SLOPE MOVEMENTS AROUND THE TUTAMOE PLATEAU (CENTRAL NORTHLAND NEW ZEALAND)

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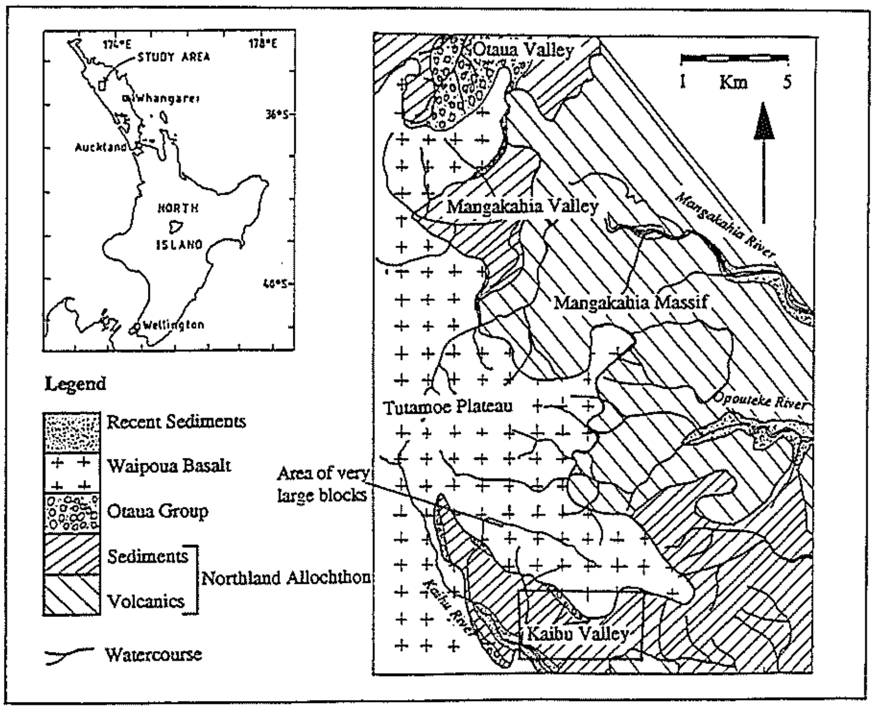
SUMMARY

The Tutamoe Plateau consists of a prominent upstanding tableland of resistant well jointed basaltic rock and regolith. Underlying sediments are highly to extremely weathered, eroded, and very weak, with subdued topographic expression. Stream superposition and erosion of these sediments by slope movement results in oversteepened slopes which maintain the edge of the Plateau in a state of disequilibrium. Continued and successive undercutting of the Plateau creates large and varied slope movements. Degradation and retreat of the Plateau edge is continuous and ongoing.

INTRODUCTION

The Tutamoe Plateau, (Fig.1.) consisting of some 500 square kilometres of basaltic rock and regolith extends inland from Northlands west coast for 15-20 Km forming a gently south westerly dipping table land which in places reaches up to 700m asl. Very weak sedimentary rock and sheared tectonic melange underlie the basalt which are practically everywhere subject to slope movement. This undermines the fringes of the basalt cap which is sustained in a barely stable state showing evidence of prolonged slope failure, with aprons and streams of slope debris extending for up to 3 Km from the plateau edge.

Figure 1. Location of the study area showing dominant geological and geomorphological features. See figure 3 for enlargement of inserted boxed area.



Hydrological conditions on the Plateau suggest that groundwater flow patterns are controlled by the basalt acting as an aquifer (with high secondary porosity) and the underlying sediments acting as an aquitard. The resulting groundwater flow is directed along the interface between these two units resulting in seepage at the base of the Plateau cap. This promotes instability with degradation of the underlying sediments and undercutting of the basalt cap.

Debris flows and earthflows along with block slides, rockfalls and small scale translational sliding are common and widespread in the sedimentary and volcanic material commonly found on slope below the Plateau cap. These cause gradual degradation of the undercut basalt Plateau cap which retreats by method of rock fall and rock avalanche.

