Loess Phytoliths as indicators of climate change: A case study on Banks Peninsula, New Zealand

2 June 2014

Katherine B. Kuklewicz [1, 2], Samuel Hampton [1] and Josh Borella[1]

[1] University of Canterbury, Department of Geological Sciences, Christchurch, New Zealand

[2] Skidmore College, Saratoga Springs, NY, United States of America, Department of Geosciences

---

1. ABSTRACT

Phytolith analysis of loess deposits can provide insight into paleoecology, temperature oscillations and deposition of particles with respect to climate. The stratigraphic section used in this study was extracted adjacent to a palerockfall boulder, which helped constrain the loess and loess colluvium depositional timeframe. Phytoliths in Holocene Birdling Flat Loess deposits of the Rapaki catchment in Banks Peninsula indicates that the paleoenvironment fluctuated between a maritime cool temperate zone to the present warm interglacial climate. The phytolith record indicates that the Insitu Loess and Loess Colluvium 1a were deposited in a maritime cool temperate environment, Loess Colluvium 1b was deposited in a wet, humid and warm environment, Loess Colluvium 2a was deposited in a maritime cool temperate environment, and the Loess Colluvium 2b was most recently deposited in a wet, humid and warm environment. Nīkau palm (Rhopalostylis sapida) and akeake (Dodonaea viscosa) grew during warmer periods as demonstrated by Loess Colluvium 2b and 1b, while trees, namely thinbarked totara (P. hallii) with broadleaf (Griselinia littoralis) and cedar (Libocedrus bidwillii), and or varied sub-canopy shrub species grew during colder periods as demonstrated by the Loess Colluvium 2a, 1a and Insitu Loess.   This study indicates the Birdlings Flat Loess deposited during both warm-wet, and cool-dry climates, primarily by aeolian activity. This is in contrast to previous studies which proposed that the Birdlings Flat Loess deposited solely in the sub-humid climatic zone (native vegetation tussock). Grain size analysis reveals that small particles (diameters 15-100 µm) were deposited during maritime cool temperate environments when vegetation was sparse, whereas large particles (diameters 225-375) were deposited during wet, humid and warm periods when vegetation was dense, creating laminations which produce a bimodal distribution. Phytoliths have a high preservation potential in insitu loess and a low preservation potential in loess colluvium, due to additional transport and remobilization of the sediments.

2. INTRODUCTION

Loess deposits represent and record climatic changes but are unreliable in preserving pollen, a key measure for environmental and climatic variations within Quaternary sediments (Carter, 2000). However phytoliths are well preserved in loess, and can act as proxy paleoenvironmental and paleoclimatic indicators since the Last Glacial Maximum (LGM; 18,000 years B.P.).

Phytoliths can be transported by the wind for up to thousands of kilometres (Pokras & Mix 1985), but the majority of phytoliths are released directly to the soil, creating a highly localized, in situ assemblage, when a plant dies and decays (Piperno, 1988; Pearsall, 1989; Rapp & Mulholland, 1992). Phytoliths are resistant to decomposition in most sedimentary environments, are morphologically distinct, and can be identifiable to the species level (Carbone, 1977; Piperno, 1988; Carter, 2000).

There has been limited phytolith research in New Zealand. Raeside (1964, 1970) described phytoliths of South Island soils. Weatherhead (1988) created a morphological classification of phytoliths in particular New Zealand soils, suggesting that phytoliths relate to genetic classification of the soil. However, Weatherhead's (1988) study did not attempt to correlate the presence of phytoliths with vegetation, which was the focus of Wallace & Neall (1986), Sase et at., (1987), and Carter (2000) in the North Island. Kondo et al., (1994) identified a wide range of phytoliths from living New Zealand native grasses, trees, and soils. More recently, Shulmeister et al., (1999) used phytolith analysis in conjunction with pollen analysis to interpret the paleoenvironment on Banks Peninsula through three glaciation-interglaciation cycles.

Banks Peninsula's topography is mantled by loess deposits, ranging in depth from 30 cm to over 20 m, which provides a unique opportunity in deciphering how the vegetation and sediment deposition on Banks Peninsula responds to temperature fluctuations. The site of this study is adjacent to a paleorockfall boulder (RAP 15, Mackey and Quigley, In Review), in Rapaki, Lyttelton Harbour, Banks Peninsula. Cosmogenic helium exposure dating of the boulder has helped constrain the age of an Insitu Loess unit and the subsequent loess colluvium sections. By determining the paleoecology of Rapaki, this study will provide insight into how the environment ecologically responds to temperature oscillations, which will be important information for future climate changes.

3. SITE LOCATION AND GEOLOGIC SETTING

Banks Peninsula is the remnants of a Miocene volcanic complex (Hampton, 2010), with the most prominent features being the long erosive harbours of Lyttleton and Akaroa (Hampton et al., 2012). The volcanic complex is connected with the mainland of the South Island by the prograding alluvial gravels of the Canterbury Plains (Forsythe et al., 2009). The two main Quaternary sediments present on Banks Peninsula are loess and remobilised loess as valley fill (Griffiths, 1973). The deposition of loess occurred during extensive glaciations when north-westerly winds transported sediment from the nearby floodplain and fan of the Waimakariri River (Griffithis, 1973).

The site location, Rapaki, sits on the northern side of Lyttleton Harbour. The site is mapped as rock and soil (basalt) (Figure 1) but is in close proximity to the Birdlings Flat Loess (Griffiths, 1973). The site was selected as it is in close proximity to a paleorockfall boulder, which has been recently dated at 13,000 years before present using cosmogenic helium exposure dating (Markey and Quigley, In Review) providing age constraints on the loess and loess colluvium sequence. A test pit was excavated behind this boulder, terminating at a horizon undisturbed from the rockfall boulder (Figure 2 and 3).

