Engineering Geological Aspects of the Ruahihi Power Scheme, Tauranga

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Abstract: The Ruahihi Hydroelectric Project is constructed in a complex sequence of Pleistocene-age pyroclastic flows and airfall deposits. The principal pyroclastic units are Waiteariki Ignimbrite, Grey Ignimbrite (informal), Waihou Ignimbrite (tentative correlation) and Waimakariri Ignimbrite. Major periods of erosion and weathering followed deposition of each unit, resulting in a spatially complex distribution of materials. Lithological variability within units is typical and, combined with complex paleotopography, leads to problems of stratigraphic identification and correlation.

The engineering geological characteristics of the main pyroclastic and airfall tephra units are described in some detail, and factors that may have contributed to the 1981 canal failure are discussed.

INTRODUCTION

The Ruahihi Hydroelectric Project, located in the lower Kaimai Range (Figure 1), is constructed in volcanic terrain dominated by Pleistocene-age pyroclastic flows and airfall deposits of predominantly rhyolitic composition. The variability and complex distribution of the primary materials, and also of their weathering products, had a significant impact on the design and performance of the project works.

Difficulties were encountered both during construction with highly variable, wet and sensitive materials and also soon after commissioning in September 1981 when a canal buttressing fill failed. A consequence of that failure was unique exposure of many of the geological units encountered during construction of the project works. Prebble (2001) highlighted the variability and difficult geotechnical properties of some of the materials exposed in the failure.

This paper examines some aspects of the engineering geology of the Ruahihi project area to illustrate the complexity of this type of volcanic terrain and the potential problems that can be encountered in the design and construction of engineering works.

The discussion is based principally on geomorphological mapping, engineering geological descriptions of exposed materials, investigation drillholes and geophysical surveys.

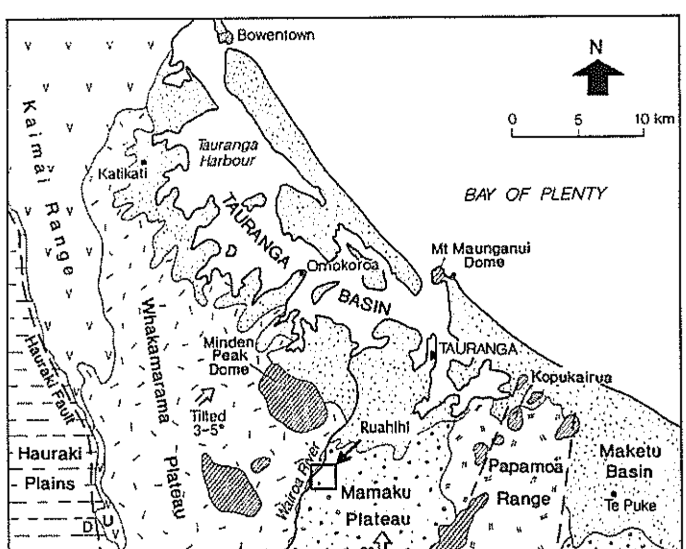

Figure 1: Physiography of the Tauranga Region (after Briggs et al 1996)

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The geology of Tauranga Basin and hinterland is mapped at a scale of 1:50,000 by Briggs *et al* (1996). The basin, a major region of Pleistocene deposition, is infilled with terrestrial and estuarine sediments intercalated with pyroclastic flows and airfall deposits. The sediments are principally derived from non-welded and poorly welded pyroclastics and airfall volcanic materials eroded from the surrounding elevated land.

The limits of Tauranga Basin (Figure 1) are defined by Papamoa Range to the east, Mamaku Plateau to the south and Whakamarama Plateau - Kaimai Range to the west. The general dip of Mamaku Plateau is north at about 2° and Whakamarama Plateau northeast at about 4°. Mamaku Plateau, the youngest of these physiographic units, is constrained to a relatively narrow corridor by the older and more elevated Papamoa Range and Whakamarama Plateau (Figure 1). The Mamaku Plateau is characterised by linear, steep-sided drainage courses and broad concordant interfluves, while the Whakamarama surface is much more eroded and dissected.

