Soil formation from volcanic deposits in Banks Peninsula

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ABSTRACT

Multiple unconsolidated red layers can be found between lava flows in Lavericks Bay on Banks Peninsula. These layers may represent ash deposits and/or paleosols. The purpose of this project is to identify paleosols in Lavericks Bay. Where paleosols can be identified, they represent gaps in time between volcanic deposits. The paleosol layers also indicate the development of an ecosystem. A comparison of the composition of the soil with the composition of the parent material shows a relationship between the mineral content of the parent material and that of the soil. The soil compositions could be used to understand the ecosystems that developed between volcanic deposits. This could have implications for modern ecosystems developed from volcanic deposits in New Zealand and around the world. In the future, further research could be done to enable paleosol thickness to be used as a measure of the length of time between lava flows.

INTRODUCTION

The main determinants of the composition of a soil are the composition of its parent material and the specific processes which led to the soil's formation. However, it is difficult to determine to what extent parent material, rather than climate, influences a soil (Jenny 1994). In various volcanic soils and paleosols that have been studied (Anda 2012, Cronin et al. 1996, Solleiro-Rebolledo et al. 2003, Tabor et al. 2004), the composition of the soil has appeared to vary according to the type of volcanic deposit (i.e. lava flow, ash, tuff) constituting the parent material. Anda (2012) studied the way in which a variety of parent materials contributed nutrients to soil. Soil developed on tuff was found to have very high levels of calcium and magnesium compared to soil developed on basalt, volcanic ash, and volcanic basaltic andesite. However, previous studies showed that basalt contributed large amounts of cations including calcium and magnesium to soil compared to non-volcanic parent materials. Basalt releases calcium and magnesium quickly due to the dissolution of feldspar (Anda 2012). Changes due to soil formation are also visible in basalt itself, through the alteration of plagioclase feldspar crystals to phyllosilicates (Tabor et al. 2004).

The structure and texture of a soil or paleosol is affected by both the parent material and the climate in which soil development occurs. Solleiro-Rebolledo et al. (2003) investigated a paleosol-sedimentary sequence which included surface soil, paleosols, and volcanic deposits. They classified the soils according to the Soil Taxonomy system, which will be discussed in the next paragraph. The surface soil was classified as an Andisol, or volcanic soil (Solleiro-Rebolledo et al. 2003; Soil Survey Staff 1999). Its high porosity and fine-grained texture is attributed to its formation on volcanic ash in humid conditions. The buried soils, classified as Luvisols, have high clay accumulation and blocky-prismatic structures. They also contain iron and magnesium nodules symptomatic of redoximorphic processes caused by high levels of moisture. These soils also show evidence of shrink-swell pedoturbation. It is likely that the soils were formed in a humid forest environment (Solleiro-Rebolledo et al. 2003).

The classification of soils and paleosols into soil orders through the Soil Taxonomy system can assist in reconstructing the environments in which they were formed (Soil Survey Staff 1999). Both Cronin et al. (1996) and Solleiro-Rebolledo et al. (2003) classify some of the soils and paleosols they investigated as Andisols. Andisols are usually defined as having developed from volcanic parent materials. They are characterized by heavy weathering and mineral transformation with little movement of minerals within the soil. Unlike some other soil orders, Andisols are not associated with specific temperature or moisture ranges or with specific landscape positions or elevations (Soil Survey Staff 1999). This makes them less useful in studying the environments in which they developed, although specific characteristics such as the presence of allophane and halloysite can indicate certain environmental conditions. Cronin et al. (1996) also identify Entisols in their paleosol sequence. Like Andisols, Entisols suggest little about the environment in which they formed, since, by definition, they do not contain well-developed soil horizons. However, their lack of development could indicate that they formed in conditions where either erosion or sediment accumulation occurred so quickly that soil formation was impeded (Soil Survey Staff 1999; Cronin et al. 1996).

Multiple pieces of evidence can be used to investigate how long a particular soil was developing for. As mentioned above, a lack of developed soil horizons indicates that soils were short-lived and did not have much time to form before being eroded or buried (Soil Survey Staff 1999). Cronin et al. (1996) use the dearth of allophane and ferrihydrite in one zone of a soil compared to other zones as evidence that the soil surface was accumulating too rapidly for those minerals to form. The increase in lapilli in this zone supports the hypothesis that deposition was increasing. In other zones, the presence of weathering minerals such as allophane and halloysite indicates slow accumulation, allowing time for minerals to develop (Cronin et al. 1996). Solleiro-Rebolledo et al. (2003) determined how weathered a paleosol is, and therefore how long it was exposed for, through both the weathering of individual minerals, and the amount of volcanic components such as rock fragments contained in the layer. Clay psuedomorphs indicate the weathering of pumice. In addition, phytoliths provide evidence of plant life, proving that the soil must have been exposed for an extended length of time. Solleiro-Rebolledo et al. (2003) used the lack of an eluvial horizon in several paleosol units as evidence of erosion, which would also require the soil to be exposed. Missing horizons could indicate either rapid burial or deposition or long periods of exposure depending on whether the horizon was never formed, or whether it was created and eroded.

