

Conclusion

The scoria and lava sequences in both the headland and Little Okains Bay are indicative of at least two source vents within the area of Okains Bay, one of which having a more evolved magmatic source than the surrounding massive lava. These are previously unmapped deposits that further define the extent of Akaroa Volcano's activity, and provide a better understanding of the events that occurred millions of years ago. Additional research is necessary to collect and analyze data from the whole of the headwall, the inconclusive sections of the Little Okains cliff face, and other scoriaceous material within the area. Further research will better establish the sequences as well as offer an analogue for features expected on the flanks of current and future volcanically active zones.

References

Hampton, S. J., & Cole, J. W. (2009).Lyttelton Volcano, Banks Peninsula, New Zealand: Primary volcanic landforms and eruptive centre identification. *Geomorphology*, *104*(3-4), 284-298. Elsevier B.V. doi:10.1016/j.geomorph.2008.09.005

Head, J. W., & Wilson, L. (1989). BASALTIC PYROCLASTIC ERUPTIONS " INFLUENCE OF GAS- RELEASE PATTERNS AND VOLUME FLUXES ON FOUNTAIN STRUCTURE , AND THE FORMATION OF CINDER CONES , SPATTER CONES , ROOTLESS FLOWS , LAVA PONDS AND LAVA FLOWS. *East*, *37*, 261-271.

Houghton, B., &Gonnermann, H. (2008). Basaltic explosive volcanism: Constraints from deposits and models. *Chemie der Erde - Geochemistry*, *68*(2), 117-140. doi:10.1016/j.chemer.2008.04.002

Houghton, B., &Schmincke, H. (1989). Rothenberg scoria cone, East Eifel: a complex Strombolian and phreatomagmatic volcano. *Bulletin of Volcanology*, *52*, 28-48.

Johnston, D. M., Cole, J. W., & Houghton, B. F. (1997). Physical volcanology of Miocene basaltic pyroclastic deposits at Pigeon Bay: Remnants of flank scoria cones of Akaroavolcano , Banks Peninsula , New Zealand. *Journal of Geology and Geophysics*, *40*(1), 109-115.

Martin, U., & Németh, K. (2006). How Strombolian is a “Strombolian” scoria cone? Some irregularities in scoria cone architecture from the Transmexican Volcanic Belt, near VolcánCeboruco, (Mexico) and Al Haruj (Libya). *Journal of Volcanology and Geothermal Research*, *155*(1-2), 104-118. doi:10.1016/j.jvolgeores.2006.02.012

Mathieu, L., van Wyk de Vries, B., Holohan, E. P., & Troll, V. R. (2008). Dykes, cups, saucers and sills: Analogue experiments on magma intrusion into brittle rocks. *Earth and Planetary Science Letters*, *271*(1-4), 1-13. doi:10.1016/j.epsl.2008.02.020

Parfitt, E. a. (2004).A discussion of the mechanisms of explosive basaltic eruptions.*Journal of Volcanology and Geothermal Research*, *134*(1-2), 77-107. doi:10.1016/j.jvolgeores.2004.01.002

Pioli, L., Azzopardi, B. J., &Cashman, K. V. (2009). Controls on the explosivity of scoria cone eruptions: Magma segregation at conduit junctions. *Journal of Volcanology and Geothermal Research*, *186*(3-4), 407-415. Elsevier B.V. doi:10.1016/j.jvolgeores.2009.07.014

Pioli, L., Erlund, E., Johnson, E., Cashman, K., Wallace, P., Rosi, M., & Delgado Granados, H. (2008). Explosive dynamics of violent Strombolian eruptions: The eruption of Parícutin Volcano 1943–1952 (Mexico). *Earth and Planetary Science Letters*, *271*(1-4), 359-368. doi:10.1016/j.epsl.2008.04.026

Polacci, M., Corsaro, R. A., &Andronico, D. (2006). Coupled textural and compositional characterization of basaltic scoria: Insights into the transition from Strombolian to fire fountain activity at Mount Etna, Italy. *Geology*, *34*(3), 201. doi:10.1130/G22318.1

Price, R. C., & Taylor, S. R. (1980).Petrology and Geochemistry of the Banks Peninsula Volcanoes, South Island, New Zealand.*Contributions to Mineralogy and Petrology*, *72*, 1-18.

