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Weathered distal ignimbrite forming problematic soil terraces in the North Waikato, New Zealand

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ABSTRACT

Allophanic soils in the North Waikato region, North Island, New Zealand, will control aspects of design cut slopes and construction of a 7km realignment of State Highway 2 and a proposed switching station platform. Several subsurface investigation methods have been used to provide information on density and shear strength of the soils for cut slope design. Recommendations are made for excavating these soils during construction.

The soils have been identified as largely comprising the Potaka tephra and its' associated ignimbrite overlain by more recent weathered tephra beds. Until now these deposits have been mapped as pumiceous alluvium and pumiceous terrace deposits that form elevated terraces through the North Waikato lowlands. The identification of the ignimbrite at this locality is not only geologically interesting, it has implications for earthworks and engineering projects within the North Waikato region of New Zealand.

INTRODUCTION

Two separate projects undertaken on either side of the North Waikato lowlands are being constructed on similar soil profiles. The rolling hills of the North Waikato are mapped as comprising pumiceous terrace deposits with alluvial soils found in low-lying areas (Edbrooke, 2001). The projects both involve significant earthworks and cuttings, the design of which is controlled by the properties of the sensitive allophanic soils in the area. Soil sensitivity is a measure of the loss of strength that occurs when the soil is disturbed or remoulded. Sensitivity is defined as the ratio of the undisturbed strength to the remoulded strength (NZGS, 2005).

This paper discusses the identification of the ignimbrite forming the terraces and the implications of the soil properties for the earthworks and cut slope design. Different subsurface investigation methods have been used at each of the sites to assist in the determination of appropriate soil parameters. Some of the investigation results are affected by the allophanic and sensitive nature of these deposits. An engineering interpretation of these results is discussed to show that representative soil parameters can be obtained.

NORTH WAIKATO PROJECTS

The two projects are located in similar undulating topography. The final designs require large cuts (up to 13m depth) within the pumiceous terraces and embankments (up to 11m depth) over the low-lying alluvial areas. Flow type failures are observed to occur at both sites and are a major indicator of the presence of sensitive soils in the area.

The projects comprise:

- A 4-lane 7km long road realignment of State Highway 2 at Mangatawhiri, some 65 km south of Auckland; and
- A switching station platform for transmission line infrastructure that is 120 m x 130 m in area, near Ohinewai, 98 km south of Auckland.

GEOLOGY

The geology of the two sites has been assessed from subsurface investigations in conjunction with relevant geological maps. The sites are mapped as comprising pumiceous terrace deposits of the Walton Sub-group of the Tauranga Group (early Quaternary) (Edbrooke, 2001). However, site investigations revealed the following profile:

- Completely to highly weathered pumiceous tephra beds interbedded with paleosols and reworked units (Coverbeds); over
- Completely to slightly weathered distal ignimbrite (Potaka tephra), and its alluvially reworked equivalent; over
- Early Quaternary interbedded tephra deposits and paleosols (not discussed in this paper).

Coverbeds

The upper layers of the Pumiceous Terrace Deposits comprise a very stiff orange brown silt-clay crust extending up to 5m maximum thickness. They include paleosols (historical soils), interbedded with highly weathered tephra beds (thin ash fall horizons) and thin reworked tephra layers (loess and alluvial). This horizon was identified as comprising the Hamilton Ash Formation (100,000 - 340,000 yrs) overlain by younger rhyolitic ash fall and re-deposited horizons, and capped by a thin veneer of basaltic lapilli in Mangatawhiri. The Hamilton Ash Formation is known to comprise 60-85% halloysite clay (Shepherd, 1994) with small amounts of allophane and other clays.

Potaka tephra

Underlying the Covered sequence, lies a pumiceous tephra that has been identified as a residually weathered profile of the non welded rhyolitic ignimbrite, the Potaka tephra, dated at 0.99 Ma (Shane, 2006) and associated ash fall horizons, thought to have originated from the Mangakino volcano (Wilson et al, 1995). This tephra is the most widely spread ignimbrite presently known, and has been found as far east as Gisborne (Coleman, 2001), and as far north as Waiuku (Wilson et al, 1995). It forms a prominent marker bed within Quaternary landscapes across the central North Island.

