Flank Scoria Deposits of Okains Bay, Banks Peninsula, NZ: Insights to Akaroa Volcanism and Coastal Evolution

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ABSTRACT:

Field work reveals previously unrecorded, laterally discontinuous scoria deposits - associated with Akaroa Volcano flank eruptions - exposed along the shore platform and in the overhanging cliffs in the area of Okains Bay and Little Okains Bay, Banks Peninsula, NZ. A combination of *in situ* field observation and remote photo interpretation of stratigraphy have revealed the presence of 2 scoria cones in the Okains Bay area, which constrained the geographic extent over which major flows sourced from the main Akaroa vent could be emplaced. Furthermore, it is suggested these scoriaceous deposits preferentially eroded during and after emplacement, and again during exhumation to give rise to today's current coastal geomorphology, which could have implications for other coastal volcanic locales around the world, including other areas of Banks Peninsula. Future work could include better describing the volcanic products located there, including via geochemical means; exploring other scoria deposits in this same vicinty; or expanding upon this work is other locales, such as other Banks Peninsula bays and inlets, or other coastal basaltic volcanoes, e.g. Santorini.

INTRODUCTION:

Scoria volcanic cones are oft labeled the most common volcanic landforms (e.g. Martin and Nemeth, 2006; Valentine and Gregg, 2008; Pioli et al., 2008). However, for all their frequency, few studies have examined scoria deposits on New Zealand's Banks Peninsula (e.g. Johnston et al., 1997; Sewell, 1988).

Banks Peninsula is the product of two large volcanic edifices – Akaroa Volcano to the southeast, and Lyttleton Volcano to the northwest (Figure 1). The product of intraplate volcanism, Akaroa Volcano deposits – including those of interspersed, sporadic Strombolian eruptions – were emplaced between 9 and ~8.0 million years ago (Sewell, 1992; Timm et al., 2009).

Deposits from Akaroa include geographically large lava flows, generally consisting of gray basalt, separated and distinguished, oftentimes, by zones of auto-brecciation that may or may not be baked (Sewell, 1988). These flows tend to be massive in nature (though the breccia zones suggest a'a' lava), and with some exceptions, tend to be aphyric to porphyritic in texture, and roughly a few meters thick.

Nonetheless, the thickness of these flows can vary greatly over small geographical distances due to channelization during emplacement.

Interspersed with these flows are laterally discontinuous scoria deposits stemming from flank eruptive events that are most likely Strombolian in nature, though some deposits – especially those containing more "cognate" clasts (Nemeth and Martin, 2007) – could be the result of magma/water interaction and subsequent phreatomagmatic activity (Buchner and Tietz 2012). One locale with such scoria deposits is Okains Bay.

Okains Bay is located on the north shore of Banks Peninsula, New Zealand, and is one of many bays that pockmark the peninsula's coastline (Figure 2). Comprised of 3 smaller inlets – westernmost Okains Bay, Little Okains Bay, and easternmost Hermit's Bay – most scoria is found exposed in cliff sections that are accessible by walking track, or viewed by boat. This study utilizes such *in situ* and remote access to investigate the Okains Bay scoria, and gain insight to Banks Peninsula Strombolian eruptions. Subsequently, the results presented here offer insight to the stratigraphy of basaltic flank explosive deposits; to the reconstruction of highly eroded cinder cones; and to locating cinder cone paleovents.

METHODS:

This project, primarily a field-based investigation, chiefly incorporated the combination of field observation and description of accessible deposits with photo interpretation of outcrops. In the field, locations of scoria deposits were mapped, as well as other local lithologies, while the faint structural fabric present in scoria deposits (often via approximate average long-axis trend of clastic material) was recorded. CorelDRAW X3 was used for photo interpretation of the same deposits in order to identify stratigraphic sequences and correlate them across time and space. Ultimately, these correlated sequences were then used to indicate the presence of multiple, discreet scoriaceous deposits. Meanwhile, local geometry and the characteristics of deposits (e.g. the abundance of fluidal bombs) were used to infer the approximate location of paleovents. Finally, the effect of scoria erosion on coastline morphology evolution and human hazard was considered.