GEOLOGIC BACKGROUND

Lavericks Bay is located on the north side of Banks Peninsula (Fig. 1). The lava flows which make up the area were deposited by Akaroa Volcano between 9.3 and 8.0 million years ago. These deposits are mainly basaltic (Hampton 2012). Some of the flows in Lavericks Bay contain calcite as well as olivine and plagioclase feldspar. The lava flows are of varying vesicularity and crystal content, with some containing crystals up to 1 cm long. Columnar jointing and autobrecciation were also observed. Many of the lava flows in Lavericks Bay are separated by layers of paleosol and/or ash. These layers are distinguishable due to their reddish coloring and crumbly texture. Some of the paleosols contain multiple layers distinguishable due to their different colors, textures, and crystal and lithic contents, including scoria, as is common in volcanic soils (Ping 1999).

METHODOLOGY

Samples of potential paleosol layers and their underyling parent material were collected from four sites in Lavericks Bay. There was also a sample collected from a paleosol whose parent material could not be sampled. For two of the sites, samples were taken from multiple layers within the paleosol. Each sample was around 7 cm in diameter and contained only fresh surfaces. The samples were washed, crushed, and powdered. To prepare the samples for major element analysis, 1.3 grams of powder from each sample were fused with 6.98 grams of $Li_2B_4O_7/Li_2O/La_2O_3$ and NH_4NO_3 (Johnson 2012). The mixture was fused into glass fusion beads at 1030°C for 15 minutes. Pressed powder pellets were made for trace element analysis by pressing 8 grams of powder from each sample and polyvinyl alcohol binder solution in 32 mm diameter pellets at 3000 psi for 10 seconds (Johnson 2012). The samples were analyzed using a Philips PW2400 Sequential Wavelength Dispersive X-ray Fluorescence Spectrometer belonging to the University of Canterbury. The analysis required a rhodium tube set which was set at 50 kV/55 mA for the major element analysis and 60 kV/46 mA for the trace element analysis (Johnson 2012).

RESULTS

Of the five sites from which samples were collected, one, Site One, only contained a visible paleosol or ash layer. Site Two and Site Three contained an underlying lava flow with a single ash or paleosol layer. Site Four contained an underlying lava flow with five ash or paleosol layers, and Site Five contained an underlying lava flow with two ash or paleosol layers (Fig. 2).

The determination of which layers were paleosols and which layers were ash was made using the assumption that if the assumed paleosol deposits are indeed paleosols, they should have higher concentrations of plant essential nutrients such as Ca, Mg, and K than their assumed parent material, the underlying deposit (Hinsinger et al. 2000). It is impossible to determine whether the single layer in Site One is an ash deposit or a paleosol, since there is no underlying deposit to compare it to. In Sites Two and Three, the overlying layer contains lower amounts of plant essential nutrients than the underlying layer (except for the increase in K_2O in Site Three) (Tables 1 and 2). This suggests that these overlying layers are ash deposits rather than paleosols.

In Site Four, there is a sharp decrease in MgO, CaO, and K_2O between the underlying lava flow and the first ash or paleosol layer (Fig. 3, Fig. 4, Fig. 5). This again suggests that the initial layer overlying the lava flow is an ash deposit. However, the amount of each mineral increases in the next layer, and the amounts of MgO and CaO increase again in the layer above that (while K_2O decreases). In the second-to-last layer, the mineral amounts stay relatively constant, and in the last layer, they all decrease. In Site 5, there is a decrease of all plant essential nutrients between the underlying lava flow and the initial ash/paleosol layer (Fig. 6, Fig. 7, Fig. 8). The top layer contains higher amounts of MgO and CaO than the initial ash/paleosol layer, and lower amounts of K_2O.

DISCUSSION

Sites Four and Five appear to be the most useful for this study, as they seem to contain paleosols. It appears that Site Four consists of a lava flow with an overlying ash deposit from which at least one paleosol has developed. The last layer, in which the amounts of plant essential nutrients have decreased from the preceding layer, may represent a second ash deposit. Site Five seems to contain a lava flow underlying an ash deposit and a paleosol which developed from the ash.