In North Waikato, the profile of the residually weathered Potaka tephra comprises the following three distinctive layers:

- a) *Completely Weathered Horizon* - Stiff orange-brown mottled red, black and white silt-clay. The volcanic glass within this layer had largely weathered to clay.
- b) *Moderately to Highly Weathered Horizon* - Soft pink mottled red and grey sensitive clayey silt to very loose silty sand. Gold (hydrated) biotite crystals and volcanic glass grains were scattered throughout the core. This horizon has graded contacts and appears to be discontinuous across the profiles of the two sites, possibly as a result of environmental conditions post-deposition.
- c) *Slightly Weathered Horizon* - Medium dense to very dense light grey dilatant pumice sand with some silt, with a trace of biotite and hornblende crystals. Underlying the ignimbrite, were a series of thin interbedded coarse and fine pumice sand layers (ash fall layers) with fine, well rounded, accreted pumice gravels known as accretionary lapilli, fossilised 'raindrops', or sometimes referred to as chalazoidites, which reflect early stages of the volcanic eruption (Shane, 1994).

The Potaka tephra was tentatively identified during the site investigations based on the presence of the biotite crystals and the accretionary lapilli underlying the unit. This was later confirmed by microprobe analysis at the University of Auckland (Shane pers. comm. 2006). Its identification in the North Waikato indicates that the paleotopography was relatively flat across the North Island of that time, or that transport routes through the main axial ranges were prolific.

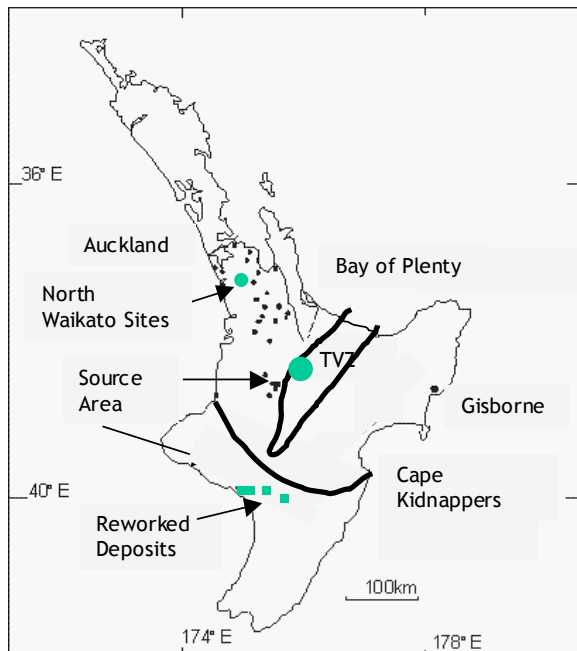


Figure 1: Map of the North Island (after Wilson et al. 1995) showing previous recorded localities of the ignimbrite associated with the Potaka tephra. Points south of the line are reworked deposits (Shane 1994).

SITE INVESTIGATIONS AND SOIL PROPERTIES

Geotechnical site investigations undertaken for the two North Waikato projects included a combination of cone penetration testing (CPT) and cored machine drilled boreholes. Standard Penetrations Tests (SPT's) and hand held shear vanes were undertaken within the retrieved core at regular intervals. The results of these investigations are provided in the following Table 1. The Coverbeds and completely weathered Potaka tephra unit, for the purposes of the investigation were considered as one layer known as the 'crust' as their engineering properties were similar. The highly to moderately weathered layer is referred to as the 'soft weathered tephra' and the slightly weathered layer is referred to as the 'ignimbrite'.

