LANDSLIDING ON THE PAEROA FAULT AT TE KOPIA

A. M. NEWSON [1], W. M. PEBBLE [1] & P. R. L. BROWNE [2]

[1] Department of Gelogy, The University of Auckland, Auckland, New Zealand
[2] Geothermal Institute, The University of Auckland, Auckland, New Zealand

SUMMARY -The Paeroa Fault scarp in the Te Kopia area has a maximum vertical expression of 525 m. Three rhyolitic ignimbrites derived from the Whakamaaru caldera are exposed. These are the source rocks for numerous debris flow deposits. Thermal fluids have interacted with these rocks for a prolonged period. Alteration marginal to the now active thermal area is dominated by mordenite, which replaces volcanic glass and pumice clasts within the ignimbrites. This is a common feature within all the debris flow deposits exposed at Te Kopia. Other slope deposits are dominated by silicified tuffaceous sediments sourced fkom the Huka Falls Formation, and are identified as hydrothermal eruption breccias. Debris flows, rockfall, earth flows and block sliding are the active slope processes, each producing a distinctive geomorphology and spatial distribution. Mordenite and other hydrothermal minerals probably had an important effect in creating the debris flows.

1. INTRODUCTION

The northeasterly striking (040) Paeroa Fault is located near the eastern margin of the Taupo - Rotorua depression within the Taupo Volcanic Zone (TVZ) (fig. 1). The fault scarp locally exceeds heights of 400 m, with slopes of 40" or steeper. Several geothermal fields are located along the fault, the largest of which is Te Kopia. The Paeroa Fault has bisected, uplifted and exposed a section through the geothermal field. The objectives of this study are to identify the various types of mass movement derived from the fault scarp, and to explore the spatial and temporal variations of the landslides.

2. GEOLOGY

Uplift along the Paeroa Fault has exposed the Te Kopia, Te Weta and the Paeroa Ignimbrites, sourced fiom the Whakamaaru Caldera. These voluminous and extensive deposits have been $^{40}Ar/Ar^{39}$ dated by Houghton et al. (1995) at **0.34-0.32** my. The minimum thickness of these three ignimbrites is 620 m, inferred from drill hole data and regional geological mapping (Grindley, 1994). The Huka Falls Formation overlies the ignimbrites and is composed of fine grained volcanic tuffaceous sediments of Upper - Mid Pleistocene age (MacKenzie, 1995).

The ignimbrites exposed along the scarp provide a minimum vertical offset on the fault, which reaches a maximum height of 524 m at the Paeroa Trig (LINZ, 2000). In the Te Kopia thermal area, the scarp is **220** m above the downthrown valley floor (MacKenzie, 1995). To the north of Waikite, the scarp becomes buried under young pumice breccias.

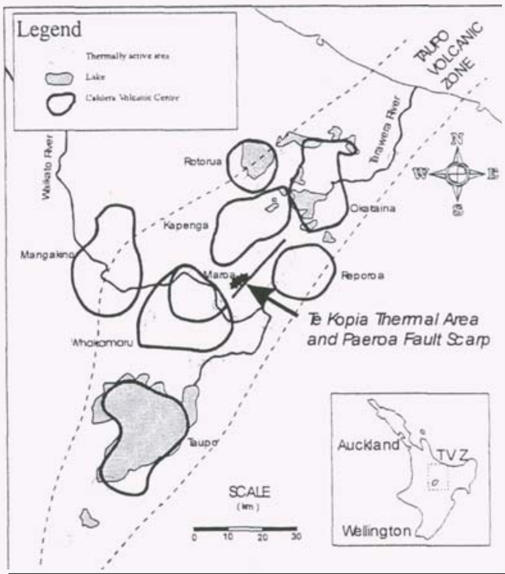


Figure 1. Locality Map (Modified from MacKenzie, 1995).