Wairoa River is located in the valley formed by the contact between the Whakamarama and Mamaku plateaux. It is likely the converging dip of these surfaces has forced the river to migrate eastward into the weaker pyroclastic materials underlying Mamaku Plateau. Ruahihi Canal runs parallels to the river close to the northwestern extremity of the plateau (Figure 2).

Mamaku Plateau in the project area is mapped (Briggs *et al,* 1996) as being underlain by Waimakariri Ignimbrite, a variably welded rhyolitic pyroclastic flow most probably originating from the Rotorua caldera a short time prior to eruption of Mamaku Ignimbrite (Fransen, 1982). The latter overlies Waimakariri Ignimbrite a little to the south. A fringe of non-welded massive sandy ignimbrite (Te Ranga Ignimbrite) mapped along the southern side of Wairoa River, is considered by Briggs *et al* (1996) to be older than Waimakariri Ignimbrite and have a local (Tauranga Basin) source. This unit and Mamaku Ignimbrite were not encountered in the Ruahihi project works.

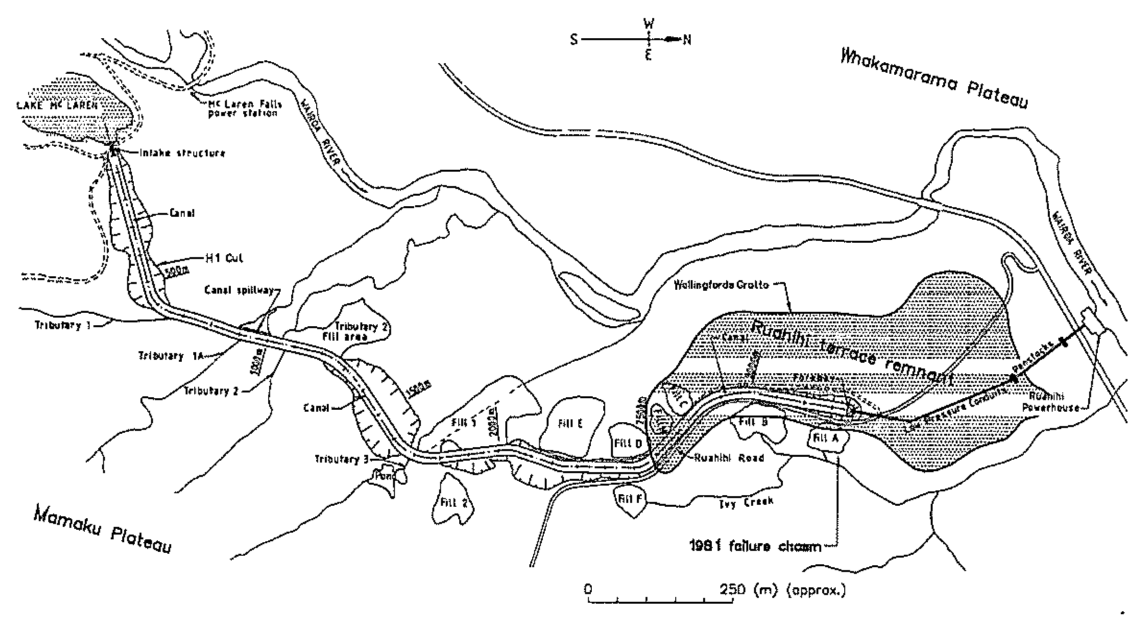

Figure 2 : Ruahihi Scheme Layout

Two distinctive geomorphic units characterise the landforms in the local power scheme area. The southern two-thirds of the canal (to distance 2500m, Figure 2) is located in dissected topography with steep, narrow ridges rising to elevations of 120m. This topography is likely to represent the northern limit of Mamaku Plateau, complicated by intersection with the underlying strongly dissected paleosurface of the Whakamarama Plateau, which rises to the southwest (Figure 1).