STRATIGRAPHY

The regional stratigraphy of the study area consists of one major tectonic and two stratigraphic units. The Northland Allochthon is a tectonically emplaced ophiolite consisting of a sequence of nappes and olistoliths of Cretaceous - early Tertiary sediments and volcanics over 3 Km thick thrust across Northland at the Oligocene-Miocene boundary [1,2]. Within the study area the allochthon consists of two complexes: (1)Mangakahia complex sediments consisting of weak and weathered olistostromes which are represented in the study area by the Punakitere sandstone and Whangai Formation. (2)Tangihua complex lithologies contain Early Cretaceous-Palaeocene sediments and volcanics.

Highly weathered and weak Otaua Group sediments consist of a regressive sequence of bathyal-terrestrial sediments which unconformably overlie the upper surface of the Northland Allochthon and interfinger with the lower surface of the other major stratigraphic unit, the Waipoua subgroup [4].

The Waipoua subgroup is the eroded remnant of a large basalt shield volcano and consists of early Miocene basalt flows and volcanogenic sediments [2].

ENGINEERING GEOLOGY

Table 1. provides an engineering geological summary of the lithological units together with their topographic expression and propensity for slope movement. Notable features reflected in the table are the relationship between weathering values, strength values and topographic expression. The volcanic lithologies (Waipoua basalt and Tangihua complex) show that a wide range of weathering is reflected in a wide range of strength values. The sedimentary lithologies (Otaua group and Mangakahia complex) are highly weathered and as a result show a narrow range of low strength values. The presence of slightly weathered material in the volcanic lithologies, reflected in the high strength values, forms the resistant and prominent bluffs seen in these units. The low strength due to a high degree of weathering in sedimentary units is reflected in gentle, highly eroded hillsides.

Grain size varies with lithology, which all show a decrease in grain size with increasing weathering. Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) analysis show that associated with this is an increase in clay content and interlayered clay abundance.

Atterberg limit values are related to clay percentage and clay species within soil units. All units with the exception of the Waipoua basalt (residual soil) plotted above the A line within the Inorganic clays of high plasticity zone of the plasticity chart, indicating high deformation potential of remoulded (disturbed) material (Fig. 2)[5]. The Waipoua basalt unusually plotted as an inorganic silt of high compressibility, indicating that the unit has a large compressibility component in its deformation potential, possibly due to a large silt component (as indicated in hand specimen and preliminary SEM work). Atterberg limit values within the Mangakahia complex sediment would seem to indicate greater instability within Whangai Formation material than the Punakitere sandstone, however this was not reflected in the field, each unit proving to be equally prone to slope movements. An explanation of this may prove to be related to a variation in microstructure, of which an analysis is currently ongoing.

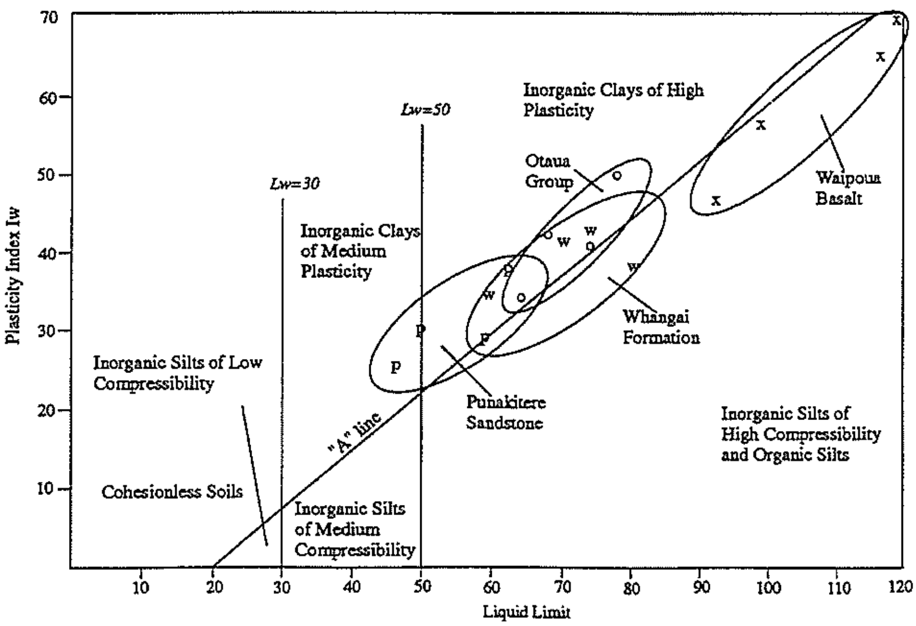
Table 1. Engineering geological summery of the lithological units and their topographic expression.