It is likely that the paleosols were able to develop only from the ash instead of from the lava flows because soil-forming factors such as climate could not weather the lava flows quickly enough before ash deposition. Hinsinger et al. (2000) showed that the presence of plants can greatly increase the chemical weathering rate of powdered basalt. Further studies could investigate whether, once soils had developed on the ash layers overlying the basalt, the plants growing in them could access the basalt’s nutrients. This could answer the question of whether the thickness of an ash-based soil is limited by the thickness of the ash, or whether underlying deposits may be incorporated into the soil.

Ash deposits on top of the soil, such as the one apparently present at Site 4, could either enrich the soil or cause soil development to cease. It is common for volcanic ash soils to contain multiple layers of ash and other tephra from different eruptions. In cross section, this can make the soil appear to have many stacked topsoil and subsoil horizons as the soil continues to develop on the new deposits (Ping 1999). The response of different ecosystems to different thicknesses of ash is varied (Thornton 1999). While soils developed from volcanic materials are known for being highly fertile due to the minerals they contain, ash deposition can also cause the introduction of harmful elements into the soil (Schaetzl and Anderson 2005, Thornton 1999). Fluorine poisoning caused by the consumption of contaminated plants is a common volcano-related cause of livestock death (Thornton 1999).

Unfortunately, more information is needed in order to successfully use paleosol thickness as a measure of the length of time between lava flows. If standard soil development rates were known, these could be used to determine how long it took for the paleosol to accumulate. However, the varied climatic and biological conditions involved in soil development mean that a standard accumulation rate for comparison is hard to determine. In addition, there is no way of knowing whether the thickness of paleosol visible in the outcrop is the true thickness of the soil when it was overlain by a volcanic deposit. Erosion may have removed part of the soil before the volcanic deposit, or an ash deposit or deposits may be indistinguishable from the soil itself. Solleiro-Rebolledo et al. (2003) suggest using clay pseudomorphs and phytoliths to determine both the identity and age of a soil; however, these can be difficult to identify in a paleosol. In general, researchers such as Solleiro-Rebolledo et al. (2003) can determine the relative level of development reached by a paleosol before it was buried, but cannot state in years the amount of time for which the soil was developing.

CONCLUSIONS

1. Paleosols exist in at least two locations in Lavericks Bay. In these locations, they developed out of ash deposits rather than out of lava flows. This suggests either that ash was deposited quickly after the eruption of lava flows, meaning there would be no time for soil to develop on the lava flows, or that soil-forming factors such as climate conditions and plant life were not conducive to the weathering of basalt.

2. At the present moment, it is not possible to determine the length of time represented by a paleosol. However, it may be possible to determine how evolved the paleosol is by studying its physical characteristics, provided they have not been altered by burial.