This elevated, dissected topography contrasts with the gently undulating terrace remnant to the north on which the northern end of the canal and headrace pipeline are located (Figure 2). The terrace is a narrow, elongated remnant of a larger surface at about elevation 80m that is concordant with similar remnants to the east.

PROJECT GEOLOGY & STRATIGRAPHIC CORRELATION

Table 1 summarises the lithological units encountered in natural exposures, excavations, drillholes and the 1981 failure chasm. Formal and informal stratigraphic names are assigned to the units, however many remain tentative.

Identification and correlation of the different units at Ruahihi has been problematic for a considerable period, including the many years during which elements of the final scheme were investigated (1955 to 1975). Healy (1955 and 1956) described a number of pumice breccia and mixed volcanogenic sedimentary units in the area, including what was later named Waiteariki Ignimbrite, although he did not attempt rigorous correlation with known units.

Lloyd (1965) correlated units with the stratigraphy of the then recently published 1:250,000 Rotorua sheet of the Geological Map of New Zealand. He defined two major units, Upper Mamaku Ignimbrite and Lower Mamaku Ignimbrite, separated by an erosional break. The upper sheet is considered by Briggs *et al* (1996) to be Mamaku Ignimbrite proper, and the lower sheet Waimakiriri Ignimbrite.

Carryer (1975) in a report on drilling investigations for the Ruahihi project, did not attempt to assign stratigraphic names to any of the drilled lithologies other than Waiteariki Ignimbrite.

Cowbourne (1985) described a number of pyroclastic units exposed in the failure chasm that are not formally identified. He tentatively correlated the massive non-welded ignimbrite underlying the Waimakariri Ignimbrite with Waihou Ignimbrite of Fransen (1982) but other units remain unidentified. Although this correlation remains tentative, the name Waihou is used here as a convenient identifier for this unit.

The fact that identification of many of the geological units at Ruahihi remains unresolved illustrates the considerable difficulties that investigators encountered when mapping the site and predicting ground conditions along the canal route.

ENGINEERING GEOLOGY OF PRINCIPAL UNITS

The following is a discussion of the engineering geology of some of the principal materials encountered during construction of the project works. The discussion is confined to the mainly pyroclastic materials that were exposed by canal excavations and the 1981 canal failure. Descriptions are from the youngest unit to the oldest.

Ash Cover

Beds of variably weathered Quaternary airfall tephra form a thin cover on all surfaces in the area except the youngest river terraces. They have been substantially eroded from steep slopes. The older beds are generally thought to be part of the Hamilton Ash Formation (150,000 to 350,000 years), although no correlation has been demonstrated. The age of Rotoehu Ash, at the base of the younger beds, is considered to be about 60,000 years (Lowe and Hogg, 1995).

The two sets of tephra are readily distinguished by the dark paleosol at the top of the Hamilton Ash beds and the coarse ash and lapilli bed at the base of the shower-bedded Rotoehu Ash (Figure 3). The Hamilton Ash beds are weathered to stiff plastic clay (halloysite and kaolinite, Oborn *et al*, 1982). Although water content and degree of sensitivity increase with depth, these beds generally present few problems in handling and compaction as an engineering material.