Lithology	Weathering range f mw hw ew	Strength range es s ms w ew	Grain size G Sa Si C	Atterberg limits (%) (Residual soil)	Topographic expression and slope stability.
Waipoua basalt				PI= 58 LL= 101 PL= 43 NMC= 75	Forms steep 70-80° oversteepened slopes.
Otaua Group				PI= 40 LL= 72 PL= 28 NMC= 40	Forms gentle to moderate sloping hillsides. Unstable on slopes greater than 20-30°.
Mangakahia Complex Punakitere Sst Whangai Fm				Pun / Wha PI= 20 / 42 LL= 50 / 75 PL= 30 / 33 NMC=35 / 38	Forms gentle to moderate sloping hillsides. Unstable on even gentle slopes (>15°)
Tangihua Complex					Forms steep to very steep slopes. Rockfalls and soil creep are common.

Key to abbreviations:

Weathering terms:	f	fresh	Strength terms:	es	Extremely strong
	mw	Moderately weathered		s	Strong
	hw	Highly weathered		ms	Moderately strong
	ew	Extremely weathered		w	Weak
				ew	Extremely weak
Grain size terms:	G	Gravel	Atterberg terms:	PI	Plasticity Index
	Sa	Sand		LL	Liquid limit
	Si	Silt		PL	Plastic limit
	C	Clay		NMC	Natural moisture content

Figure 2. Plasticity chart showing classification of soil units.



GEOMORPHOLOGY AND SLOPE MOVEMENT PROCESSES

Superficial features such as soil slips, flows, rockfalls, and talus development are all found in the study area. Block slides and rock avalanches form where lateral support of the basalt cap has been removed by erosion resulting in the down slope movement of large coherent masses and smaller displaced blocks of basalt. Figure 3 is an enlargement of a portion of the study area showing geology and geomorphology and an associated cross section to indicate the topographic expression of individual units.

Mass movement by debris flow is the dominant landform process within the study area. this creates a landscape dominated by large lobate, hummocky areas with poorly defined stream courses, scattered swampy patches, and poorly graded soil profiles. Debris flows develop where there is an abundance of material which can be mobilised by the addition of water. This usually occurs after a prolonged period of high intensity rainfall or a series of high intensity storms causing saturated ground conditions. Within the study area hydrological flow conditions suggest that prolonged storm events would result in high seepage rates at the base of the basalt cap resulting in super saturated ground conditions. Catastrophic flow follows upon reductions in viscosity with increased shear rates, down to values associated with hyper-concentrated fluids (ie. at or above the liquid limit). Catastrophic flow is most likely where a trigger is provided by a sudden event such as an earthquake or landslide creating an initial movement [6]. Within the study area two mechanisms of debris flow initiation exist: Away from the Plateau edge rotational or translational sliding will produce sufficient energy (providing the slip is large enough) to remould debris incorporating water beyond the liquid limit, resulting in a highly viscous and mobile flow. On the edge of the Plateau, collapse of the soil/rock mass off the Plateau edge onto the underlying sediments may raise pore water pressures in the lower mass to such an extent that overburden weight is transferred to the fluid leading to liquefaction. This method of "undrained loading" as proposed by Hutchinson and Bhandari [3] will again lead to extremely viscous and mobile flows, some extending for up to 3 Km from the Plateau edge. The Otaua and Mangakahia valleys are dominated by composite debris flow features (multi storied debris flow) which represent the continued and successive down slope movement of material over a period of time.