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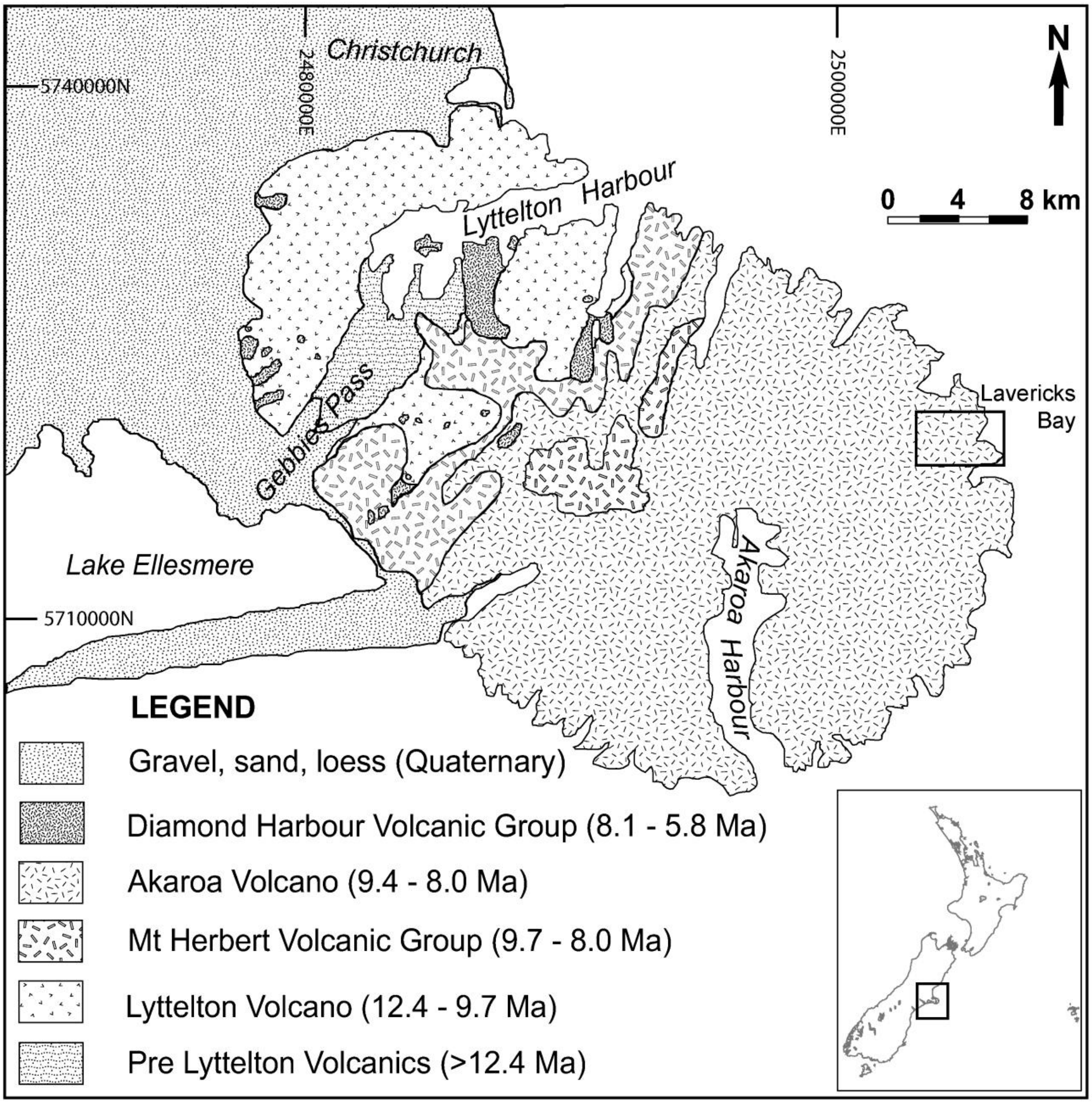
FIGURES

Figure 1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Lyttelton Harbour
Gebbies Pass
Lavericks Bay
Lake Ellesmere
5710000N
Akaroa Harbour
LEGEND
Gravel, sand, loess (Quaternary)
Diamond Harbour Volcanic Group (8.1 - 5.8 Ma)
Akaroa Volcano (9.4 - 8.0 Ma)
Mt Herbert Volcanic Group (9.7 - 8.0 Ma)
Lyttelton Volcano (12.4 - 9.7 Ma)
Pre Lyttelton Volcanics (>12.4 Ma)