	unit	graphic log	thickness	subunit / description	form
LATE QUATERNARY ASHES	Post <50ka Ashes		2-3m	interbedded or pedogenically mixed volcanic ash, tephric loess and colluvium. Some minor paleosols. see TABLE 3·3	mantles present topography
				Rotoehu Ash	
	Hamilton Beds		~ 1·5m	well developed paleosol " " "	
				highly weathered tephric loess	
YOUNGER IGNIMBRITES	Concretionary Layer		~ 2·5m	«sharp contact»	
	Waimakariri Ignimbrite (~180ka)		~8m (up to 15m)	massive unwelded to moderately welded IGNIMBRITE. (pumice breccia) pumice lag deposits	Plateau forming
			0·1m	pumice lapilli bed - base surge deposit	
	"Caprock"		~1m (0·5-5m)	lithified well developed paleosol.	
	bedded sands		0-4m	bedded sands either phreatomagmatic or fluvial origin.	
	Waihou (?) Ignimbrite (~ 300ka)		~ 8m (up to 11m)	massive unwelded to poorly welded IGNIMBRITE. (sandy pumice breccia) fossil fumeroles, carbonised log casts, erosional contacts	Plateau forming
				« 50mm well cemented paleosol »	
	Pink Tuff		0-0·5m	highly weathered tuff	
?	finely bedded unit		~2m	graded airfall ash	
OLDER DEPOSITS	diatomaceous SILTS		0-2m	lacustrine sediments	paleovalley infilling
	Peat		0-4·8m	coarse ash peat, containing small logs	
	slightly organic sediments			overbank deposits or seat earth.	
	bedded unit		~3m (2-9m)	interbedded fluvial, pyroclastic flow and graded airfall deposits	
				Basal Conglomerate—matrix supported; fluvial origin	
	Chalazoidite Tuff (~500ka)		~2m (0-6m)	pyroclastic airfall unit, containing a variable abundance of accretionary lapilli. (phreatomagmatic origin?)	
				pumice lapilli bed	
	faintly bedded unit		~2m (0·5-6m)	interbedded pyroclastic and fluvial deposits	
				«coarse ash paleosol»	
			0-1·4m	white clay—massive, contains decomposed twigs—lacustrine.	
BASAL IGNIMBRITES	Brown Tuff		0·6-1·6m	completely weathered tuffaceous unit. Probably airfall origin.	mantles paleotopography
	Grey Ignimbrite (~ 650ka?)		0-26m	massive, weakly welded to moderately strongly welded IGNIMBRITE. Moderately crystal- and pumice-rich. lenticular and platey pumice	
	Basal Tuffs		0-1m	HW-CW pyroclastic deposits (ash tuffs): Ignimbrite※1 — basal halloysite nodules, thin halloysite layers	mantles paleo-topography
			0-1·8m		
			0-0·3m	coignimbrite airfall ash?	
			0-2m		
	Waiteariki Ignimbrite (840ka)			massive dacitic highly welded IGNIMBRITE. Flattened pumice (fiamme) and rock fragments in a sandy matrix. Crystal- and pumice-rich. At least two flow units.	'basement'

Based on Table 3.2 in Cowbourne (1985). Note that insufficient exposure means that the relationship between the sediments and tuffs of the Ivy Bridge Section (Healy 1955) and the Waimakariri and Waihou(?) Ignimbrites remain unclear.

Table 1 : Summary of Stratigraphy, Ruahihi Area

Rotoehu Ash is thinly bedded, loose gravel, sand and silt (1m thickness) overlain by 0.5m of weathered ash. Overlying Rotoehu Ash is about 1m of firm orange brown clayey silt, which is moderately sensitive, wet and greasy when worked and includes some recognisable pumice lapilli (probably Mangaone Sub-Group, Froggatt and Lowe, 1990). The uppermost 1m of ash is firm clayey silt characterised by relatively strong aggregation of the constituent allophane clays (Parfitt, 1990) producing a free-draining texture.

Waimakariri Ignimbrite

This unit is widespread over the project area, and forms one of the more important materials encountered in the engineering works. When emplaced, it substantially inundated the pre-existing topography. It is variable in thickness, lithology, degree of welding and weathering products. Characteristic features are a topography-mantling, thin basal bed of coarse ash and pumice lapilli, and a ubiquitous zone of red weathering in the uppermost 2m to 6m.

The red weathered zone is unusual. The ignimbrite is completely weathered to bright reddish and orange brown clayey silt with some sand (quartz, feldspar, glass) that is greasy and wet when worked. The clay dominated by halloysite with some allophane (Cowbourne, 1982). The transition to the underlying completely/highly weathered ignimbrite is sharp and very irregular forming pseudo-flame structures and 'blobs'. Hard elongate tubes and spherical 'concretions' comprising halloysite shells with an iron/manganese oxide core are common, particularly at the base.