Sewell, R. J. (1988). New Zealand Journal of Geology and Geophysics Late Miocene volcanic stratigraphy of central Banks Peninsula , Canterbury , New Zealand. *New Zealand Journal of Geology and Geophysics*, *31*, 41-64.

Shelley, D. (2011). Radial dikes of Lyttelton Volcano — their structure , form , and petrography. *Geology*, (April 2012), 37-41.

Valentine, G. a., Krier, D., Perry, F. V., &Heiken, G. (2005). Scoria cone construction mechanisms, Lathrop Wells volcano, southern Nevada, USA. *Geology*, *33*(8), 629. doi:10.1130/G21459.1

Figures

Figure 1 Map of the field area highlighting both the headwall and Little Okains cliff face in Okains Bay (B) within the larger Banks Peninsula (A) on the South Island of New Zealand (C).

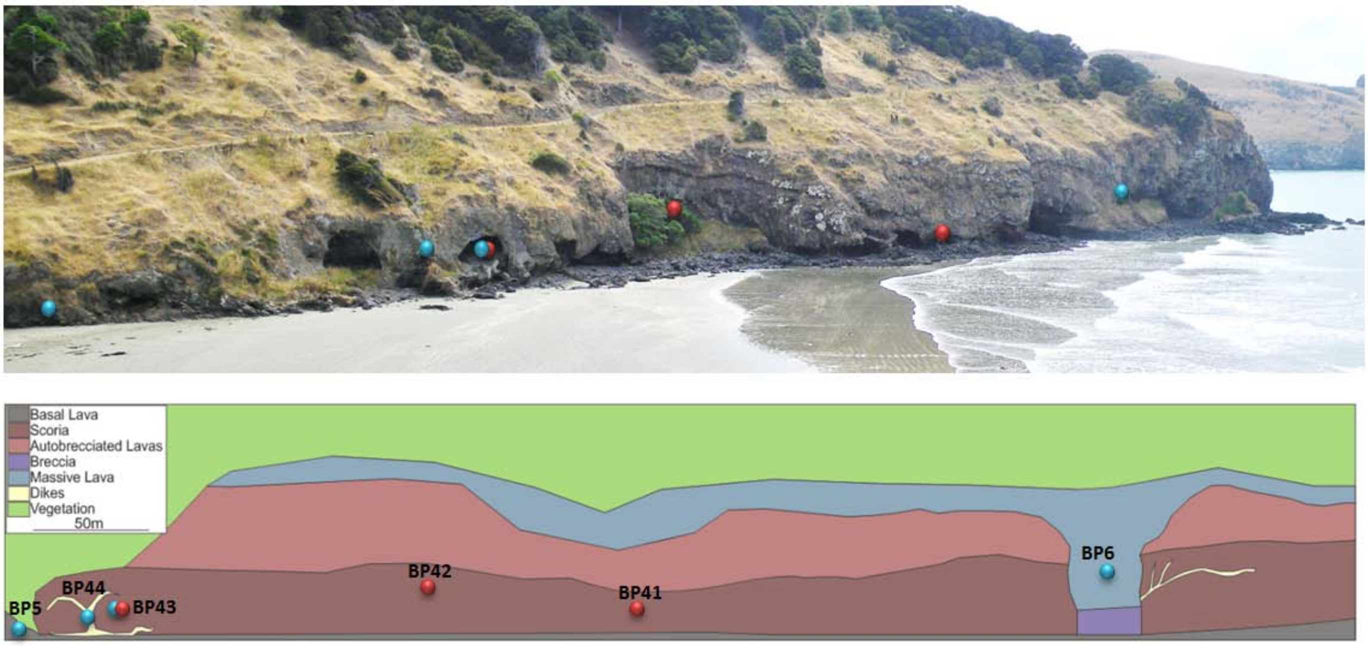

Figure 2 Model of the main sections in the Little Okains Bay cliff face. Blue dots are samples geochemically analyzed. Red dots are samples examined in thin section. The key gives the deposits from oldest to youngest. The view is looking to the west at the deposits.