Figure 2

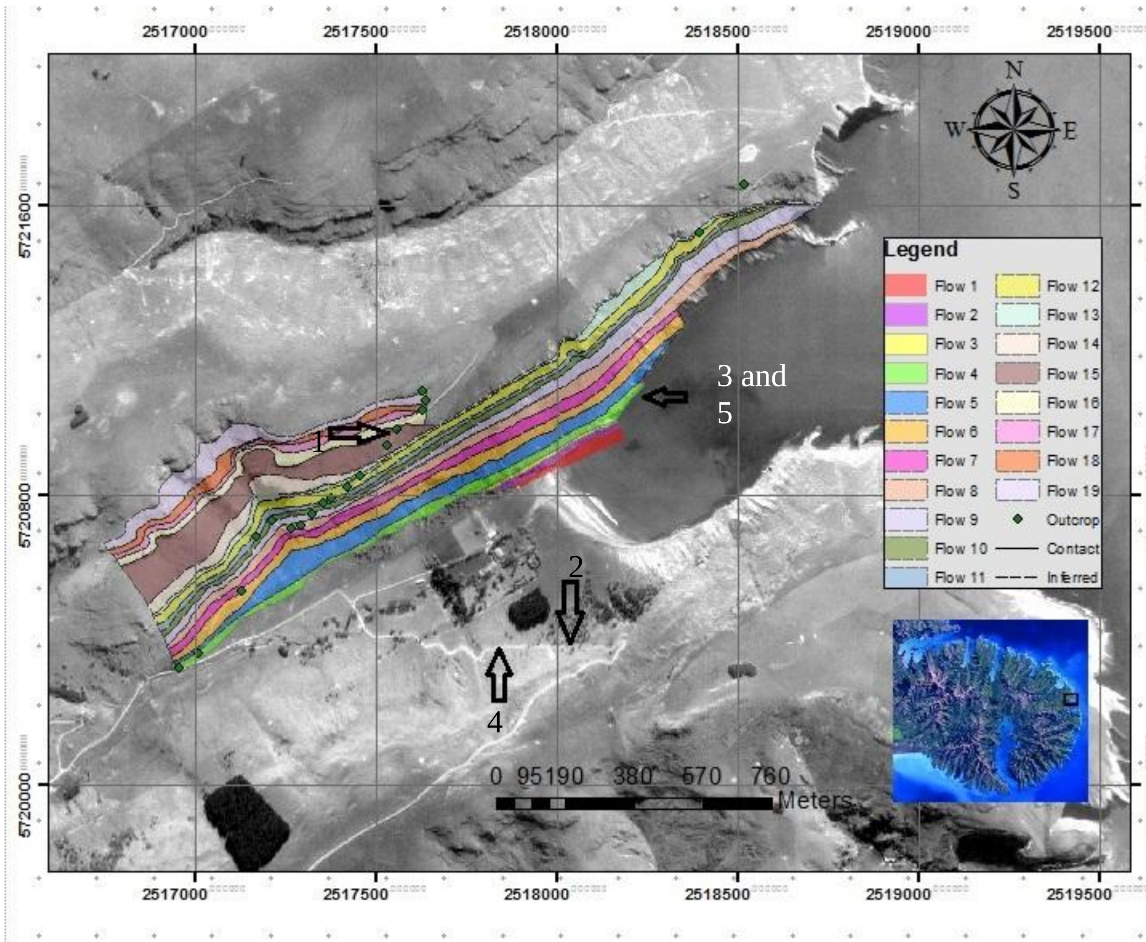
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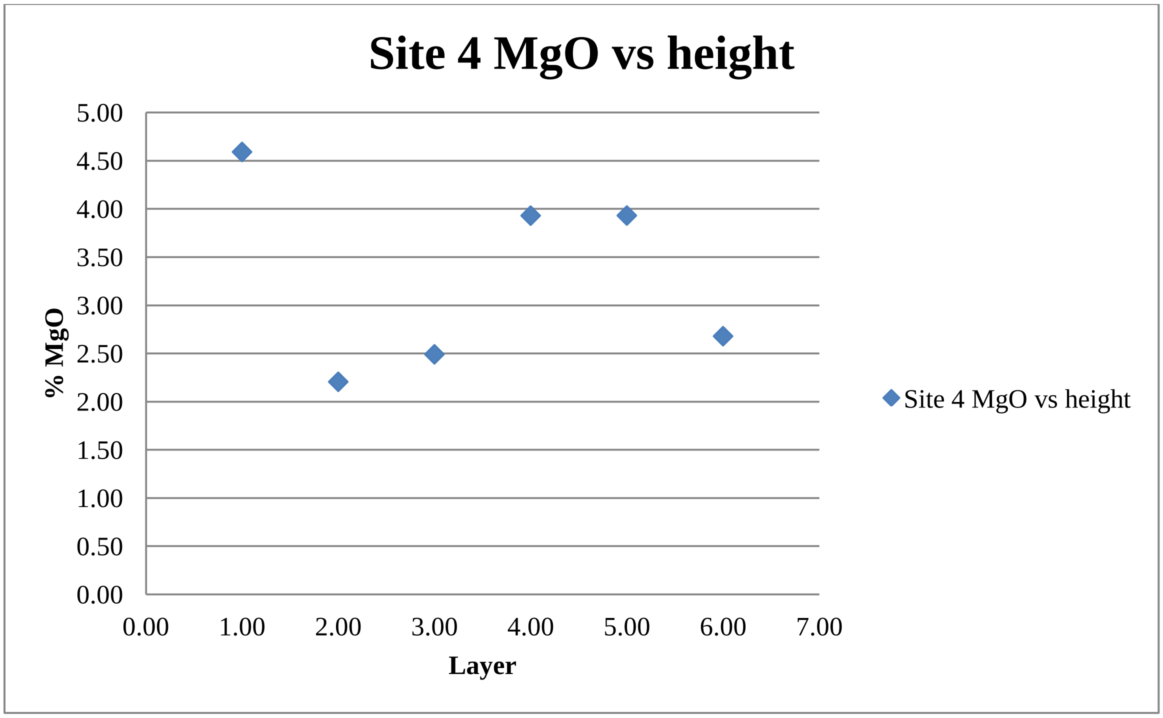
Figure 3