Waimakariri Ignimbrite is massive, sandy and the content of pumice is variable. In general it grades with depth from a completely weathered upper zone through a middle section of commonly highly sensitive, pale yellow clayey silt, to a lower zone of pale pink, compact pumiceous silty sand. The concentration of pumice blocks increases towards the base and pumice is particularly abundant in paleovalleys, where some stratification is evident (Figure 4).

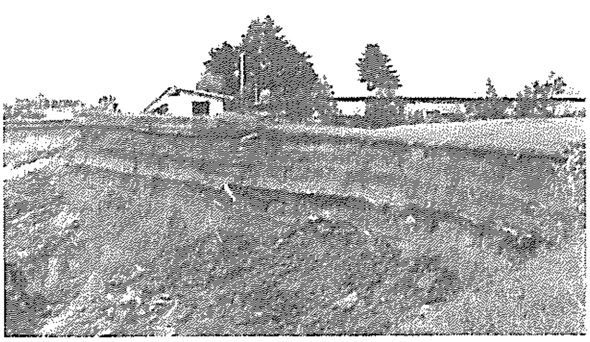

Figure 3 : Quaternary Tephra Exposed in Western Scarp of Failure Chasm

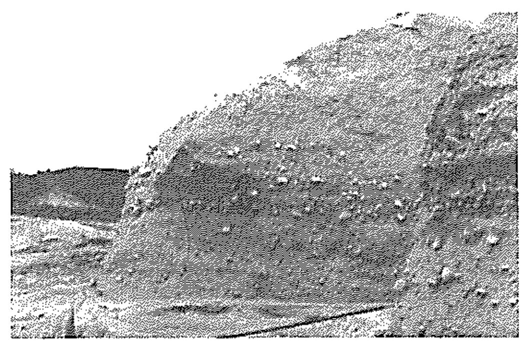

Figure 4 : Weak Stratification Near Base of Waimakariri Ignimbrite

Lateral and vertical variability is characteristic of Waimakariri Ignimbrite. Although predominantly unwelded, isolated welded zones occur (e.g. the northeastern extremity of the collapse scarp), forming a columnar-jointed weak rock. Lateral changes to unwelded, weathered, sensitive material can be abrupt (over less than 2m) accompanied by little visual change in appearance. At the upstream end of the canal, in the cut 500m east of Lake McLaren, the ignimbrite is compact, predominantly unweathered and stands in subvertical cuts to heights of 20m (Figure 5). In contrast, in canal cuts between 1km and 2km to the north, the ignimbrite is completely weathered and sensitive to the base.

The sensitive middle and upper parts of the ignimbrite were widespread in the canal excavation and were difficult materials to excavate, transport and place in spoil dumps. The sensitive materials were also widespread in the failure area and lead to regression of the failure scarps away from the initial canal breach as support to the material was progressively lost.