DATA:

FIELD DESCRIPTIONS:

Photo Perspective (PP) 1, Okains Bay: Figure 3

1: Black porphyritic basalt, with <15% white plagioclase phenocrysts. Phenocrysts are generally blocky, and <1cm in size. Basalt, where thick outcrops are exposed, exhibits jointing patterns, both columnar and horizontal styles; massive otherwise.

2: Massive, grey, aphyric.

3: Matrix-supported, faintly bedded scoria, alternating with finer tephra. Mostly non-welded. Pyroclasts' long axis size averages ~6cm, while vesicularity averages ~40% and is of mm-scale. Pyroclasts generally non-phenocryst-bearing, though some are porphyritic, non-vesicular, and resemble [1]. Strikes ~090, dip ~15 degrees S.

4: Small, <1m thick, gray, predominantly aphyric (rare plagioclase phenocrysts, <1cm in size?) lava. Bounded by small amount of breccia, and red oxidized tuffaceous zones.

5: Moderately welded, generally clast-supported scoriaceous blocks and bombs. Some bombs approach ½ meter in size, and/or show evidence for deformation upon impact, e.g. cow pat bombs. Millimeter scale vesicles common in all pyroclasts, and sometimes show a fabric. Deposit is weathered to purple, or oxidized red/brown colors. Capped by ~5cm thick red baked tuffaceous layer that occasionally contains interbedded clasts. Strikes ~050, dips ~15-20 degrees SE.

6: Grey, massive, aphyric to porphyritic (<<15% crystalline, again with <1cm white plag, if at all) basalt. Appears to be small Akaroa flows lapping up against scoria.

7: Large basalt flows physically identical to [6]; only distinguished by size. Capped by [8]. Noted primarily for being major Akaroa effusions, and for stratigraphically overlying Okains Bay scoria deposits

8: Inaccesible deposit. Appears to be ~10cm (max) thick, red baked tuff that caps [7]. Stratigraphically noteworthy for its utility as a chronostratigraphic marker; layer can be traced or inferred across entire headlands between Okains and Little Okains Bay. Also noteworthy for underlying scoria deposits of Little Okains Bay (PP3).

Photo Perspective 2, Headlands: Figure 4

1: Grey, massive, aphyric to porphyritic basalt; major Akaroa effusions, and same as [7] in PP1. Appearance largely influenced by slopewash.

2: 10cm thick red baked tuff; chronostratigraphic layer noted as [8] in PP1.

3: Agglutinate flows of varying, but generally meter scale size. Grey, aphyric lava otherwise similar to other local flows.

4: Little Okains Bay scoriaceous deposits.

Photo Perspective 3, Little Okains Bay: Figure 5

1: ~10cm thick orange/red, baked, chronostratigraphic tuff. Caps lava flows from earlier photo perspectives, and underlies scoria. Same chronostratigraphic tuff as mentioned in PP1 and PP2. Underlain by black/grey aphyric to porphyritic lava described as [7] in PP1.

2: Bedded, non- to lightly welded scoria; alternates between lapilli or larger pyroclasts and more ash-rich beds. Larger blocks and bombs (e.g spindle, fusiform) are also present and can be up to 30 cm or more in size; pyroclast size also seems to show subtle increase up-section. Pyroclasts are again moderately vesicular (averaging 40%, and millimeter in scale), though the amount of non-vesicular “cognate clasts” (as classified by Nemeth, 2007) gradationally increases as on travels back west toward Okains Bay, or south toward Little Okains Bay Beach. One distinct reddish orange oxidized layer stands out, and is recorded as a separate unit because it may correlate with later oxidized scoria layers. Grades from matrix-supported to clast-supported up through the exposure. Especially near the upper reaches of the deposit, cored bombs are evident.