4. METHODS

The test pit excavated, on the upward slope of the boulder, lies on the east facing slope of Rapaki, approximately 540 meters from the harbour's shoreline. A stratigraphic log was recorded from the 2 meter deep stratigraphic section (Figure 3) and a total of 5 samples were collected from each unit. Five units were identified within the section, with key attributes recorded such as the presence of clasts, organics, and coarse lithics. Sediment colour was determined using the Munsell Colour Chart, and unit descriptions follow guidelines of Muschamp (2005). Grain size analysis utilised a Micrometrics Saturn DigiSizer II, High Definition Digital Particle Size Analyzer, with samples prepped through soaking in 50g/L Sodium "Hexametaphosphate"/Sodium Polymetaphosphate, to disperse particle clumps.

The phytoliths extraction follows the method of Carter (2000). In brief, for each sample, organic material was removed by heating the sample in 25% H_20_2 for 72 hours. H_2O_2 was then washed off by the addition of 40 mL distilled water, and then centrifuged three times at 2,500 rpm for 10 minutes. The residue was wet-sieved at 250 µm and the coarser material discarded. Samples were then heated in an oven at 40°C for 24 hours to decrease the amount of water. Phytoliths were isolated by adding heavy liquid lithium heteropolytungstate (LST; specific gravity of 2.13 g/mL) to rinsed samples, mixed to suspend particles, and then centrifuged for 10 minutes at 2,000 rpm. Phytoliths were extracted from the top of the samples with a Pasteur pipette, transferred to a clean tube, and mounted with Naphrax on glass slides for microscopic examination. Phytolith classification followed the method developed by Carter (2007), and Banks Peninsula flora was identified using Wilson (2012). Each slide was examined in a grid-like manner, and phytolith assemblages were tallied. Approximately 100 phytolith forms were counted per sample, and the numbers were converted to percentages.

5. RESULTS

Six units were identified and described within the Rapaki stratigraphic section (Figure 2, Table 1), with key layers identified as Insitu Loess, Loess Colluvium 1a, Loess Colluvium 1b, Loess Colluvium 2a, and Loess Colluvium 2b. The insitu loess was distinguished from the loess colluvium sediments because it was planar with the paleoboulder, and textually had no volcanic clasts. Phytoliths were recovered from the insitu loess and the four loess colluvium units (Figure 4, Table 1), key phytolith types found originated from either grass, tree/shrub, and palm origins. The Types of phytoliths encountered and their abundance in each unit is presented in Table 1.

Grain size analysis reveals that the loess and loess colluvium samples have a bimodal grain-size distribution (Figure 5). The main component has a large particle grain size (diameters 225-375 µm) which composes about 3.5-6.2% of the loess and loess colluvium samples. The secondary component has a small particle grain size (diameters 15-100 µm) which composes about 1.8-2.5% of the loess and the loess colluvium samples.

6. DISCUSSION

6.1 Rapaki Loess Classified as Birdlings Flat Loess

Griffith (1973) did not sample nor describe the loess in the Rapaki region, he interpreted the site location to be Rock and Soil (basalt) adjacent to a deposit of Birdlings Flat Loess (Figure 1). The loess and loess colluvium found in Rapaki has a very fine clay silt texture which loosely corresponds to Griffith's (1973) description of Birdlings Flat Loess as "a sandy loam texture to loamy fine sand texture." Also supportive of the Birdlings Flat Loess classification is the presence of gammate structures with grey fissure zones, carbonaceous particles of hard white plant material, and some cracking with infilled white precipitate (Griffiths, 1973). This study confirms the existence of Birdlings Flat Loess in Rapaki, and infers the boundary of loess units to be further upslope than was previous identified.

6.2 Paleoenvironment Reconstruction Using Phytolith Analysis

Paleoenvironments are discussed for each layer based on the abundance of phytoliths present and in the context of stratigraphy, correlated units and dates. An assumption is made that the phytoliths extracted are considered to represent the vegetation growing at the time that the loess was deposited, and limited by the assumption that no distal phytoliths are encountered. Though some of the phytolith assemblages were corroded beyond recognition, the majority of phytolith forms were well preserved and distinctly identifiable using schematic drawings and Scanning Electron Microscope photos from Cater (2007). The phytoliths extracted from the Insitu Loess were predominantly well preserved, with the majority of phytolith morphologies intact. Phytoliths extracted from the loess colluvium samples (Loess Colluvium 1a, 1b, 2a, 2b), were commonly more fragmented (angular) and more degraded. This variation between insitu loess and loess colluvium is suggested to be the result of formational processes with the poorly preserved phytoliths in the loess-colluviums being a result of remobilisation in slope wash. Due to the extensive depth of the loess and the infrequent sampling, this study did not record the recent botanic change induced by humans.

The Loess Colluvium 2b (50 cm) is dominated by globular echinate phytoliths, indicating the vegetation was primarily palm in origin. The abundance of both graminoid phytoliths and phytoliths from trees/shrubs are quite low. The most abundant species were probably nīkau palm (Rhopalostylis sapida) and akeake (Dodonaea viscosa). Due to the abundance of phytoliths assemblages, the paleoclimate is hypothesized to have been wet, humid and warm.

The Loess Colluvium 2a (30 cm) is dominated by globular granular phytoliths, indicating the vegetation was primarily tree/shrub in origin. In this unit the graminoid phytoliths increased while phytoliths from palm origins decreased. The most abundant species were probably thinbarked totara (P. hallii) with broadleaf (Griselinia littoralis) and cedar (Libocedrus bidwillii). Due to the abundance of phytoliths assemblages, the paleoclimate is hypothesized to be a maritime cool temperate environment.

The Loess Colluvium 1b (30 cm) is dominated by globular echinate phytoliths, indicating the vegetation was primarily palm in origin. The abundance of graminoid phytoliths decreased slightly, and the abundance of tree/shrub phytoliths decreased significantly. Due to the abundance of phytoliths assemblages, the paleoclimate is hypothesized to have been wet, humid and warm.