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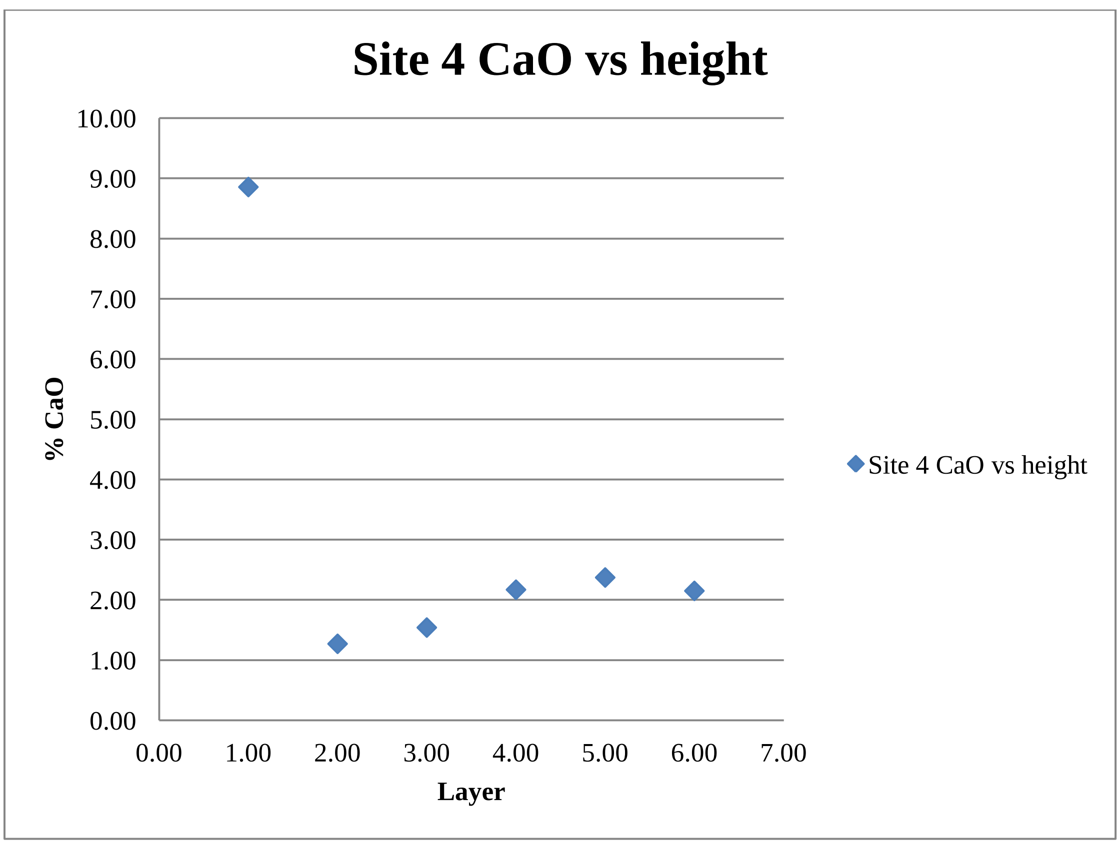