3: Grey, aphyric, massive agglutinate flows. Often of meter scale, and laterally discontinuous.

4: Capping red, baked tuff. Like its underlying counterpart, also <10cm thick and unwelded. Inaccessible.

5: Inaccessible deposit, but appears to be black to gray, massive Akaroa basalt, presumably mostly aphyric like its more accessible counterparts in other photo perspectives.

Little Okains Bay Island

The island offshore Little Okains Bay island also is home to scoria deposits, particularly to the north. The south is dominanted by aphyric to porphyritic black/grey lava identical to [7] from PP1. The north finds scoria deposits consisting of blocks and bombs often no larger than 10cm, and of variable vesicularity; long axis trends show subtle north/northeastward-dipping trend (strike ~100-110, dip ~20 degrees NNE).

East Little Okains Bay

East Little Okains Bay is not included as part of this study, as few – if any – scoriaceous deposits are found in this area.

DISCUSSION:

Both photo interpretation and field observation of scoriaceous deposits of Okains Bay shed light on the geographic extent of such deposits, as well as the relative temporal relationships of all volcanic ejecta in the area. Diagnostic characteristics also suggest the locations of paleovents associated with Akaroa Volcano flank explosive activity. All this is analyzed below with respect to photo locations (Figure 6) beginning on the east side of Okains Bay (the west end of the study area), and ending with the southwest end of Little Okains Bay (the study area's eastern terminus).

Photo Perspective 1, Okains Bay

Here, the nature of scoria deposits can be used to gain insight to the local cone's structure: the degree of welding present is taken to be a proxy for distance from vent, after Johnston et al. 1997. Thus, the faintly bedded scoria of [3] is said to be representative of more medial and distal deposits, as its non-welded nature implies a lesser accumulation rate and/or increased cooling in flight and thus greater distance from the vent (Head and Wilson 1989). Conversely the more densely welded scoria of [5] is taken to represent more proximal deposits. Meanwhile, the relatively thin lava flows of [6] appear to be small, onlapping flows associated with effusions from the Akaroa central vent, and suggest local parasitic cones played a role in determining the geographic extent of subsequent lava flows.

[2] appears to be a dike, as its aphyric nature differs from the porphyritic texture of the basement lava, [1]. The dike's broad girth is presumed to be the result of an oblique angle of exposure, while it's non-linear nature is due to propagation through poorly consolidated material, e.g. non-welded scoria, and subsequent free surface effects (Dr. Darren Gravley, pers. comm., 2012). As it seems to be positioned roughly orthogonal to the internal pyroclastic bed structure, the dike seems to represent a radial intrusion from the cone's central conduit.

Meanwhile, to the east, larger and more laterally continuous lava flows also associated with Akaroa's central vent [7] are seen lying stratigraphically atop all local scoria, and distinguished from one another by basal breccia zones, as is common amongst Akaroa volcanics (Sewell, 1988). Of important note is [8], the red baked tuff, as it can be seen lying above local scoria, but traced or inferred back east across the headlands between Okains and Little Okains Bay, until it finally underlies the scoriaceous deposits of Little Okains Bay.

Photo Perspective 2, Headlands

While the headlands lack any major scoria deposits, it is crucial to investigate them to ensure significant stratigraphic evidence exists to support the hypothesis that there are multiple scoria cones in the Okains Bay locale. Photo Perspective 2 offers such evidence, as the tuff [8] from PP1 is clearly laterally continuous, and can thus be used as a chronostratigraphic marker. Furthermore, to the east side of the photo, the scoriaceous deposits of Little Okains Bay can be seen beginning to outcrop. This offers hard evidence that there exists multiple scoria outcrops in the Okains Bay vicinity, and also allows for a more accurate size inference when determining the extent of the paleocones.