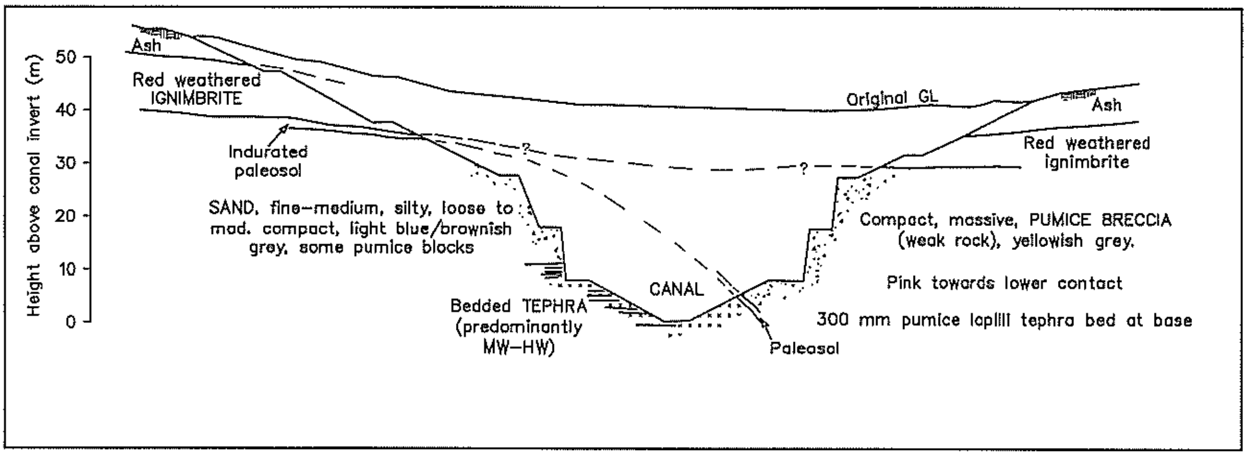

Figure 5: Example of Paleotopography, H1 Cut, Chainage 540m

Lithified Paleosol

An un-named ignimbrite that ranges in thickness up to 5m (generally 1m) is widespread in the failure exposures but less prominent in the canal excavations. The ignimbrite is unwelded, compact, moderately weathered and is capped by a lithified paleosol that has well-developed, polygonal, vertical joints, some infilled with iron and manganese oxides. At the top of the paleosol is a thin layer of greenish clayey silt that although hard is slightly sensitive and greasy when worked.

Bedded Sands

This unit was observed only in the failure exposures and comprises up to 8m of loose silt, sand and gravel (pumice and rock fragments) that in places is distinctly bedded (planar and cross-bedded, Figure 6). Mostly, bedding is diffuse and, although generally flat-lying, the sands mantle topographic highs. The sands appear to be pyroclastic in origin although a fluvial mode of emplacement is possible.

Waihou Ignimbrite

An unwelded sandy ignimbrite exposed in the failure chasm and in the 20m high cut on the southern side of the canal 500m east of Lake McLaren (Figure 3). The unit is up to 15m in thickness, is slightly to moderately weathered and comprises massive, loose, pale grey gravelly sand with pumice blocks scattered throughout. The gravel comprises pumice lapilli and rock fragments. The basal 3m to 4m is compact.

Figure 6 : Cross and Planar Bedding in the 'Bedded Sands', 1981 Failure Chasm

In the failure exposures, log casts are common near, and at the base of the flow (Figure 7). The casts are empty, subhorizontal, up to 300mm in diameter, 0.5m to 2m long and some are lined with iron and manganese oxide. Elongate fossil fumaroles infilled with loose coarse sand also are common near the base of the flow.

Discontinuous, subhorizontal, erosive contacts and thin seams occur at different levels throughout the unit. A line of log casts is associated with one of the contacts. Other features noted include a scour channel infilled with blocks of intact, slightly more compact ignimbrite. It is likely that these features are associated with the mode of emplacement of the flow.

Although predominantly a loosely packed sand this material has performed satisfactorily in the well-drained 20m high subvertical cut east of Lake McLaren. Given its relatively open structure however, it is susceptible to internal erosion (piping) and potential for collapse by densification on wetting.

Graded Tuffs

In the canal failure area the Waihou Ignimbrite rests unconformably on a series of tuffs that form a paleosurface with relief in excess of 10m. These materials are likely to form part of the Older Deposits (Table 1).

The tuffs are the lowermost unit exposed in the failure area and comprise a 2.5m sequence of 100mm thick graded beds of pumice lapilli fining upwards to fine ash (Figure 8). The beds are very compact and are capped by 0.5m of pinkish white, hard clayey silt that is slightly sensitive and greasy when worked. Underlying the tuff beds is massive brown/grey hard clayey silt at least 2m in thickness.