The Loess Colluvium 1a (40 cm) is dominated by graminoid phytoliths, indicating the vegetation was primarily grassland in origin. However, there is a significant palm component (33%). This is in agreement with Carter (2000), who suggests that coastal Southland was covered in grassland prior to 12,000 years (Carter, 2002). Due to the abundance of phytoliths assemblages, the paleoclimate is hypothesized to be a maritime cool temperate environment. The abundance of palm phytoliths are characteristic of a steep rainfall gradient from dry headlands to humid valley heads, related chiefly to increasing altitude (Wilson, 2013).

The Insitu Loess (20 cm) is dominated by globular granular phytoliths, indicating the vegetation was primarily tree/shrub in origin. Due to the abundance of phytoliths assemblages, the paleoclimate is hypothesized to be a maritime cool temperate environment. The presence of some palm phytoliths (up to 28%) indicates warmer micro-climates near the sea.

The phytoliths from Rapaki records changes in vegetation patterns caused by climatic fluctuations over the last 13,000 years in eastern South Island, New Zealand (Table 1). The overall general vegetation patterns indicate that nīkau palm (Rhopalostylis sapida) and akeake (Dodonaea viscosa) were growing during warmer periods as demonstrated by Loess Colluvium 2b and 1b, while trees, namely thinbarked totara (P. hallii) with broadleaf (Griselinia littoralis) and cedar (Libocedrus bidwillii), and or varied sub-canopy shrub species grew during colder periods as demonstrated by Loess Colluvium 2a, 1a and insitu loess. The growth of grasses, such as *microlaena stipoides*, remained relatively stable throughout climatic fluctuations, apart from their drop in abundance in the youngest sample. During the present interglacial, Rapaki was occupied by plants with a palm origin, until recent Maori and European settlement. Currently, Rapaki and most of Banks Peninsula are covered in open grassland, making the bioclimate zones less discernible. The response of past vegetation and ecosystems to climate change can help extrapolate their behaviour to future climatic conditions.

6.3 Grain Size Analysis Discussion

Grain size analysis of loess sediments indicates that deposition of small (diameters 15-100 µm) and large particles (diameters 225-375 µm) correlates with the climate conditions (warm or cool). The grain size analysis of loess also demonstrated that the Insitu Loess has a high phytolith preservation potential while Loess Colluvium 2b, 2a, 1b, 1a has low phytolith preservation potential, due to additional transport and remobilization of the sediments. In addition, grain size analysis reveals that the loess and loess colluvium contains laminations which produce a bimodal distribution.

Climate and Grain Size:

There is a distinct relationship between the climate and the particle diameter being deposited (Table 2). Loess Colluvium 2b and 1b were deposited during wet, humid and warm periods, and shared similar particle diameter curves. Of all the sediments, they have the highest volume of particles ranging from 225-375 µm in diameter and lowest volume of particles ranging from 15-100 µm in diameter, indicating that during wet, humid and warm periods, large particles are deposited. Due to the warm climate, vegetation densely covered the loess source region (floodplain of the Waimakariri River), thus holding small particles in place (diameters 15-100 µm) and allowing large particles (diameters 225-375 µm) to be remobilized by aeolian winds. The Insitu Loess, Loess Colluvium 2a and 1a were deposited during cold, dry periods, and have the highest volume of particles ranging from 15-100 µm in diameter and the lowest volume of particles ranging from 225-375 µm in diameter. Due to the cold climate, vegetation sparsely covered the loess source region (floodplain of the Waimakariri River), thus allowing smaller particles (diameters 15-100 µm) to be remobilized by aeolian winds. These results imply that during cold dry periods larger particles ranging from 15-100 µm in diameter are deposited and during wet, humid and warm periods smaller particles ranging from 225-375 µm in diameter are deposited. Griffith's (1973) study proposed that the Birdlings Flat Loess deposited solely in the sub-humid climatic zone (native vegetation tussock). However, this study indicates the Birdlings Flat Loess was deposited during both warm-wet and cool-dry climates.

Phytolith Preservation Potential

The Insitu Loess contains the highest volume of particles ranging from 15-100 µm in diameter and the lowest volume of particles ranging from 225-375 µm in diameter, indicating that smaller grains are well preserved insitu. Since the insitu sediment did not undergo as much transport and remobilization as the loess colluvium sediments, the preservation potential of phytoliths was high. The Loess Colluvium samples contains the highest volume of particles ranging from 225-375 µm in diameter and the lowest volume of particles ranging from 15-100 µm in diameter, indicating that smaller particles are not well preserved. Since these sediments experienced the most transportation and remobilization compared to the insitu loess, the preservation potential of phytoliths was low.

Bimodal Distribution:

Not only does grain size analysis reveal a correlation between particle size deposition and the climate, it also demonstrates the different preservation potential within the Insitu Loess and the Loess Colluvium samples. The incremental volume percent grain size analysis of samples from Rapaki reveals that loess generally shows a bimodal grain-size distribution (Figure 5). The Insitu Loess sediment contains the highest volume of small particles (diameters 15-100 µm) and the lowest volume of large particles (diameters 225-375 µm). The Loess Colluvium samples contain the lowest volume of small particles (diameters 15-100) and the highest volume of large particles (diameters 225-375 µm). This reveals that sediments have a higher preservation potential in Insitu Loess and a lower preservation potential in Loess Colluvium, due to the remobilization. These findings correlate with the preservation of phytoltihs. Phytoliths were well preserved in the Insitu Loess and poorly preserved in the Loess Colluvium.