Topography indicates that the Te Kopia Geothermal Field is structurally controlled by NE / SW faults and NW / SE faults. Resistivity surveys, magnetic interpretation, and detailed topographic analysis support this model (Soengkono, 1999). Thermal activity at Te Kopia has been long lived, with changes in style and the location of activity. A change from near neutral pH chloride waters hotter than 220°C, to cooler, more acidic fluids is evident by a **quartz** + adularia ± illite ± albite assemblage overprinted by a **quartz** + alunite + kaolinite assemblage (MacKenzie, 1995). Fluid inclusion studies of quartz crystals recovered from 200 m above the valley floor indicate a change of at least 260 m in the water table, suggesting a minimum uplift of 460 m, however the highest point along the fault scarp is c. 525 m above the valley floor (MacKenzie, 1995). An apron extending from the foot of the scarp is made up of altered rhyolitic debris and layers of tephra.

3. GEOMORPHOLOGY

The most striking feature is the massive range front of the Paeroa Fault scarp, extending for 25 km. Hummocky, sloping topography dominates the apron at the base of the scarp and extends out 1.5 km. Lobes within the apron are interpreted as landslide deposits (fig. 2). The extent and size of the apron and individual lobes suggests that the landslides were large and fast moving. Four distinct geomorphic signatures are present at Te Kopia, and these correspond to different deposits.

3.1 Hummocky tongue shaped lobes

These dominate the landscape of the apron in front of the fault scarp. The lobes are perpendicular to the scarp, and are easily identified on aerial photographs. Small curved scarps represent the source area. The runout distances for these lobes is highly variable, and can extend up to 2 km from the source area where the surrounding topography does not constrain their extent. Complex structural features complicate the topography west of the fault scarp near the outer edge of the apron.

3.2 Rockfall Debris

This, common along the base of the fault scarp, arises from recent slope failure, and usually occurs as small talus deposits. Block size varies, but some blocks exceed 3.5 m in diameter with an overall decrease in number and size away from the source area. Runout distance for these rockfall deposits is commonly no more than 150 – 200 m from the base of the fault scarp, but this varies as a function of source area and height drop.

3.3 Recent earth flows

These are identified by areas of barren ground within the vegetated scarp. Older failures are identified by subtle changes in the vegetation highlighting chute-like features. Deposits are not usually found, suggesting that either their runout distance is very short, or that they are highly mobile and of small volume.

3.4 Block sliding

This is identified by benches within the fault scarp, and by isolated hills located below an embayment in the scarp.

Source areas are not always obvious as a result of post slide modification in the highly active thermal area. Several isolated hills are located on the eastern side of the road within a broad basin, adjacent to the thermal area. Runout distances for these features are up to 700 m fiom the scarp.

Other significant geomorphic features mapped at Te Kopia include hydrothermal eruption craters, and lineaments (interpreted as defects).

4. LANDSLIDE LITHOLOGIES

Detailed logs and lithologic descriptions were compiled in 8 places for slope deposits which originated either from the Paeroa Fault scarp, or from a hydrothermal eruption crater in the Te Kopia Geothermal area. The majority of these are from the hummocky lobes in the apron in front of the fault scarp.

The deposits are all similar. All the slope deposits are loosely to moderately packed coarse grained gravels. Thermal activity has affected the in-situ ignimbrites and tuffaceous sediments, and is reflected in the gravel clasts. Activity has weakened the rock mass.