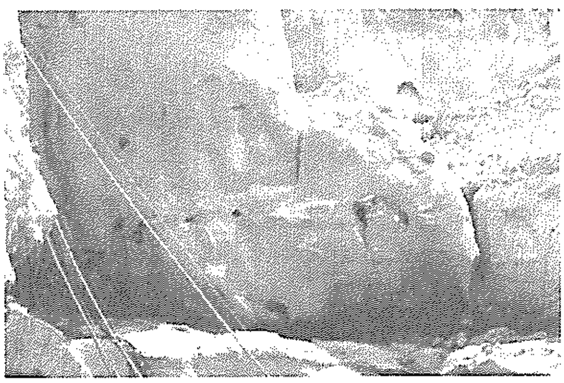

Figure 7 : Log Casts Along Flow Contact Near the Base of the Waihou Ignimbrite

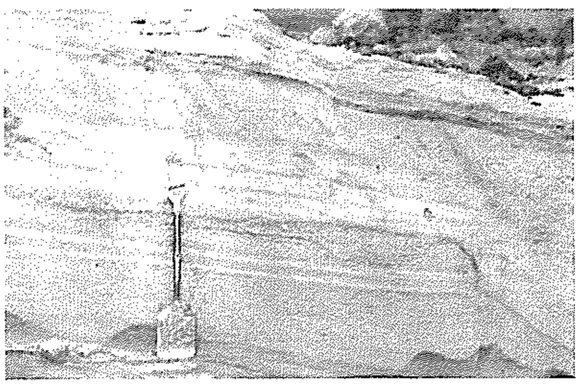

Figure 8 : Compact Graded Tuffs, the Lower-Most Unit Exposed in the Failure Chasm

The tuffs may correlate with a sequence of topography-mantling weathered airfall beds underlying Waihou Ignimbrite in canal exposures east of Lake McLaren and midway along the canal. Although occupying the same stratigraphic position, the characteristics of the deposits are distinctly different.

Grey Ignimbrite

An un-named, massive, grey, sandy ignimbrite of 1 to 5MPa compressive strength was the lowermost unit encountered along the middle sections of the canal excavation. It was also encountered midway down the penstock slope excavation and Cowbourne (1985) correlated it with a grey ignimbrite exposed by the failure flood in Ivy Creek. The rock weathers to reddish brown slightly sensitive clay. The transition from unweathered to completely weathered rock commonly is abrupt.

Waiteariki Ignimbrite

Basement in the Ruahihi area is a strongly welded unit of the Waiteariki Ignimbrite, a Plio-Pleistocene-age dacitic to rhyolitic flow from the Coromandel Volcanic Zone that underlies Whakamarama Plateau (Briggs *et al*, 1996). It is exposed in rapids and waterfalls along the Wairoa

River and was encountered at shallow depth at the canal intake and power station excavations. It was not however, conclusively identified in drillholes and excavations along the canal alignment.

PALEOTOPOGRAPHIC CONTROLS

Paleotopography has been a fundamental factor controlling the distribution and variability of geological units at Ruahihi. Major periods of erosion and weathering followed deposition of each of the principal pyroclastic flow deposits, i.e. Waiteariki Ignimbrite, Grey Ignimbrite, Waihou Ignimbrite and Waimakariri Ignimbrite.

Airfall material is common between each of the flow deposits. Weathering of the ignimbrite and ash materials resulted in the development of clay-rich soils (paleosols) at the top of each ignimbrite unit. The paleosols have an important influence on groundwater movement as they generally act as aquicludes between the more permeable sandy ignimbrite flows. They can concentrate flow in paleovalleys and trap groundwater behind paleoslopes. Measurement of spring flows around the perimeter of the terrace remnant (undertaken prior to significant horticultural development) indicates the total discharge is at least 15% of the maximum possible infiltration recharge. This is unexpectedly high, given the highly dissected nature of the terrace remnant and the presence of a thick, stratified ash soil mantle. Additional groundwater recharge may be occurring from a paleovalley aquifer or from the underlying jointed Waiteariki Ignimbrite.

The paleotopographic controls on groundwater are likely to be responsible for an apparent association with internal erosion and cavity formation. A particularly good example is Wallingford's Grotto on the western side of the terrace remnant, a cave feature more than 2.5m wide and 1.4m high, formed at the base of an ignimbrite unit.