Table 1 Generalised Soil Profile with Investigation Parameters

Description	Thickness (m)	Vane Shear Strength (kPa)	SPT N (Blows /300 mm)	Cone Penetrometer			Assessed effective stress parameters
				qc (MPa)	fs (%)	Dynamic Pore Pressure (MPa)	
Crust	Typ 4.5	30-UTP Typ 140	5-17 Typ11	Typ 2	6	4	$\gamma=16-17, c'=3-5$ $\phi'=30-36$
Soft Weathered Tephra	2.9-10.5	19-110 Typ 36	0-5 Typ 0	Typ 1	1	0.7	$\gamma=15-17, c'=2-3$ $\phi'=22-28$
Ignimbrite	5-12	Typ UTP	7-50+ Typ 40	Typ 20	2	0	$\gamma=17-18, c'=1-2$ $\phi'=30-32$

Typ=typical value, qc= cone resistance, fs=friction ratio UTP=Unable to Penetrate with vane

The CPT was assessed to provide a more accurate interpretation of the in situ soil strengths of the soft weathered tephra, due to the continuous nature of the results obtained. However, borehole and test pit investigations do provide an understanding of in situ soil behaviour showing that these materials appear competent until disturbed.

The vane shear strengths and standard penetration test (SPT's) recorded within borehole investigations (Table 1) were relatively low and did not correlate well with the data obtained from the cone penetration test (CPT) investigations. It was considered that the action of machine drilling and the vane tests undertaken in the end of core barrel, or SPT's, disturbed the sample so much that the vane shear strength results reflected the residual strength of the soil and not the peak value. Using a correlation factor of (N_k) of 15, the CPT results correspond to an undrained peak shear strength of about 65 kPa, which is consistent with the results presented by Wesley (2003) of allophanic soils near New Plymouth. Residual strengths of the soft weathered tephra could be half of the peak values i.e. typically 19-40 kPa. The range in assessed parameters reflects the variable nature of the in situ test results across the site.

Allophanic Soils

Based on site observations and laboratory testing undertaken as part of both projects, the soft weathered tephra deposit does not behave as typical clayey silts that are derived from a sedimentary deposit. Unlike sedimentary deposits where in many cases the engineering properties of a particular unit remain relatively constant from one part of the country to another, the properties of volcanic ash layers and ignimbrites can vary dependent on climatic conditions and post depositional history. This is essentially because their soil properties are governed by origin, and formation process by in situ weathering and not their stress history (Wesley, 2003).

Allophane tests undertaken (NZS 4402:1986, Test 3.4) show that the crust and the soft weathered tephra layers contain some (5-7%) to a significant amount of allophane (> 7%). Tests undertaken on weathered reworked Potaka tephra deposits did not register a presence of allophane - possibly as a result of the depositional process or post depositional environment. In Gisborne, site observations indicate that there is no overlying weathered horizon that is developed into the Potaka tephra, possibly as a result of the drier, more arid climatic conditions.

Soils that contain allophane exhibit the following engineering properties (Wesley, 2003): 1) High Atterberg Limits; 2) Undergo irreversible changes when dried (from plastic to non plastic); and, 3) Has high sensitivity (suffer marked loss of strength on disturbance).

Within the upper crust horizon, although it contained some 5-7% allophane, and the soil largely comprised weathered in situ ash fall layers and paleosols, its behaviour is observed to be controlled by other clays within the material, namely halloysite. In that, on excavation the cut slopes developed a crumbly frittering surface, as the wetting and drying caused the clays to shrink and swell with the change in moisture content. Allophanic soils, once dried, would not be expected to swell on rewetting. Based on Wesley (2001), halloysite is the next stage in weathering from allophane and imogolite within a well-drained environment.

DESIGN CUT SLOPES

Cut slopes for both projects were up to 13 m in height and dissect through the soft weathered tephra that underlies the stiff crust layer. Natural slopes mantled by the crust material in the region are about 4H:1V.

For the two projects different cut slope profiles have been designed within the soft weathered tephra layer. Slope stability analyses were performed in Geoslope Slope/W software using the Morgenstern and Price method for calculating inter-slice forces (constant side function). Analysis for static conditions is carried out using assessed effective stress parameters presented in Table 1.

SH2 Mangatawhiri Realignment

The recommended cut slope design comprised short steep cuts with wide benches (Table 2) to provide relatively flat overall cut slopes of 4H:1V, to achieve the required margins against instability and to reduce the potential for surface erosion. As the behaviour of the crust was dominated by the presence of halloysite and not allophane, the slope angles were retracted to 1V:1H in the crust zone.