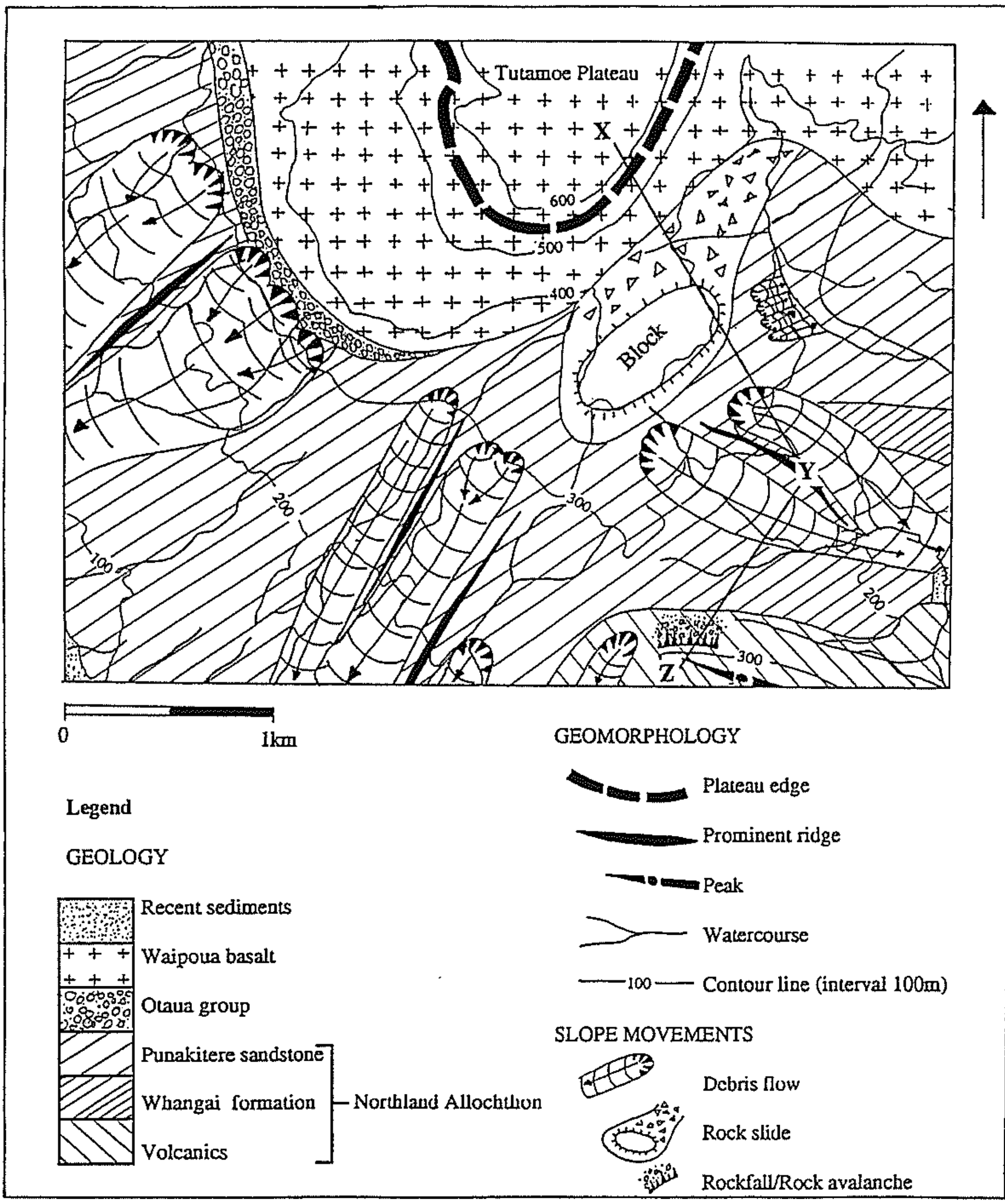
Rockfalls and rock avalanches are found at the base of basalt cliffs. These deposits provide debris for boulder fans which are well developed in major valleys. Rock falls are confined to the failure of individual blocks from the cliffs by joints sliding or toppling in the rock. Rockfalls are common in both the Waipoua subgroup and Tangihua complex where prominent bluffs out crop. Rock avalanches are confined to the Waipoua basalt. This unit exhibits high, very steep bluffs with sub vertical, continuous, and widely to moderately widely spaced columnar joints. Removal of support by erosion of the underlying sediments results in failure of the defects in shear or by outward rotation on a fixed base.