Photo Perspective 3, Northwest Little Okains Bay

Northwest Little Okains Bay is where the red baked tuff [8] from PP1 is most readily accessible, as here it is located at sea level, stratigraphically beneath almost all other deposits including local scoria. Local scoria never exhibits dense welding, suggesting none of the scoria here is located immediately proximal to the paleovent. However, the abundance of meter scale clastogenic lava flows suggests a relatively nearby vent, lest the clasts be too cool upon emplacement to meld into a single rootless flow.   Bed geometry shows pyroclasts dipping roughly south, suggesting the location of the paleovent is offshore to the north.

Further up-section, later Akaroa lava flows are evident, particularly where a red baked ash horizon lies between scoria and overlying flows. However, smaller, thinner flows appear as well, and though inaccessible, seem to somewhat resemble their clastogenic counterparts down-section. If so, this suggests that this particular cone's explosive cycle didn't fully end until after a major Akaroa effusion; scoria was emplaced by Strombolian processes, topped by Akaroa lava, and later all this was covered in smaller flows emanating from the cinder cone's central vent as it's eruptive sequence waned.

Little Okains Bay Island

While previously hypothesized to be an exposure of rafted scoria (e.g. as described in Valentine, et al. 2005), the opposing dip (NNE, versus the southerly dip of scoria exposed in the Little Okains Bay/PP3 exposure) of the island's scoriaceous deposits instead suggest the island to be comprised of basement lava overlying by scoria deposited on the north side of the edifice.

Scoria Deposits: Paleovents and Local Coastline

The nature of the Okains Bay scoria deposits falls squarely within the definition of a Type 1 cone, as proposed by Martin and Nemeth, 2006. That is, these cones are typically small, with basal diameters of only a few hundred meters, commonly comprised of local tephra including fluid bombs only found generally within the cone construct. However, these types of cones are often said to have slope angles of ~30 degrees, while in Okains Bay the observed value is somewhat less (~15-20 degrees). Given that cinder cone slopes will fail over time as they naturally try to fall into a more stable state (Wood 1980), it is theorized that cinder cone reworking has – and still is – an active process here as weathering causes the preferential erosion of scoria. Meanwhile, utilizing the internal bed geometry of the pyroclastic deposits, the orientation of the radial dike, and the degree of deposit welding allowed for the approximate reconstruction of the Okains Bay scoria cone; it's approximate location is shown in Figure 6. Found to have a basal diameter of roughly 200 meters, simple trigonometry (e.g. the Sine Rule) can then be used to suggest that, given an approximate slope angle of 20 degrees, the Okains Bay Cinder Cone attained a maximum height of ~40 meters.

To the east, scoria deposits in Little Okains Bay are evidently more extensive. While in most respects similar to the deposits found in Okains Bay, these deposits are also characterized by lack of prominent bomb impact sags, and by an up-section trend toward a more clast-supported nature. Such diagnostic characteristics label the Little Okains Bay Cinder Cone a "Type 2" by the Martin and Nemeth terminology scheme. Furthermore, the presence of non-vesicular clasts suggests a highly explosive mode of eruption, as might be common in a coastal setting where magma has easy access to water (Nemeth 2003). As for the paleovent, approximate reconstruction suggests that the cone boasted a basal diameter of roughly 600 meters. Using the same math as before, it is suggested that a cone of 600m diameter with a slope angle of ~20 degrees was roughly 100 meters in height; Figure 6 offers a probable vent location.

It should be noted that the Little Okains Bay cone is significantly larger than that of Okains Bay; this is presumably because the eruptive sequence at the former spanned a greater duration. Cored bombs in Little Okains Bay suggest as much, as they are indicative of multiple, significant eruptions that recycled any ejecta that may have fallen back into the vent after a first explosion.