The bimodal distribution also indicates that the loess contains small-scale stratification like paleosols due to climate induced vegetation abundance. The loess may be laminated with alternating sheets of fine particles and courser particles, thus forming two distinct curves on the grain size analysis graph. Scott (1979) proposes that the loess on Banks Peninsula contains laminations from either a single episode of aeolian activity, such as a north-westerly gate, or they may reflect one season of gales. This hypothesis correlates with the assumption that certain grain sizes are deposited during different climates. The laminations containing large particles (diameters 225-375 µm) are deposited during wet, humid and warm periods due to the abundance of vegetation holding the small particles insitu, thus preventing aeolian remobilization of the smaller particles. The laminations containing small particles (diameters 15-100 µm) are deposited during cold and dry periods due to the scarcity of vegetation which allows aeolian remobilization.

7. CONCLUSION

Phytoliths in the loess and loess colluvium deposits of Rapaki record the paleoecology and how the past vegetation and deposition of particles responded to climate oscillations during the last 13,000 years. Climate induced vegetation patterns indicate that nīkau palm (*Rhopalostylis sapida*) and akeake (*Dodonaea viscosa*) were growing during warmer periods as demonstrated by Loess Colluvium 2b and 1b, while trees, namely thinbarked totara (P. hallii) with broadleaf (Griselinia littoralis) and cedar (Libocedrus bidwillii), and or varied sub-canopy shrub species grew during colder periods as demonstrated by Loess Colluvium 2a, 1a and the insitu loess. The growth of grasses, such as *microlaena stipoides*, remained relatively stable throughout climatic fluctuations. The phytolith assemblages indicate that the paleoenvironment from approximately 13,000 years ago, fluctuated from a maritme cool temperate zone to the present warm interglacial climate. During the present interglacial, Rapaki was occupied by plants with a palm origin, until recent Maori and European settlement.

Loessic sediments of this study are classified as Birdlings Flat Loess. The loess and loess colluvium sediments were deposited during wet, humid and warm periods as well as cold and dry periods, with bimodal grainsize distributions, indicating sources from aeolian activity. In addition, grain size analysis indicates that the highest volume of large particles (diameters 225-375 µm) were deposited when it was wet, humid and warm, due to dense vegetation coverage of the loess source region (floodplains of the Waimakariri River) which held small particles insitu. The highest volume of small particles (diameters 15-100 µm) were deposited when it was cold and dry, due to scarcity of vegetation which allowed aeolian remobilization. This research, utilising phytoliths extracted from the Birdlings Flat Loess, was successful in determining the post (LGM) paleoclimate, and highlights the opportunity of further studies on loess phytolithic records of Banks Peninsula. Phytolithic research, such as this study, furthers our understanding of botanical and sedimentary responses to climate change, which will be important information for future climate changes.

ACKNOWLEDGEMENTS

I would like to thank Dr. Brendan Duffy for his helpful comments and reviews on this paper. I am grateful to Chris Grimshaw for the laboratory instruction and procedure guidance in extracting the phytoliths.

REFERENCES

Carbone, V. A., 1977. Phytoliths as paleoecological indicators. Annals of the New York Academy of Science, Vol. 288, 194-205.

Carter, J. A., 2000. Phytoliths from loess in Southland, New Zealand. New Zealand Journal of Botany, Vol. 38, 325-332.

Carter, J. A., 2002. Phytolith analysis and paleoenvironmental reconstruction from Lake Poukawa Cove, Hawkes Bay, New Zealand. Global and Planetary Change, Vol. 33, 257-267.

Carter, J. A., 2007. Phytoliths. In S.A. Elias (ED, in chief), Encyclopaedia of Quaternary Science. Amsterdam, The Netherlands: Elsevier B.V.

Griffiths, E., 1973. Loess of Banks Peninsula. N.Z. J. Geol. Geophys, Vol. 16, 657-676.

Hampton, S., 2010. The volcanic history of Lyttleton Volcano. PhD thesis, University of Canterbury.

Hampton, S.J., Cole, J.W., Bell, D.H., 2012. Syn-eruptive alluvial and fluvial volcanogenic systems within an eroding Miocene volcanic complex, Lyttelton Volcano, Bank Peninsula, New Zealand. New Zealand Journal of Geology and Geophysics, Vol. 55, No. 1, 53-66.

Mackey, B.H., Quigley, M.C., in review. Extreme earthquake shaking recorded by prehistoric rockfalls, Christchurch, New Zealand. Journal of Geology.

Muschamp, K., 2005. Field description of soil and rock: guidline for the field classification and description of soil and rock for engineering purposes. NZ Geotechnical Society Inc.

Pearsall, D. M., 1989. Paleoethnobotany: A handbook of procedures San Diego, Academic Press.

Petrie, L., 1963. From bush to cocksfoot: an essay on the destruction of Banks Peninsula's forests. Unpublished MSc thesis, University of Canterbury. Christchurch, New Zealand.

Piperno, D. R., 1988. Phytolith analysis, an archaeological and geological perspective. San Diego, Academic Press.

Pokras, E. M., Mix, A. C., 1985. Eolian evidence for special variability of Late Quaternary climates in Tropical Africa. Quaternary Research, Vol. 24, 137-149.

Raeside, J.D., 1964. Loess deposits of the South Island, New Zealand, and soils formed on them. N.Z. J. Geol. Geophys., Vol. 30, 41-64.

Raeside, J.D., 1970. Some New Zealand plant opals. New Zealand Journal of Science, Vol. 13, 122-132.

Rapp, G. Jr., Mulholland, S. C., 1992. Phytolith systematics, emerging issues. New York, Plenum Press.

Scott, G.L., Lewis, D.W., 1979. Structure in loess revealed by X-ray radiography, Banks Peninsula, New Zealand. New Zealand Journal of Geology and Geophysics, Vol. 22, 755-757.

Shulmeister, J., Soons, J., Berger, G., Harper, M., Holt, S., Moar, N., Carter, J., 1999. Environmental and sea-level changes on banks Peninsula (Canterbury, New Zealand) through three glacial-interglacial cycles. Palaeogeography, Palaeoclimatology, Palaeoecology 152, 101-127.