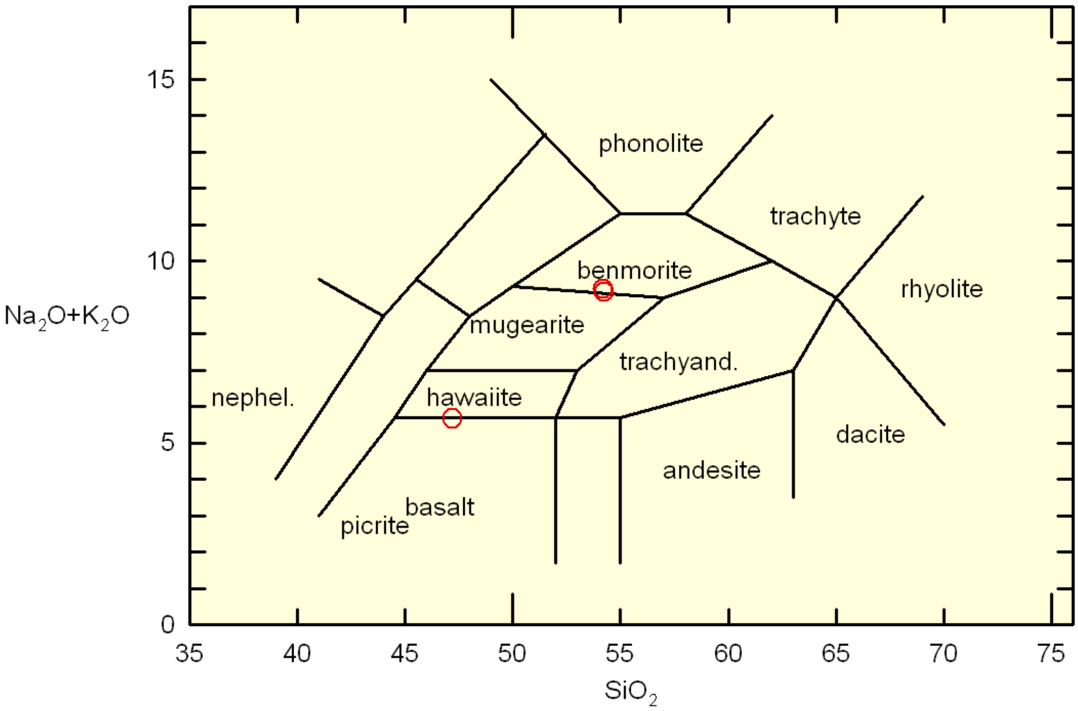

Figure 3 Geochemical analysis of the rock type based on the data from Table 1. The scoria and basal lava both plot as benmorite while the overtopping lava is hawaiite.