The lack of scoria dipping in toward a common center, as well as an apparent lack of vent breccias, meanwhile, means that some process has removed two of a scoriaceous edifice's three dominant lithofacies, leaving behind only the scoria of the edifice wall (Buchner and Tietz 2012). It has long been known that scoria cones are prone to failure on their downslope flanks (e.g. Valentine et al. 2006), and research has suggested that it is the erosion of scoria to smaller particles (e.g. the yellow-brownish clays described by McCraw, 1962) that is responsible for steeper slope instability, thereby encouraging mass wasting events (Wood 1980). The presence of water, as well, can effectively hasten weathering or lubricate an edifice flank such that mass wasting is more likely, as was seen at Paricutin after heavy rainfall (Wood 1980). Thus, it seems likely that the exposure of coastal scoria to water both via rain and destructive wave action is a definite means by which to encourage erosion. Because of lava's more resilient nature, then, preferential erosion of scoria is proposed as a likely mechanism by which coastal geomorphologies evolve over time in volcanic settings, and the mechanism by which Okains Bay current coastline took shape. Such a mechanism has far-reaching impacts given the large population around some coastal volcanoes (e.g Hawaii, USA, and Santorini, Greece), and that cinder cones are considered the most numerous volcanic edifices on Earth (Martin and Nemeth 2006). It should be kept in mind that should any coastal scoria deposits sudden fail, especially in the vicinity of humans, the effects could be harmful, both physically, and elseways, e.g. undermining a local tourist industry.

CONCLUSION:

Photo interpretation of stratigraphy and field observations support the theory that there exist 2 scoria cones in the vicinity of Okains Bay, Banks Peninsula, New Zealand. Both cones show signs of Strombolian eruptive behavior in their past, though the Okains Bay Cinder Cone is "Type 1" and the other, Little Okains Bay Cinder Cone, is "Type 2." Meanwhile, the internal structure of these deposits has allowed for their approximate reconstruction and the identification of inferred paleovents.

Also, in the time since their emplacement, weathering processes have preferentially eroded these cones; this mechanism is now proposed as the primary means by which the modern coastal geomorphology of Okains Bay took shape. Finally, the preferential (and potentially sudden) erosion of scoria in coastal volcanic settings – such as Santorini or Hawaii – is presented as a future hazard that needs monitoring.

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APPENDIX of ASSOCIATED FIGURES

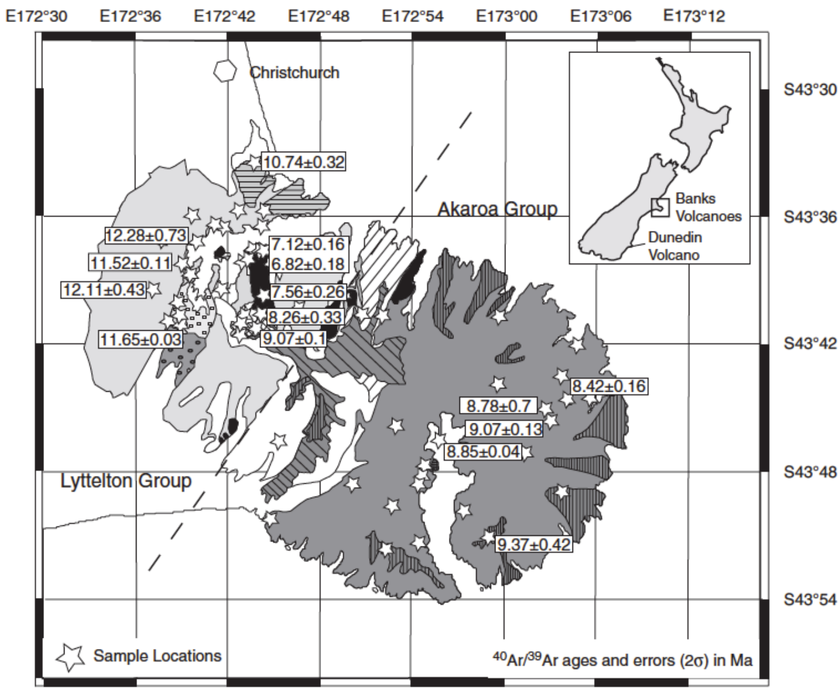

Figure 1: Geologic map of Banks Peninsula volcanoes. Note Lyttleton and Akaroa Volcanic Groups clearly marked. Map from Timm, et al., 2009.