Soons, J. M., Moar, N. T., Shulmeister, J., Wilson, H. D., Carter, J. A., 2002. Quaternary vegetation and climate changes on Banks Peninsula, South Island, New Zealand. Global Planetary Change, Vol. 33, 301-314.

Weatherhead, C.N.J., Switsur, V.R., Ward, A.P., 1988. A new 14C age for the Oruanui (Wairaki) eruption, New Zealand. Geological Magazine, Vol. 125, 297-300.

Wilson, H., 2013. Natural History of Banks Peninsula. Canterbury University Press, Revised Edition.

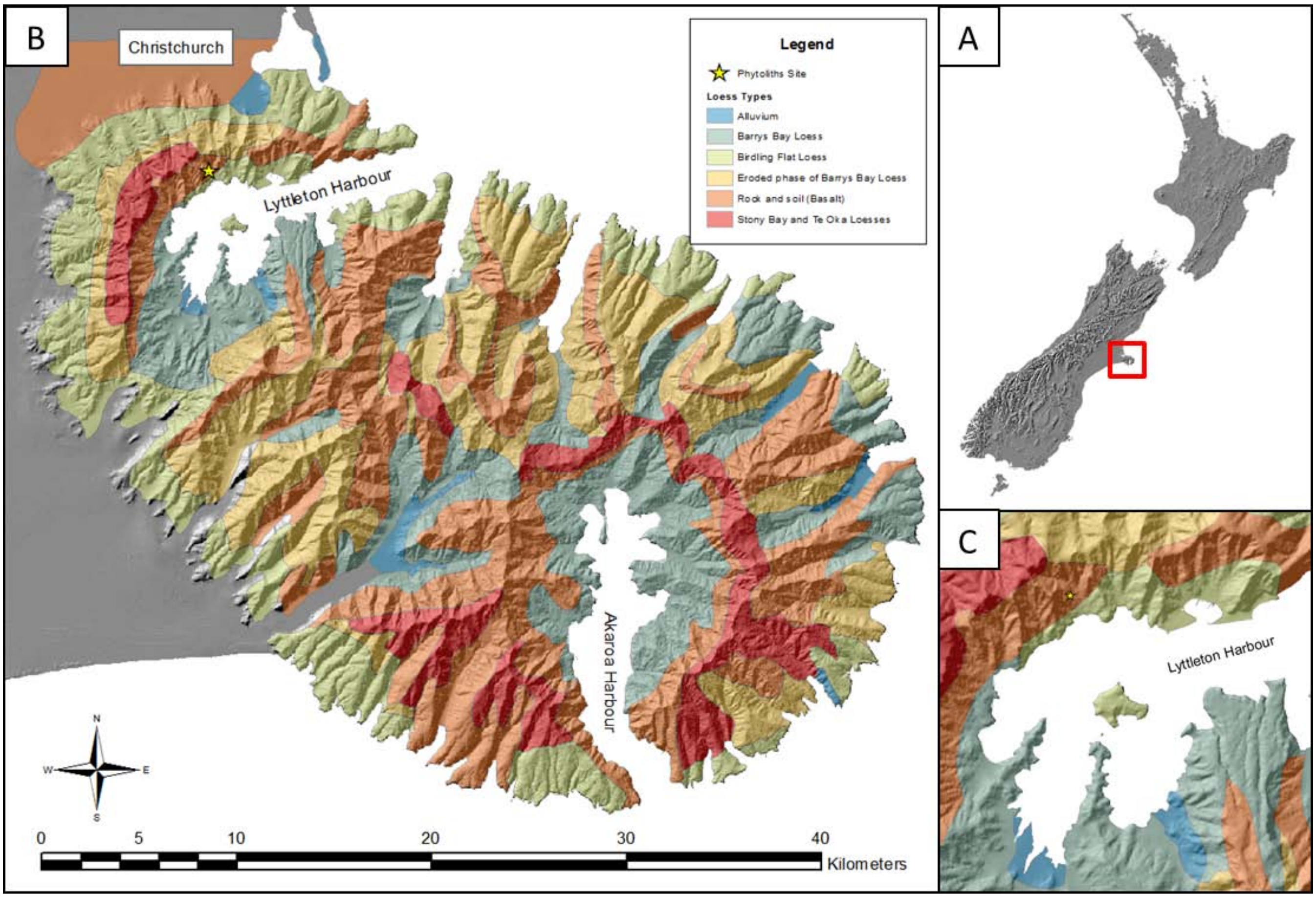

Figure 1. (A) An aerial view of New Zealand, indicating the geographic location of Banks Peninsula. (B) An aerial view of Banks Peninsula displaying the different distribution of loess types, mapped by Harris (1983). (C) A closer aerial view of Lyttleton Harbour displaying the location of the research site.

Figure 2. Image of loess stratigraphic column adjacent to paleorockfall boulder (on right).