Paleotopography is likely to have been a significant control on the formation of the terrace remnant. The near flat surface of the terrace contrasts with the more elevated and rugged relief immediately to the south. Waimakariri Ignimbrite was the last major event to significantly alter landforms in the area. It mantled, and in places infilled the considerable paleotopography that developed on the underlying Waihou Ignimbrite and older units. The gentle dip of the terrace remnant suggests that the northern fringe of Waimakariri Ignimbrite was contained (ponded), possibly against the adjacent older rocks of the Whakamarama Plateau.

The Wairoa River and its tributaries substantially removed the larger surface, leaving the narrow terrace remnant. Subsurface modelling using drilling and geophysical surveying (Cowbourne, 1985) suggests a ridge of Grey Ignimbrite, and possibly Waiteariki Ignimbrite, underlying the northern end of the terrace remnant has partially protected the terrace remnant from erosion by the Wairoa River.

1981 CANAL FAILURE

Paleotopographic control on the distribution of materials and groundwater flow is considered to have been a significant contributor to failure of the canal at Fill A (Figure 2). The fill was constructed to buttress the eastern canal embankment at a location where the canal was judged to be too close to the steep slopes along the eastern side of the terrace remnant. The fill is mainly cohesive material from the canal excavation.

The committee reporting on the failure (Hatrick et al 1982) concluded that failure was promoted by build-up of pressure under the relatively impermeable fill, destabilising the fill and allowing it to separate from natural ground at the head. The removal of support resulted in settlement of the canal embankment leading to its overtopping and eventual breaching. Erosion of the weak materials underlying the canal by escaping water, in addition to regressive failure of the scarps in the sensitive weathered Waimakiriri Ignimbrite, led to development of the extensive failure chasm.

The critical materials and factors contributing to the failure were:

- The presence of Waihou Ignimbrite underlying the 'seat' of the fill (Figure 9). The ignimbrite thins to the north and south due to the paleotopographic controls of the overlying lithified paleosol and underlying graded tuffs, both resistant, relatively impermeable units.
- The open structure of the loose silty sands of the middle and upper parts of the Waihou Ignimbrite. The sands are susceptible to internal erosion and potential collapse (densification) on wetting.
- The resistant graded tuffs form a 'floor' in the failure washout in the fill area and are close to foundation level of the lower part of the fill. It is likely therefore that part of the fill was founded on, and essentially formed a seal against the tuffs.
- The widespread occurrence of the sensitive, weathered Waimakiriri Ignimbrite, which was a major factor in determining the actual extent of the failure chasm.

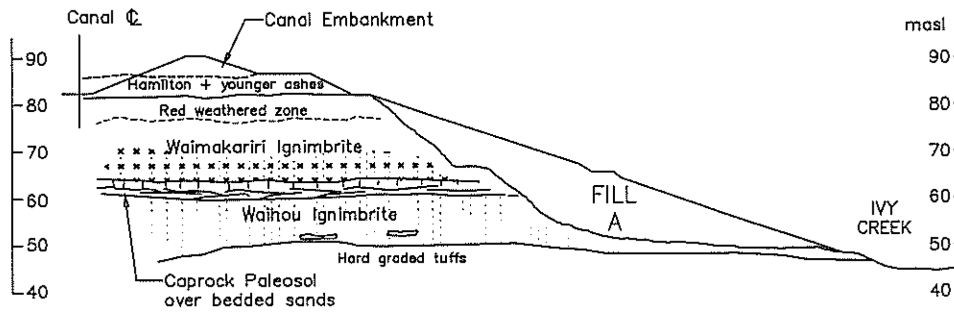

Figure 9 : Geological Section Through 1981 Failure Chasm

Construction of the fill is likely to have prevented free drainage from the Waihou Ignimbrite, allowing groundwater levels to rise in that material, promoting development of cavities and piping erosion. The seal that resulted from placing fill against the graded tuffs prevented relief of pressure at the toe. Pressures eventually created sufficient buoyancy to destabilise the fill, which moved eastward as a coherent mass, removing support to the canal. This model essentially supports the findings of the inquiry committee.

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