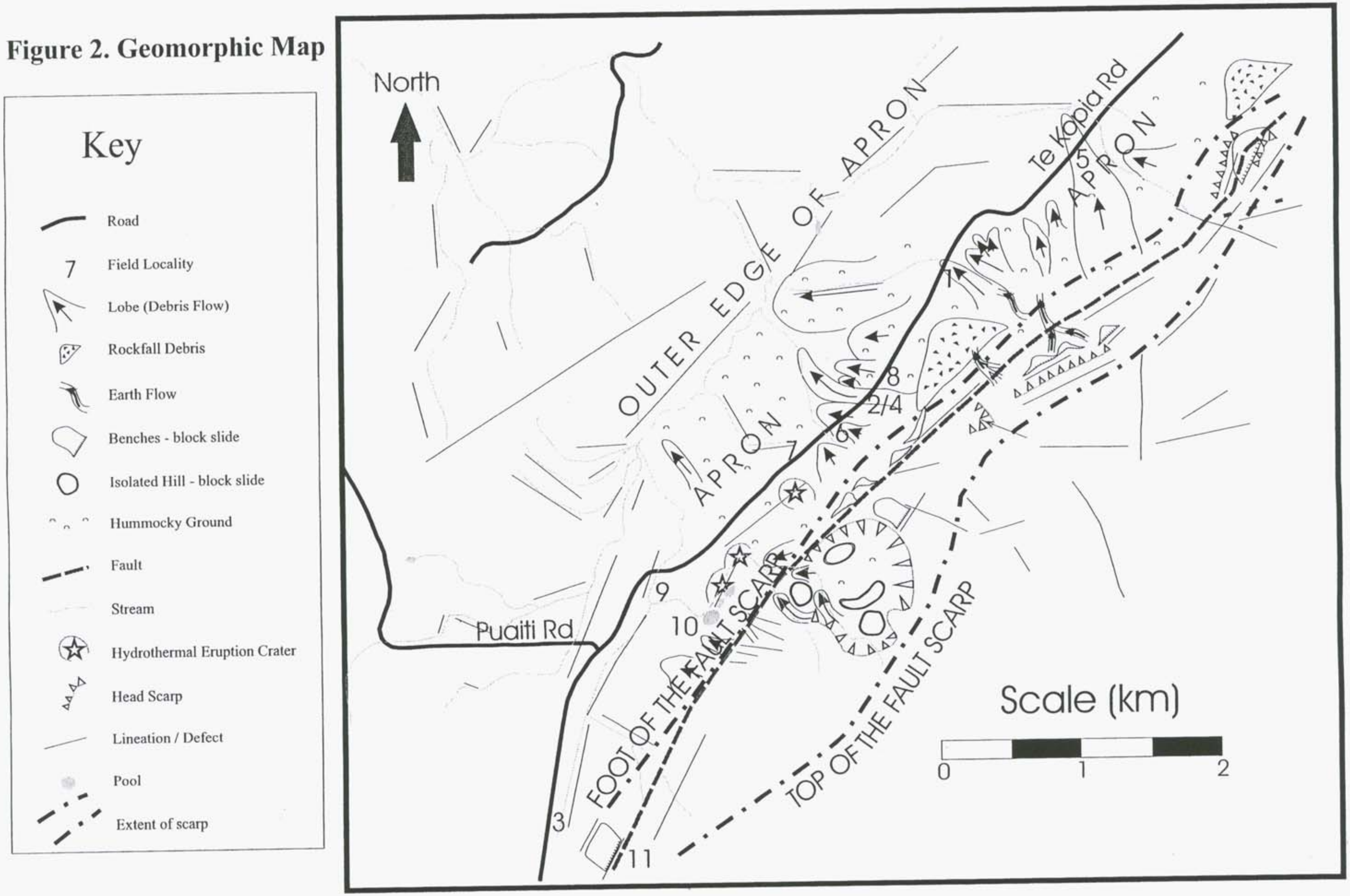
4.1 Thickness and Fabric

The thickness of slope deposits (i.e. localities 1 to 8) is highly variable, but can be broadly categorized into 2 classes. Slope deposits at outcrops 1, 2/4, 6 and 8 are all clast supported and > 0.5 m thick, reaching a maximum of 6.5 m at outcrop 214. There are two small exceptions. The upper flow deposit of outcrop 2/4, 0.5 m thick is assumed to have had a higher fluid content and was of less volume. It mantles the topography as opposed to constructing it. Outcrop 5, is a 0.3 m thick lens of matrix supported clasts, probably the result of reworking after initial deposition. The characteristic lobate morphology is still present, but is less distinctive than other deposits. This deposit is also much older than most within the field area, and so has been eroded longer. Outcrops 3 and 7 are thinner and matrix supported, with dominantly angular, flat lying clasts of a different lithology fiom the other slope deposits. The immediate surrounding morphology is very subdued, and its mode of emplacement is not obvious.

4.2 Clasts Analysis

Clasts from outcrops 1, 214, 5, 6, and 8 are different from those of outcrops 3 and 7, and hence reflect a different origin. Maximum clast size is > 1.2 m, and comprises dominantly sub-angular ignimbrite debris fi-om the fault scarp. Outcrop 2/4 has a distinct lateral zonation of clast lithologies, with pockets of totally clast supported silicified tuff. These pockets of Huka Falls Formation debris came from the top of the fault scarp, and were not brecciated into fine debris as at outcrops 3 and 7.