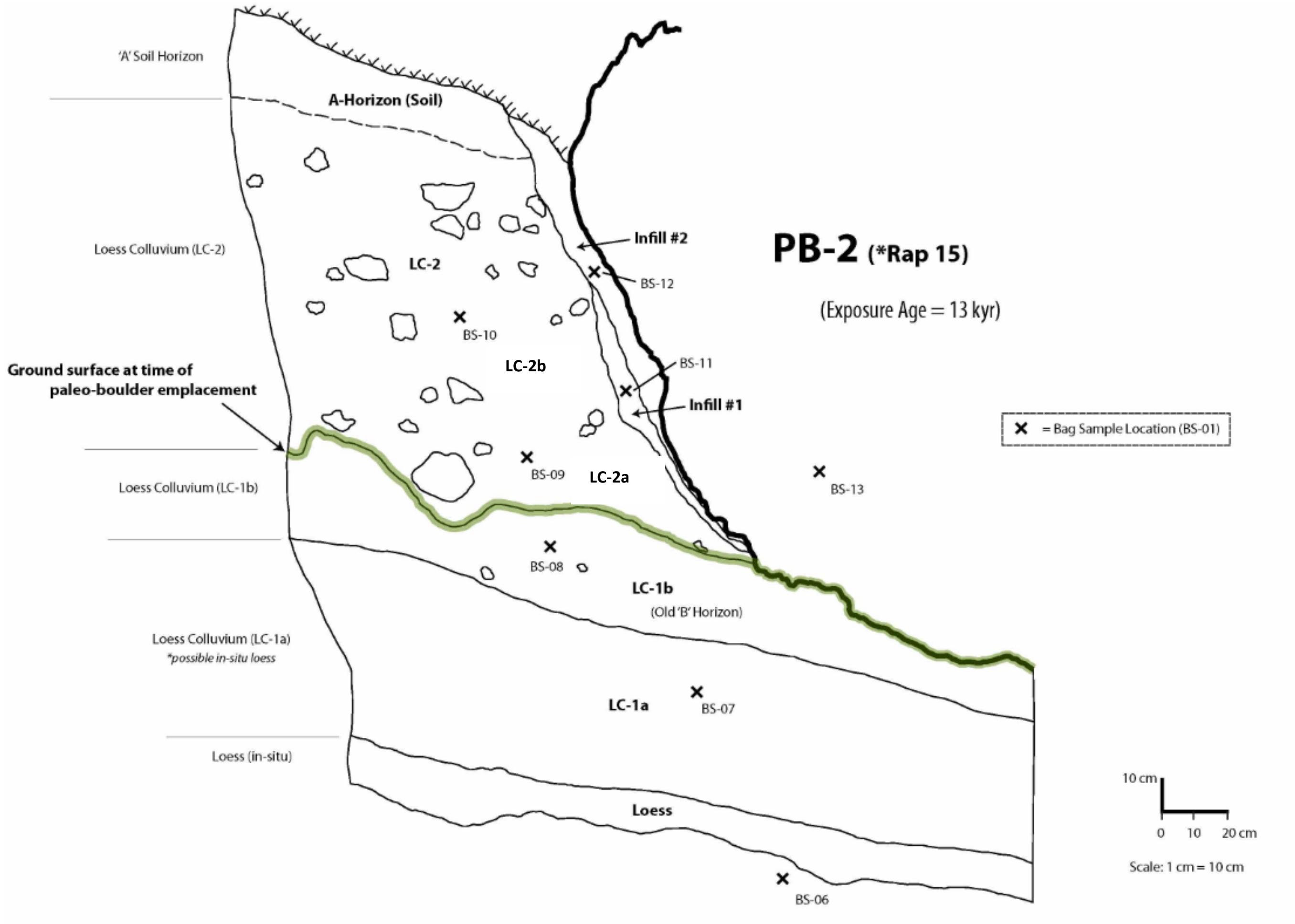

Figure 3. Trench log indicating where the phytolith sediment samples were retrieved adjacent to paleorockfall boulder, PB-2 (Rap 15).