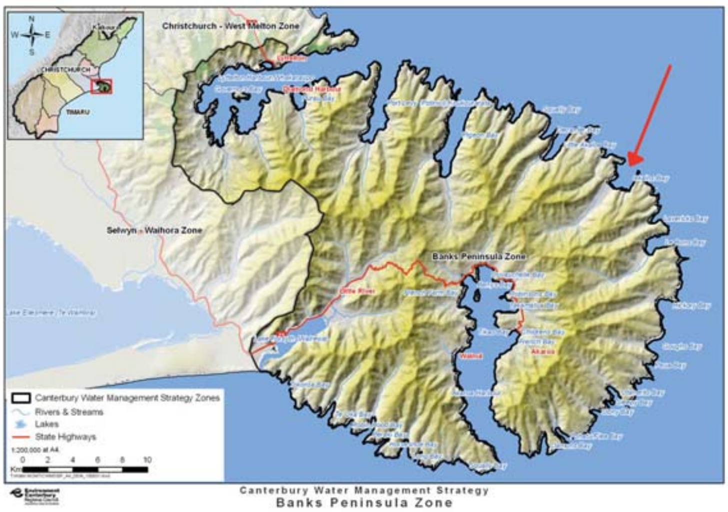

Fig. 2: Map of Banks Peninsula. Okains Bay is indicated by the red arrow. Map courtesy of http://ecan.govt.nz

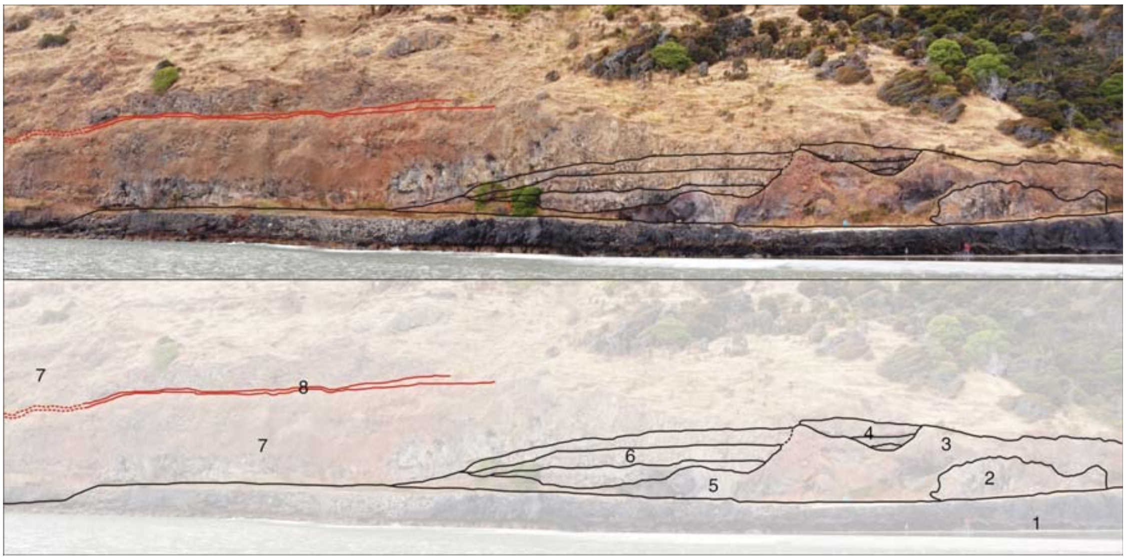

Figure 3: Stratigraphy of Okains Bay Cinder Cone. Correlated with field observations in earlier "DATA" section.