Block slides although rare in the study area are notable due to the large size of individual coherent blocks. Removal of lateral support has allowed individual blocks to break off from the Plateau edge and slide down slope on a basal rupture surface of highly weathered and extremely weak remoulded sediments. The resulting failure is a planar glide as the hard basalt mass is rafted on the remoulded sediments (Fig.3.). Near the head of the Kaihu river, on the western head of the Tutamoe Plateau (Fig.1.) there are several benches at different levels , each up to 1.5 Km long and backed by a steep scarp. These benches are interpreted as very large block slides of basaltic plateau cap on a basal rupture surface of underlying soft sediment.

Smaller rotational and translational movements are common in the study area, developing in highly weathered (HW) to extremely weathered (EW) volcanic and sedimentary units. They often lead to other slope movements such as debris flows or rock avalanches. Smaller rotational and translational movements are not shown in Fig.3 due to their relatively small size.

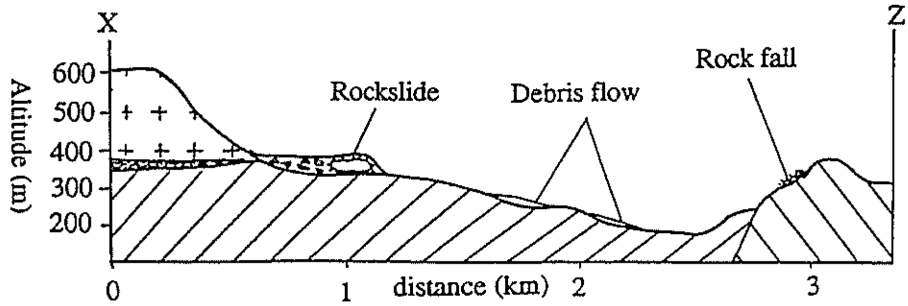
The highly weathered (HW) to extremely weathered (EW) (rock-soil) transition boundary correlates with the border between regolith related slope movements and failures involving fresh rock.

Figure 3. Geology and geomorphology of the Kaihu valley area with an associted cross section of line X-Y-Z. (see Fig.1. for location).



Cross section along line X-Y-Z (Kaihu valley)

VE=1.7



CONCLUSIONS

The Tutamoe Plateau consists of a gently southwesterly dipping table land composed of well jointed basalt rock and regolith. Very weak sedimentary rock and sheared tectonic melange underlie this basalt cap. Continued and successive slope movements in these materials undermine the basalt cap resulting in failure along joints by removal of lateral and underlying support.

Weathering has a significant influence on strength and slope movement. Physical strength, density, and grain size decrease with weathering increasing propensity for slope movement related phenomena. Clay content and the presence and abundance of reactive species (Smectite and interlayer clays) increase with weathering further increasing a slopes propensity for movement.

Debris flows and soil slips (translational and rotational) are basically regolith slides (occurring below the HW-EW rock-soil transition boundary) caused by catastrophic collapse generally as a result of hydraulic overloading.

Rock avalanches, rock falls, and block slides, involving slightly weathered to moderately weathered rock (material above the HW-EW rock-soil boundary) are related to defect orientation and spacing. Defects directly influence the geometry of slope movements by providing failure surfaces. Failure occurs as a result of erosion undermining the rock face, removing support.

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