Figure 2. Geomorphic Map



In outcrops 3 and 7, maximum clast size is < 10 cm. Most clasts are angular and tabular, with their longest axis lying either vertically or horizontally. Clast lithology is dominated by fine grained tuffaceous sediments, probably from the now underlying Huka Falls Formation. Minor amounts of ignimbrite occur, and are suspected to be fiom the upper section of the Paeroa Ignimbrite, which underlies the Huka Falls Formation. This suggests one specific type of emplacement mechanism. The brecciated nature of the deposit, and its small maximum clast size indicates emplacement by a hydrothermal eruption. Circular depressions nearby which have been previously identified as hydrothermal eruption craters (MacKenzie, 1995) support this conclusion. Hence there are two types of slope deposits – landslide debris and hydrothermal eruption deposits.

4.3 Thermal Alteration

Thermal alteration is evident within both types of deposit, but shows different characteristics at each. The thick, dominantly clast supported, ignimbrite rich, debris deposits typically have mordenite alteration. This is characteristic of warm, near neutral pH heated groundwaters that interact with rocks marginal to the geothermal field, where surficial thermal expression is not always evident (Bignall and Browne, 1994). The thinner, matrix supported eruption breccias are highly silicificed, and probably came from the core of the geothermal field. The one exception is the pockets of coarse Huka Falls Formation debris within outcrop 2/4. These are also silicificed, however, but not so intensely as at outcrops 3 and 7.

Sourced from the top of the fault scarp, this indicates hydrothermal activity at Te Kopia has been more widespread than previously thought.

4.4 Younger Debris Flows and Earth Flows

Outcrop 10 exposes *6* separate units, all younger than 1.8 ka. They are a series of sandy gravel deposits, generally comprised of redeposited Oruanui Ignimbrite material, and Taupo Pumice. The oldest deposit at outcrop 10 is a clay rich, matrix supported, cohesive gravel. Clasts present are silica sinter, probably from the lower reaches of the fault scarp. The youngest deposit is a soft, plastic, clay with no clasts, and is considered to be an earth flow deposit fiom the nearby hydrothermal eruption craters. These craters are acid sulfate pools in an area dominated by soft plastic clay.

The above characteristics allow the deposits to be divided into three distinct classes.

1. Gravelly debris dominantly consisting of mordenite altered ignimbrite blocks, emplaced as debris flows (outcrops 1, 2/4, 5, 6, 8).
2. Gravelly deposits dominantly consisting of silicified tuffaceous sediments, emplaced as a hydrothermal eruption breccia (outcrops 3 and 7).
3. Cohesive clayey debris flows, and clay rich earth flows (outcrop 10).

4.5 Relationship to Cover Beds / Age

Slope deposits have been identified stratigraphically above the 1.8 ka Taupo Pumice Formation (TPF) (Froggatt and Lowe, 1990), outcrops 2/4, *6;* below the T.P.F and above the 8,530 C^{14} ± 10 yr Rotoma Ash (Froggatt and Lowe, 1990), outcrops 7 and 8; below the Rotoma Ash and above the 14,700 C^{14} ± 100 yr Rerewhakaaitu Ash (Froggatt and Lowe, 1990), outcrop 1; below the Rerewhakaaitu Ash and above in-situ *26.5* ka Oruanui Ignimbrite (Wilson, 2001), outcrops 3 and 5.

The relationship of the deposits to these marker horizons throughout the field area indicates that debris flows and thermal alteration have been occurring at Te Kopia for at least the last *26.5* ka (fig. *3).*

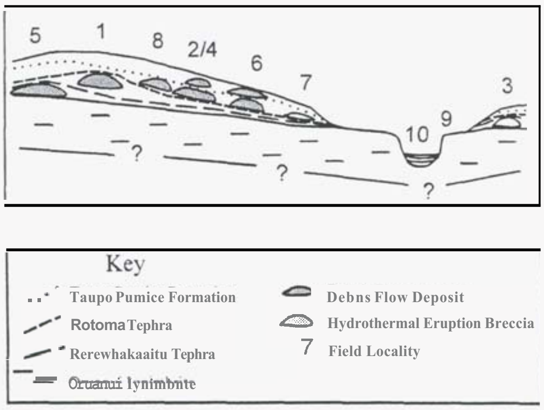


Figure 3. Stratigraphic Model

5. LANDSLIDING AT TE KOPIA

As mentioned, four distinct types of landslide mechanisms are evident within the Te Kopia area.