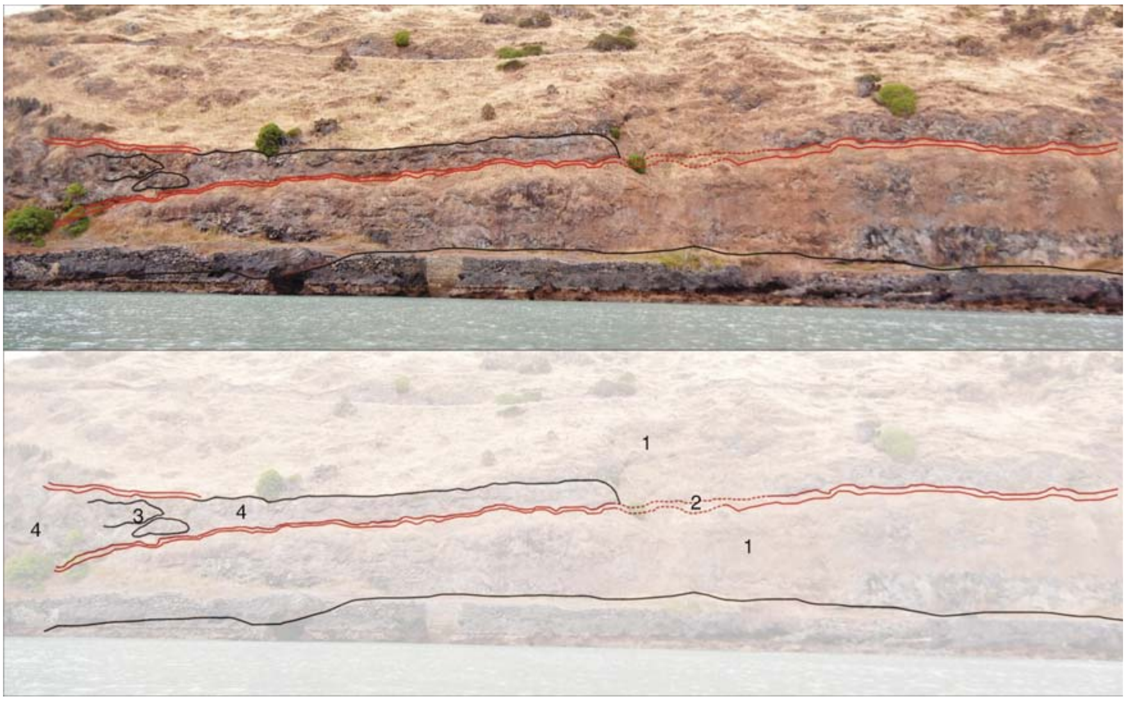

Figure 4: Stratigraphy of Headland between Little Okains Bay to east (left) and Okains Bay to the west (right). Correlated with field observations in earlier "DATA" section.