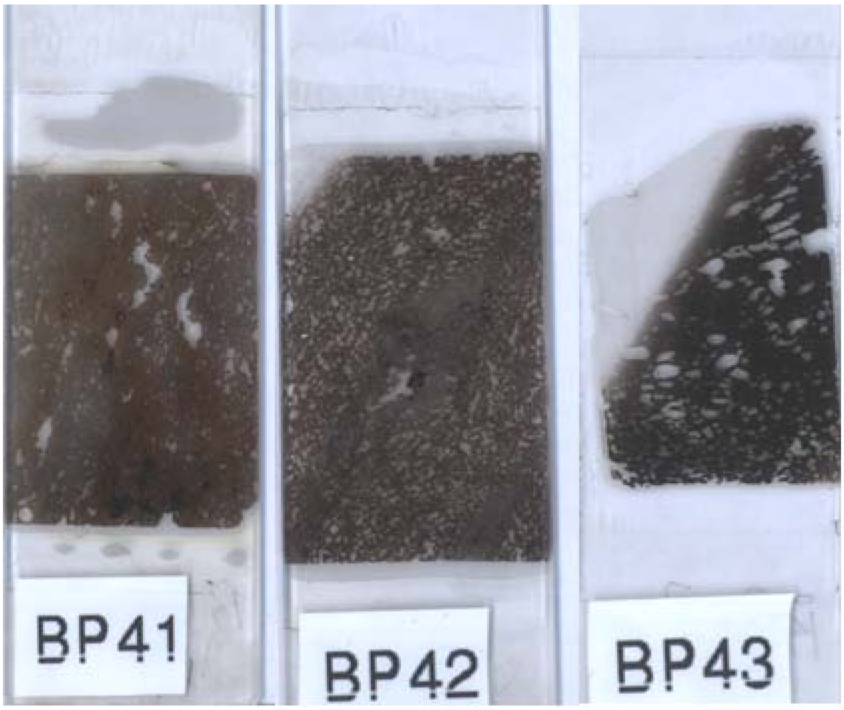

Figure 4 Scoria samples in thin section are highly vesiculated and contain irregularly shaped vesicles.

Figure 5 A series of composite images of the headwall starting with the west side, moving to the central section and finally to the eastern edge. These deposits are viewed looking to the southwest.

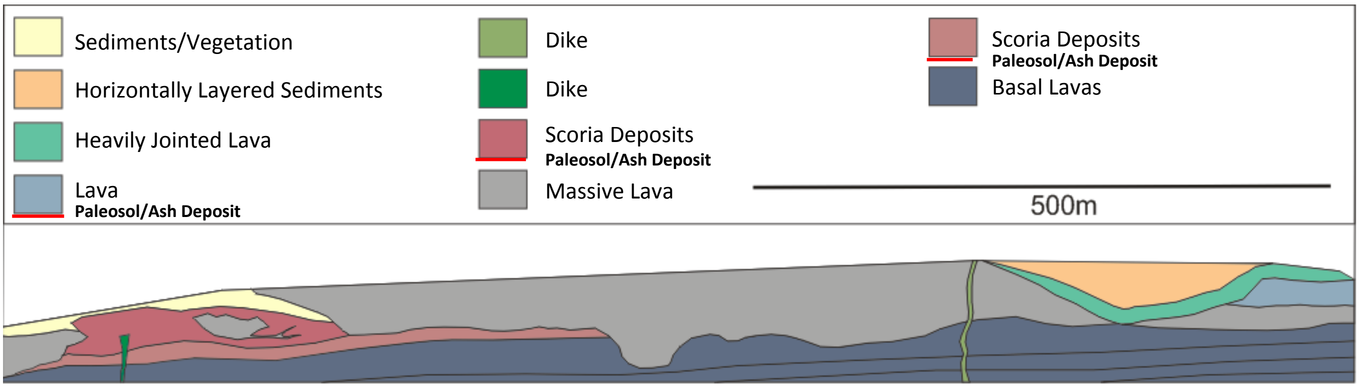

Figure 6 Model of the deposits in the headwall. They are labeled in order from youngest to oldest

Tables

Sample Number	**UC Field ID**	SiO2 (%)	TiO2 (%)	Al2O3 (%)	Fe2O3T (%)	MnO (%)	MgO (%)	CaO (%)	Na2O (%)	K2O (%)	P2O5 (%)	LOI (%)	Total (%)
35403A	**BP-5**	54.18	1.27	17.75	9.96	0.22	1.83	4.42	6.47	2.77	0.56	0.43	99.85
35404A	**BP-6**	47.20	3.07	17.14	12.13	0.20	4.17	8.23	4.15	1.52	0.80	1.27	99.87
35436A	**BP-38**	47.06	3.15	17.41	12.45	0.17	3.52	7.99	4.07	1.56	0.81	1.71	99.89

Table 1: XRF Geochemical analysis of thebasal lava, piece of overtopping lava, and scoria samples.