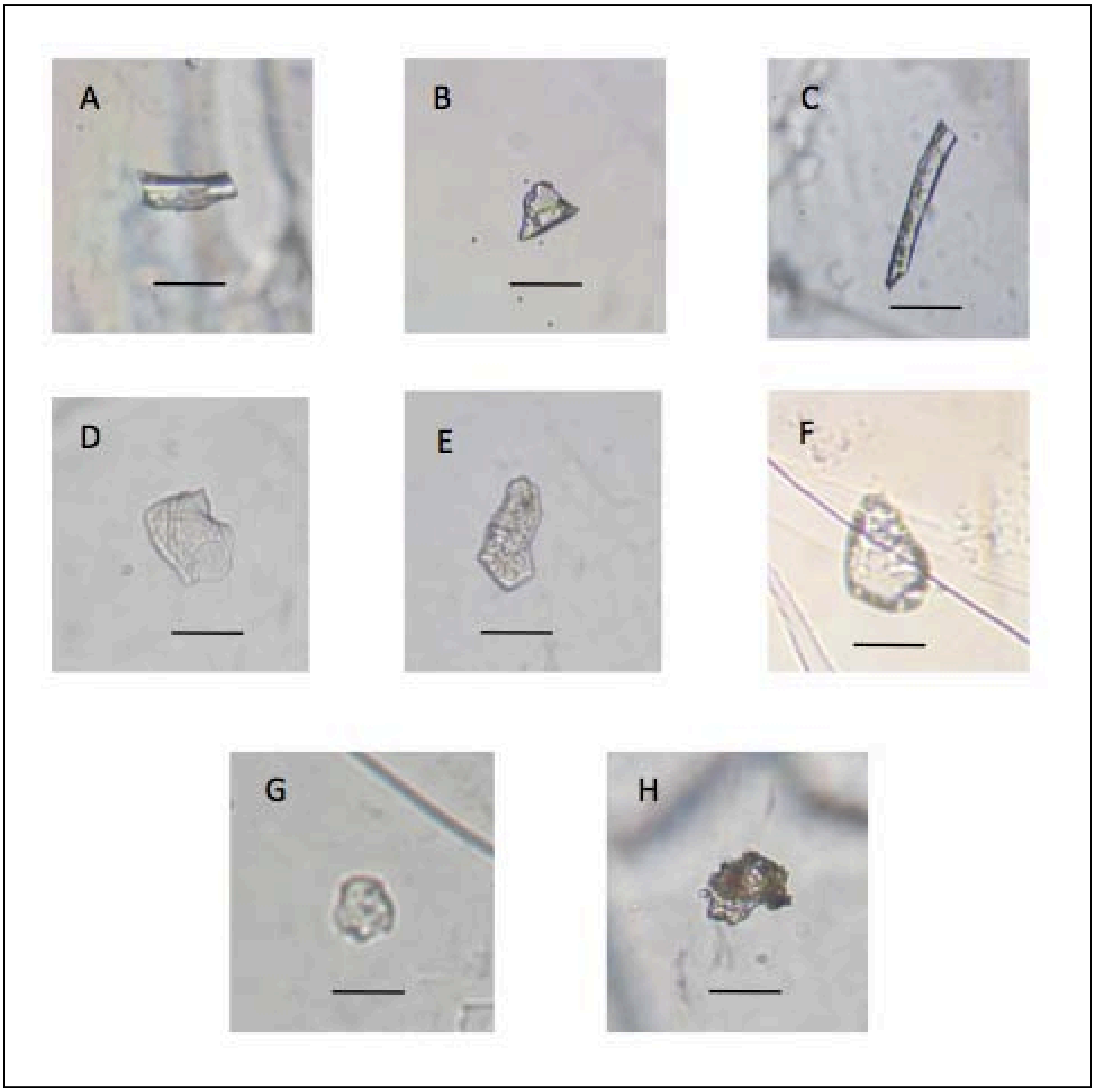

Figure 4. Examples of major phytolith morphologies extracted from Rapaki stratigraphic column. (A) Trapeziform polylobate: bone shaped (grass origin). (B) Conical short cell: spool shaped (grass origin). (C) Elongate long cell: rectangular shaped (grass origin). (D) Saddle short cell: circular with cut out (grass origin). (E) Cinuform bulliform cell: fan shaped (grass origin). (F) Polyhedral: hexagon shaped (tree/shrub origin). (G) Globular granular: spherical with surface ornamentation (tree/shrub origin). (J) Globular echinate: spherical with spiky ornamentation (New Zealand native nīkau palm *Rhopalysis sapida*). Scale bar is 10 µm.

Unit	Description	Grain Size (µm)	Phytolith percentages (%)	Phytolith Interpretation	Environment/Events
Soil (20 cm)	Silty sand with low percent of clay, gray to dark grey, homogeneous. Loosely packed, low density, soft, dry, no apparent grading, high plasticity, small rootlets, small worm borrows are observed throughout the layer. The soil contours the slope and has a thickness ranging from 15 to 26 cm.	N/A	N/A	N/A	Human occupation altered the native vegetation. Vegetation is primarily grass due to agricultural practices.
Loess Colluvium 2b (50 cm)	Clay to silt, grayish brown (fresh) and mottled sections are yellowish brown to brownish yellow, highly mottled silt, homogeneous. Loosely packed, low density, soft, moist, no apparent grading, high plasticity, abundant pebble to cobble-sized clasts of volcanic rock, volcanic clasts range from angular to subrounded, small rootlets less than 0.5 mm in diameter. Poor stratification and alignment of clasts is apparent. The loess colluvium has a thickness of 60 cm.	0-375	Trapeziform polylobate: 4 Conical short cell: 0 Elongate long cell: 16 Saddle short cell: 1 Cuniform bulliform cell: 1 Polyhedral: 7 Globular granular: 3 Globular echinate: 68	The assemblage of phytoliths are **dominated by globular echinate phytoliths, indicating a palm origin.** Phytoliths produced by grasses were the next most abundant while phytoliths from a tree/shrub origin were the least dominant.	**Wet, humid, and warm environment** due to the abundance of palm phytoliths.
Loess Colluvium 2a (30 cm)	Clay to silt, light yellowish brown (fresh) to pale brown (dry), mottling, homogeneous. Loosely packed, low density, soft, moist, no apparent grading, high plasticity, occasional volcanic clasts. Based upon the abundance of clasts within the colluvium and chaotic mixture of the unit, interpret LC-2a and LC-2b as a possible debris flow or landslide. The size of the contained clasts would indicate high velocity deposition. It is likely during periods of heavy rainfall, that material higher up the mountain would have been dislodged and then entrained within a silt and clay matrix. The loess colluvium has a thickness ranging from 30 to 35 cm.	0-375	Trapeziform polylobate: 1 Conical short cell: 1 Elongate long cell: 22 Saddle short cell: 0 Cuniform bulliform cell: 10 Polyhedral: 9 Globular granular: 31 Globular echinate: 27	The assemblage of phytoliths are **dominated by globular granular phytoliths, indicating a tree/shrub origin.** Phytoliths produced by grasses were the next most abundant while phytoliths from a palm origin were the least dominant.	**Maritime cool temperate environment,** due to the abundance of tree/shrub phytoliths.
Potential Boulder Emplacement 13,000 years					
Loess Colluvium 1b (30 cm)	Clay to silt, light yellowish brown (fresh) to pale brown (dry), mottling, homogeneous. Tightly packed, very stiff, very dense, dry, no apparent grading, high plasticity, occasional volcanic clasts. The contact with the overlying LC-2 is not visually sharp, but apparent due to the differences in density. The loess colluvium has a thickness ranging from 10 to 30 cm.	0-355	Trapeziform polylobate: 12 Conical short cell: 0 Elongate long cell: 22 Saddle short cell: 2 Cuniform bulliform cell: 1 Polyhedral: 10	The assemblage of phytoliths are **dominated by globular echinate phytoliths, indicating a palm origin.** Phytoliths produced by grasses were the next most abundant while phytoliths	**Wet, humid, and warm environment** due to the abundance of palm phytoliths.