All cut areas were specified to require subsoil drainage. Although the overall gentle slope profile achieved the required design criteria under static and seismic loads, the individual cut slope batters have long term FOS < 1.5, with a risk of localised slumping of the cut face. The wide benches enable any localised slumping to be caught on the bench below. This design limits surface erosion from significant rainfall events, but is likely to be complex to construct.

Table 2: Design Cut Slopes For SH2 Mangatawhiri Road Realignment

Soil layer	Cut slope height (m)	Cut face slope	Bench width above cut
Crust	2	1H:1V	2
SW tephra	2	0.25H:1V	8
Ignimbrite	5	3H:1V	5

Ohinewai Switching Station

The switching station platform was to be founded partially on a cut surface comprising crust and soft tephra with the remainder founded on up to 9m of fill material. The 13 m high cut slope was designed at 4H: 1V similar to natural slopes, and the slope is in excess of 50 m length. Counterfort drains (inclined bored drains are considered to be unsuitable for these fine grained soils) were designed to draw down the groundwater levels by 2 m to improve the stability of proposed cut slopes. The drains are 3 to 4 m deep, and spaced at 6 m centres running down the slope. To achieve adequate factors of safety under both static and seismic conditions, it also required the construction of a toe buttress comprising compacted hardfill, within a 5 m wide key trench at the toe of the slope extending 2 m up the face. Until the vegetation takes hold on the cut slope, the slopes are likely to be susceptible to erosion.

IMPLICATIONS FOR EARTHWORKS

Based on the observed soil behaviour and laboratory testing results, earthworks carried out within these sensitive soils can be anticipated to experience difficulties. The crust layer has a lower natural moisture content than the soft weathered tephra layer, and its properties are controlled by the dominance of halloysite clay. It is therefore likely to be less problematic than the underlying softer layer.

Due to the allophanic properties of the underlying soft weathered tephra layer that is being encountered within the cut slopes, heavy machinery is anticipated to experience difficulties and are likely to get bogged down, and the materials will possibly become mobile during excavation. Previous roading projects in similar soils (Taranaki and Bay of Plenty, NZ) indicate that these soils will not be able to be excavated by motor scraper and trafficked by trucks without temporary haul roads.

Recommended options for undertaking excavations in the soft weathered tephra include:

- Use of a hydraulic excavator or dragline for excavation, it may be necessary to work from a bench with haul roads established above on the crust or below on the ignimbrite and excavate from the top down; or
- Excavate the weak soils from below. Access would be formed to the cut area by undercutting the weak soils and forming a temporary haul road on the underlying subgrade.

CONCLUSIONS

Subsurface investigations undertaken within the North Waikato reveal a soil profile comprising a sequence of interbedded weathered tephra beds and palaeosols overlying the widespread 0.99 Ma Potaka tephra.

Within the North Waikato region the Potaka tephra is observed at several stages of weathering. At each of these stages the soils exhibit different strengths, colour, grading, and sensitivity ranging from a stiff crust, to soft sensitive clay, to slightly weathered dilatant sand. In our experience, the development of the soft weathered allophanic horizons are climatically controlled and are not

observed in drier parts of the country within the Potaka tephra. They are more likely to occur within in situ ignimbrites and ash fall layers and not within reworked equivalent deposits. Site observations in conjunction with investigations and laboratory testing are recommended to adequately assess the soils behaviour.

Several investigation methods were utilised within the projects. The cone penetration test was believed to provide a more accurate indication of the in situ soil properties than the vane shear strength and SPT's carried out during machine drilled boreholes.

Designed cut slopes for each of the projects are up to 13 m in height with an overall slope of 4H:1V. The cut slope design for SH2 Mangatawhiri uses wide benches and short steep cut slopes. At Ohinewai the design slopes are to be cut at 4H:1V with counterfort drains running down the slope.

Recommendations for undertaking earthworks in these materials include constructing a temporary platform and excavating from the top down or from below, and constructing haul roads on underlying or overlying more competent material.

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