5.1 Debris Flows

Debris flow deposits are widespread through the area. The flow deposits dominantly occur marginal to, and on the northeastern side of, the thermal activity. This area presents a much steeper fault scarp than to the southwest. This is a function of two important features:

(i) Increasing density of fault splays towards the southwest, that accommodate the movement of the fault without producing a single fault scarp;

(ii) Mordenite - smectite hydrothermal alteration, an assemblage characteristic of warm (<120°), near neutral pH heated groundwaters. This alteration assemblage is present within all ignimbrite clasts analysed fiom the area. The alteration is commonly of volcanic glass, but the zeolite sometimes occurs within voids present in the rock. The alteration has significantly weakened the ignimbrite rock mass. Although individual runout distances are not always evident, where minimum deposit thickness and minimum runout distance can be seen, individual flow volumes regularly reach 15,000 m^3, but some exceed 400,000 m^3. It is unlikely that extreme rainfall alone would be sufficient to trigger flows that produce deposits of this size and nature. The occurrence of some slightly rounded clasts within the deposits suggests interaction of water during their deposition. Groundshaking caused by fault movement and / or hydrothermal eruptions is a possible trigger for landsliding, or a combination of the two. The stratigraphic relationship of the deposits to hydrothermal eruption breccias can help reveal the relationship between the two processes; landsliding and hydrothermal eruptions.

5.2 Rockfall

Rockfall at Te Kopia is presently constrained to local areas along the fault scarp. Fields of rockfall debris are more common at the northern extent, and northward of the field area. This is where the fault scarp is noticeably much steeper, and hence where oversteepening and erosion are most active. The jointed and fractured host ignimbrites are prone to regular rockfall. Debris fields were not visited, but the northernmost extent of altered debris flow deposits suggests that the thermal field was once larger than assumed,' or else activity has migrated to the southwest.

5.3 Earth Flows

Earth flows are a frequent event along the range front of the Paeroa Fault, and have been reported by local farmers to occur immediately after intense rainfall events. No obvious deposits are left after failure, suggesting a low volume with a high fluid content. Surficial debris and unwelded ignimbrite material are the two types of material most susceptible to this type of failure after prolonged, heavy rainfall. These earth flow failures occur both inside and outside of the thermally active area.

5.4 Block Sliding

Geomorphic mapping of the area reveals block slide deposits along the extent of the fault scarp. These are recognised as benches within the scarp. Block slide deposits are also identified to the south, adjacent to the thermal area, and are recognised as isolated hills within a large embayment, likely to be the source area. These deposits are assumed to have a structural control associated with the failure mechanism.

6. CONCLUSIONS

- Landslide deposits are numerous and widespread throughout the Te Kopia geothermal area, and have been occurring for at least the last 26.5 ka.
- Detailed analysis of the slope deposits and their dominant lithologies reveals two discrete classes of deposits.
    1. Gravels dominantly comprised of mordenite altered ignimbrite blocks, emplaced by debris flow (outcrops 1, 2/4, 5, 6, 8).
    2. Less abundant gravels dominantly comprised of silicified tuffaceous sediments, emplaced as hydrothermal eruption deposits (outcrops 3 and 7).
- Debris flow deposits are the most common type of landslide deposit in the area, presenting the highest hazard, and are dominantly marginal to the thermal field.
- Rockfall is a regular feature, and is constrained to areas of very steep relief, in fractured ignimbrite.
- Earthflows have a frequent occurrence along the entire length of the fault scarp, after prolonged, intense rainfall events.
- Block sliding occurs along the extent of the scarp, and can be recognised by benches or isolated hills below a similar sized embayment. Failure is probably associated with the rock defects and overall structure.

7. ACKNOWLEDGEMENTS

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