			Globular granular: 11 Globular echinate: 41	from a tree/shrub origin were the least dominant.	
Loess Colluvium 1a (40 cm)	Clay to silt, light olive brown (fresh) to light yellowish brown (dry), no mottling, homogeneous. Tightly packed, very stiff, very dense, dry, no apparent grading, high plasticity, contains some cracking with infilled white precipitate, occasional pebble to large cobble-sized clasts of local volcanic rocks. The contact with underlying loess contains nearly completely dissolved clasts of volcanic rock. The loess colluvium has a thickness ranging from 45 to 40 cm.	0-355	Trapeziform polylobate: 20 Conical short cell: 1 Elongate long cell: 18 Saddle short cell: 0 Cuniform bulliform cell: 4 Polyhedral: 8 Globular granular: 16 Globular echinate: 33	The assemblage of phytoliths are **dominated by Trapeziform polylobate phytoliths, indicating a grass origin**. Phytoliths produced by palms were the next most abundant while phytoliths from a tree/shrub origin were the least dominant.	**Maritime cool temperate environment,** due to the abundance of grass phytoliths. The abundance of palm phytoliths are characteristic of a steep rainfall gradient from dry headlands to humid valley heads, related chiefly to increasing altitude.
Insitu Loess (20 cm)	Fine sand to clay, light yellowish brown (fresh) to yellowish brown to olive yellow (dry), no mottling, gammate structures with grey fissure zones, homogeneous. Tightly packed, very stiff, very dense, dry, no apparent grading, high plasticity, carbonaceous particles of hard white plant material, significantly dissolved clasts of volcanic rock. The insitu loess has a thickness ranging from 8 to 15 cm.	0-375	Trapeziform polylobate: 6 Conical short cell: 2 Elongate long cell: 13 Saddle short cell: 1 Cuniform bulliform cell: 9 Polyhedral: 5 Globular granular: 35 Globular echinate: 28	The assemblage of phytoliths are **dominated by Globular granular phytoliths, indicating a tree/shrub origin.** Phytoliths produced by grass were the next most abundant while phytoliths from a palm origin were the least dominant.	**Maritime cool temperate environment**, due to the abundance of tree/shrub phytoliths. The presence of some palm phytoliths (up to 28%) indicates warmer micro-climates near the sea.

Table 1. Unit descriptions, grain sizes, percent frequency of phytolith forms, phytolith interpretations, and proposed paleoenvironments for each loess and loess colluvium sample.

Unit	Peak 1		Peak 2		Climate
	Volume (%)	Grain Size (μm)	Volume (%)	Grain Size (μm)	
Loess Colluvium 2b (50 cm)	1.84	53.10	**6.22**	**316.27**	Wet, humid and warm period
Loess Colluvium ab (30 cm)	**2.18**	**50.13**	5.04	316.27	Cool, dry period
Loess Colluvium 1b (30 cm)	1.73	50.13	**5.83**	**298.58**	Wet, humid and warm period
Loess Colluvium 1a (40 cm)	**2.04**	**31.63**	5.59	298.58	Cool, dry period
Insitu Loess (20 cm)	**2.54**	**44.67**	3.53	316.27	Cool, dry period

Table 2. Grain size analysis of loess and loess colluvium samples demonstrates a bimodal distribution with two peaks, indicating the most abundant particle size (μm).

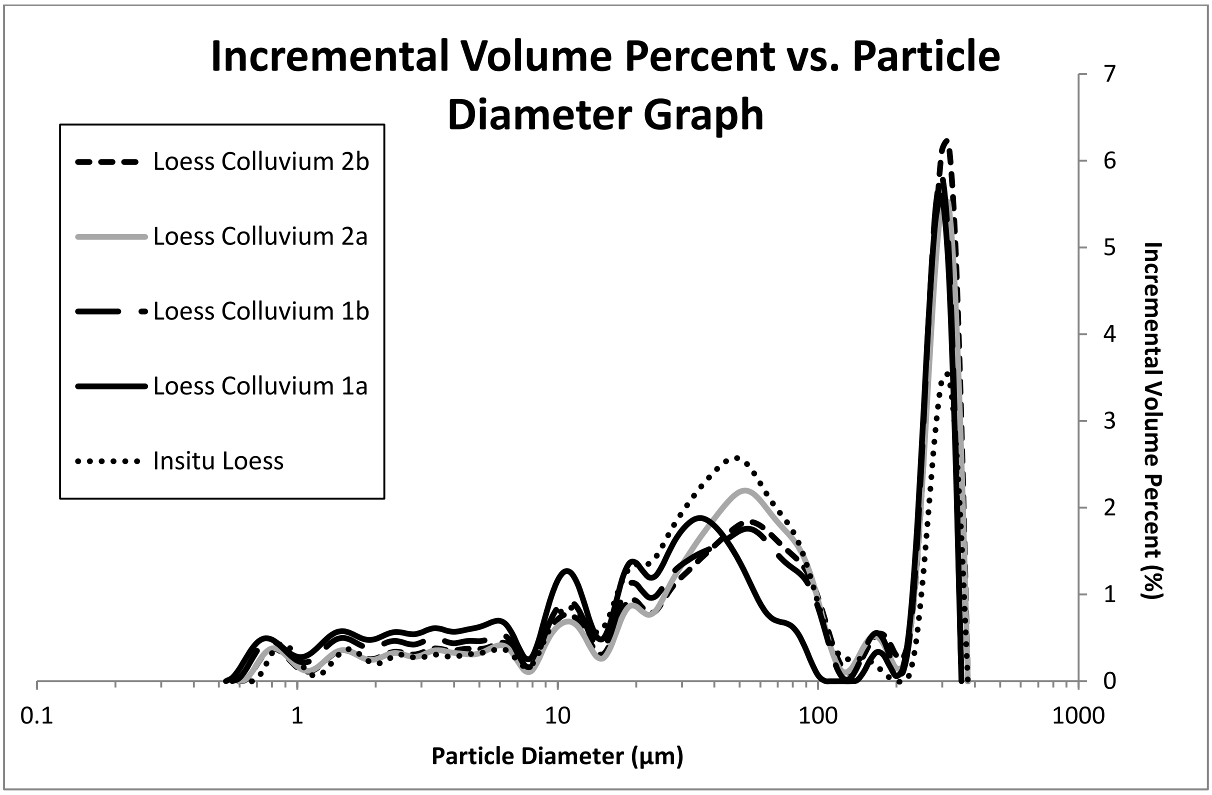

Figure 5. A graph depicting the incremental volume percent verse the particle diameter. Data obtained from a Micrometrics Saturn DigiSizer II, High Definition Digital Particle Size Analyzer.