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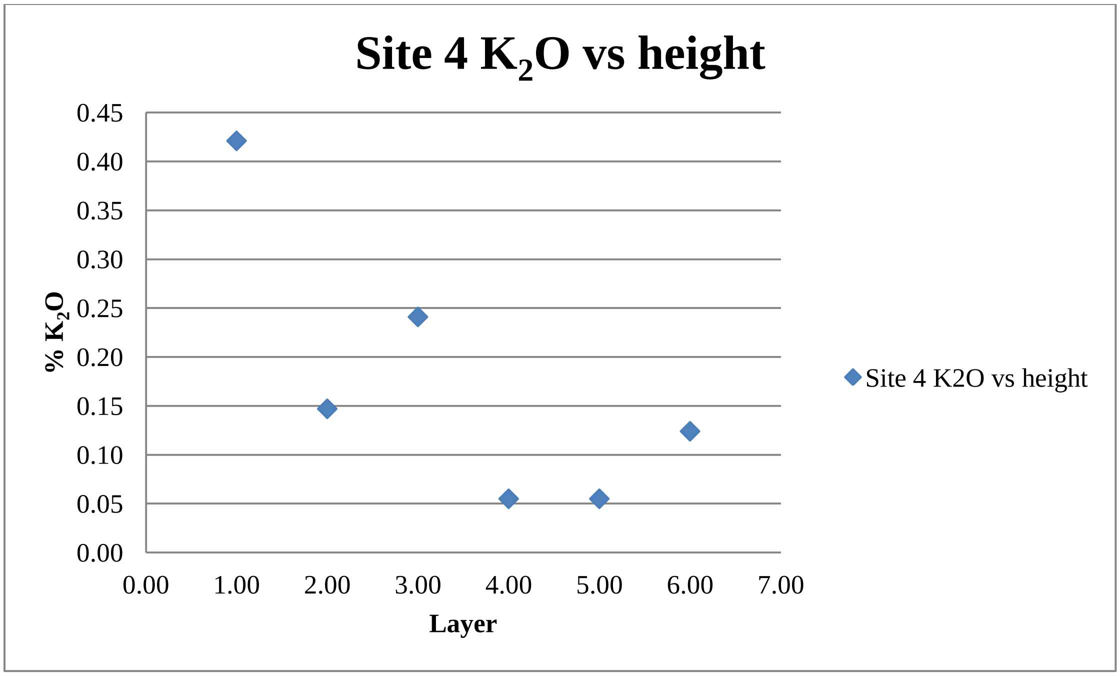

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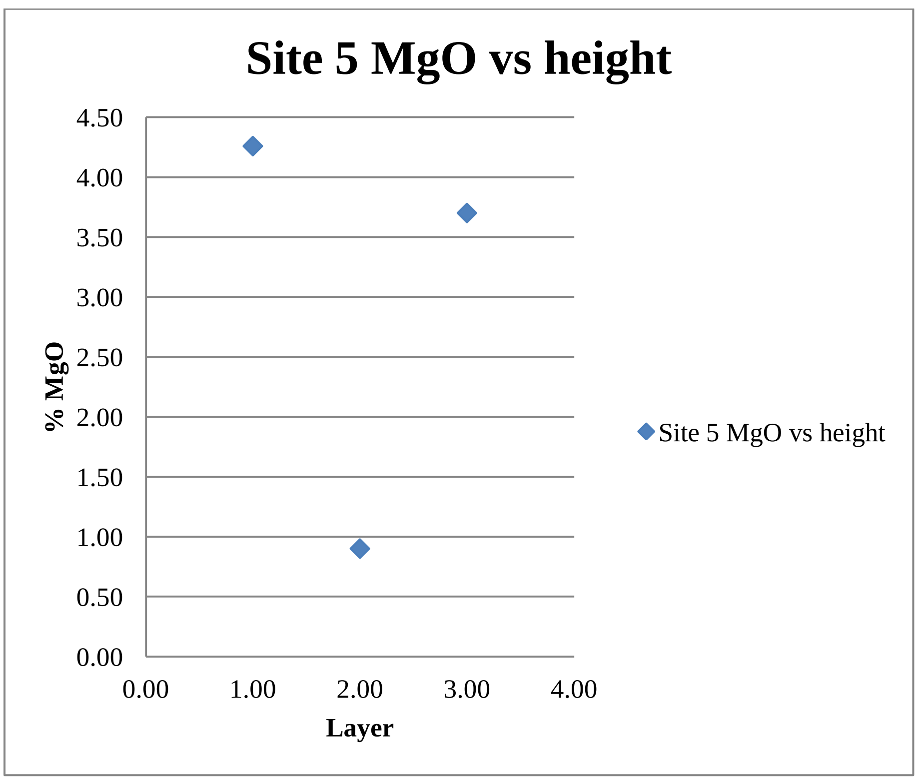