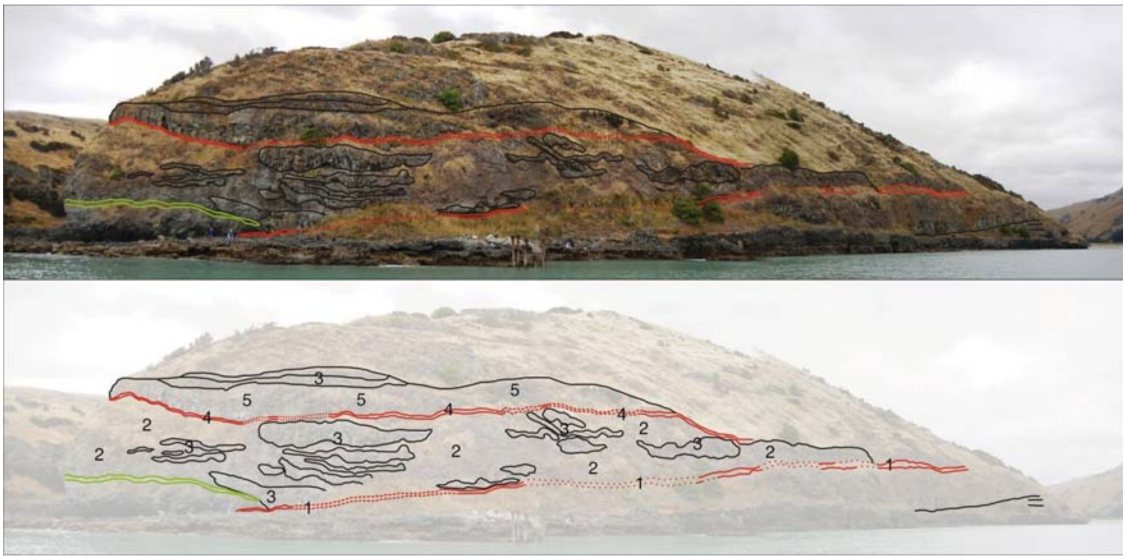

Figure 5: Stratigraphy of Little Okains Bay scoria deposits. Correlated with field observations in earlier "DATA" section.

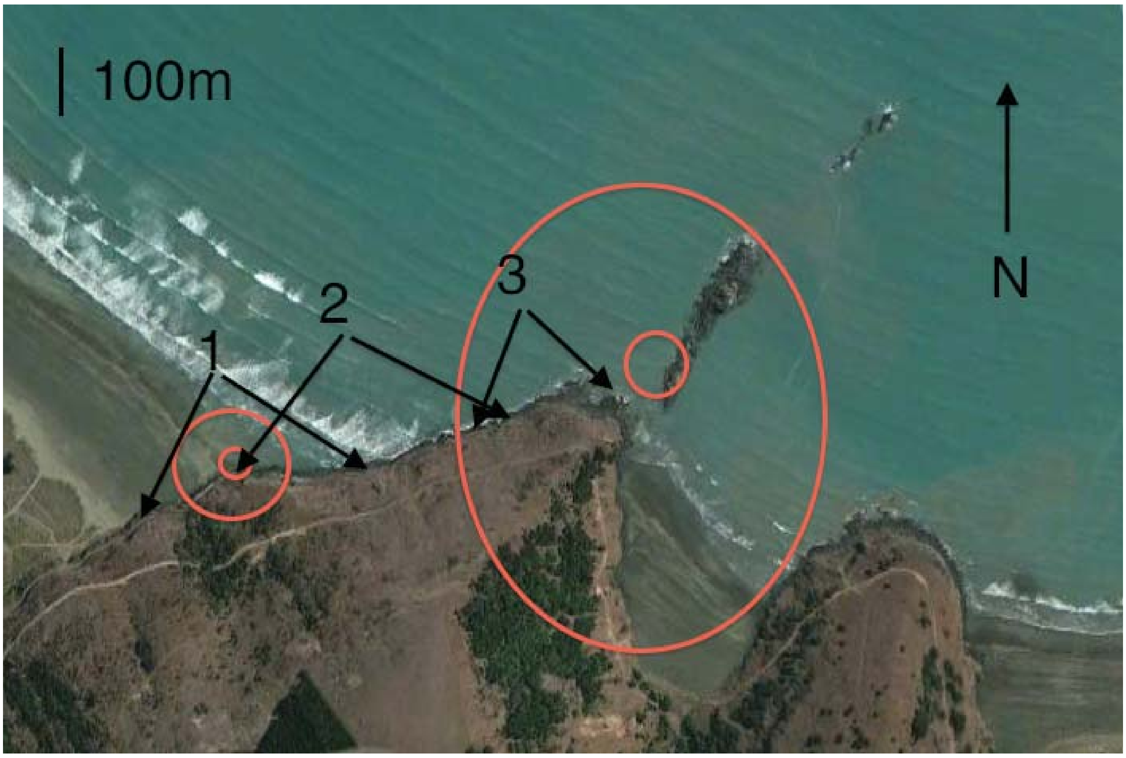

Figure 6: Aerial view of field area. Okains Bay to west, Little Okains Bay is low/center in image. Arrows and number correlate to photo perspectives, while red circles indicate approximate extent of scoria cones, and inferred vent location.