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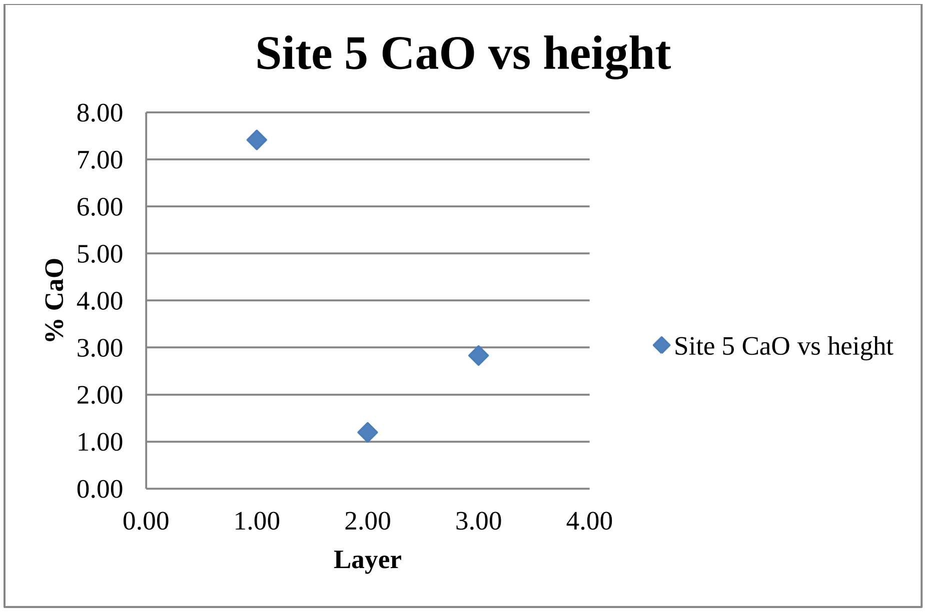

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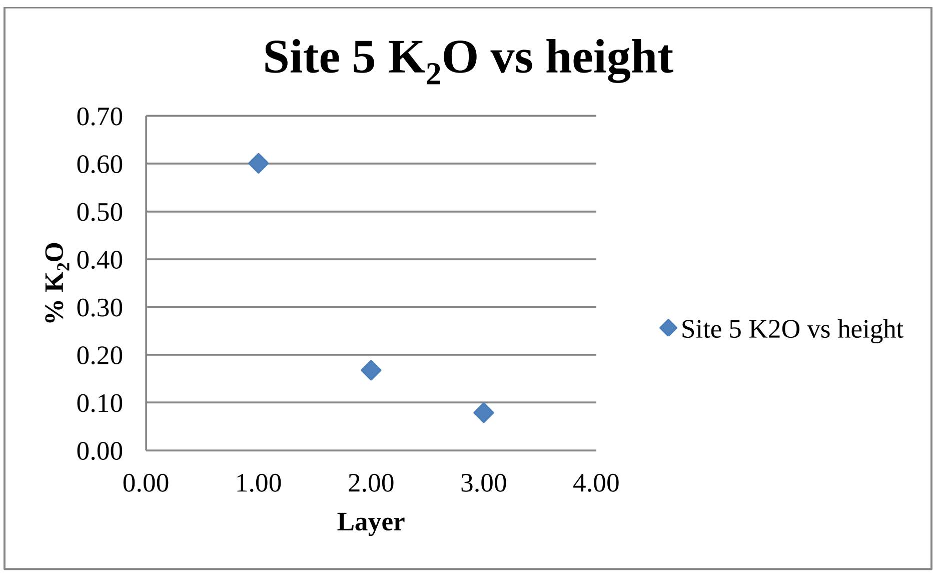

FIGURE CAPTIONS

Figure 1. Map of Banks Peninsula, with Lavericks Bay highlighted (Hampton 2012).

Figure 2. Map of Lavericks Bay showing lava flows, created by Ben Chiewphasa, modified to show locations of sites discussed.

Figure 3. Graph of percent MgO versus height at site 4. Layer 1 corresponds to the lava flow underlying the paleosol/ash, layer 2 corresponds to the lowest ash layer, layers 3, 4, and 5 appear to be paleosol, and layer 6 may be another ash deposit.

Figure 4. Graph of percent CaO versus height at site 4.

Figure 5. Graph of percent K_2O versus height at site 4.

Figure 6. Graph of percent MgO versus height at site 5. Layer 1 corresponds to the lava flow underlying the paleosol/ash, layer 2 appears to be ash, and layer 3 appears to be paleosol.

Figure 7. Graph of percent CaO versus height at site 5.

Figure 8. Graph of percent K_2O versus height at site 5.

TABLES

Table 1: Site 2

	MgO (%)	CaO (%)	K_2O (%)
Layer 1	5.50	9.01	1.22
Layer 2	2.75	2.23	0.14

Table 2: Site 3

	MgO (%)	CaO (%)	K_2O (%)
Layer 1	4.56	8.54	1.02
Layer 2	2.26	2.55	1.19

TABLE CAPTIONS

Table 1. Percentages of MgO, CaO, and K2O at site 2. Layer 1 is the lava flow underlying the paleosol/ash layer. Layer 2 appears to be an ash layer.

Table 2. Percentages of MgO, CaO, and K2O at site 3. Layer 1 is the lava flow underlying the paleosol/ash layer. Layer 2 appears to be an ash layer.