Preliminary Paleoseismic Assessment of the Wairoa North Fault

ARC Environment
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Preliminary Paleoseismic Assessment of the Wairoa North Fault

A report prepared for the
Auckland Regional Council

D.L Fellows
Woodward-Clyde (NZ) Ltd
Auckland, New Zealand
August 1996

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1.0 INTRODUCTION

The Wairoa North Fault has been identified by the Institute of Geological and Nuclear Science (IGNS) as presenting the greatest potential for future fault activity and consequent large earthquakes in the Auckland Region (Figure 1).

Auckland Regional Council (ARC) has commissioned Woodward-Clyde (NZ) Ltd to carry out a Stage 1 paleoseismic study of the Wairoa North Fault. This work is one of a number of studies being carried out for the ARC on earthquake hazard in the area.

The purpose of this study is to determine the feasibility of a detailed paleoseismic study through desk study and reconnaissance field work and to carry out an assessment of tectonic tilting of the river terraces on the Wairoa River and its tributaries. The overall aim is to determine whether the Wairoa Fault has been active recently (in the last 10,000 years).

1.1 SCOPE OF WORK

The work carried out for this study includes the following:-

1. Literature review of available information on the Wairoa North Fault and its tectonic setting.

2. Review of aerial photography, made available by ARC, flown in 1977 and 1980 to identify geomorphic features along the fault.

3. Production of a strip map of the fault at 1:25000 scale showing all geomorphic and geologic features related to faulting.

4. Review available drilling information for the area provided by ARC. Most of this information took the form of water bore logs and lacked detailed geologic descriptions to enable confident correlation of strata between boreholes.

5. Carry out reconnaissance level field work to validate the fault map and identify

potential sites for future trenching or drilling investigations. This targeted streams and terrace surfaces likely to record Quaternary deformation.

6. A survey of river terraces heights associated with the Wairoa River north of the Wairoa Gorge and its tributaries to assess any tectonic deformation. This work was contracted to CKL Surveys to record spot heights by Global Positioning System (GPS) methods. A Trimble Series 4,000 GPS total station with real time kinematic method was used for this work. A base station was set up centrally within the survey area at a known location with a roving station picking up the spot heights. Accuracy of the GPS locations are ±10 mm in the horizontal direction and ±30 mm in the vertical direction. Terrace profiles were drawn from these data.

7. Prepare a report presenting all data collected, recommending sites that warrant detailed investigation, together with the nature of these proposed investigations.

2.0
TECTONIC SETTING

The Auckland Region is located to the west of the active Tonga-Kermadec subduction zone. The motion of the subducted plate is oblique to the subduction zone and the complex geological structure of the eastern and central North Island and South Island results from this. The Auckland Region is characterised by oblique extensional tectonics which form a dominant system of rectilinear faults. This area is known as the Auckland - Northland Block Faulting Province (Berryman 1984).

The geological structure preserved in the rocks records two major periods of deformation (Schofield 1976). The first, known as the Rangitata Orogeny, produced a compressional regime giving rise to NE-SW to N-S trending reverse faulting and folding. This occurred during the late Jurassic and Lower Cretaceous periods (120-150 million years ago).

The second and most recent period of deformation occurred from late Miocene to Pliocene times (7 to 2 million years ago). During this period the deformation was dominated by the formation of the rectilinear fault system which is well developed south and east of Auckland City. The Hauraki Rift, east of Auckland City, also formed during this period. Both fault systems appear to follow the pre-existing geological structures (Sporli 1989, Hochstein and Ballance 1993). The Auckland basaltic volcanoes also formed during this time with the youngest being Rangitoto at 600 years old.

The Wairoa North Fault trends NNW-SSE and parallels the Hauraki Rift, Geological mapping indicates Tertiary aged deposits on both sides of the Wairoa North Fault. The strike of the fault coupled with the distribution of deposits suggests that it is related to the most recent period of deformation.

3.0
WAIROA NORTH FAULT

3.1 INTRODUCTION

The Wairoa North Fault is a NNW-SSE trending fault downfaulting Mesozoic basement rocks to the west by approximately 250 m (Cocks 1993). The resultant fault angle depression has been infilled with Pleistocene and recent sediments and is known as the Hunua Basin. The Hunua Basin is drained by the Wairoa River through the Wairoa Gorge.

3.2 GEOLOGICAL SETTING

The geological strata recognised in the vicinity of fault are: (Schofield 1976, 1979).

1. Basement greywackes of Jurassic age

2. Tertiary sediments encompassing very weak to moderately strong sandstone, siltstone, mudstone, limestone, and conglomerate and coal measures. Remnants of these deposits are preserved across the fault.

3. Marine-deposited sediments and alluvium composed of sand-silt, mud, clay and lignite with microflora and shell fossils.

4. Localised volcanic deposits composed of basaltic tuffs and lava flows of Quaternary age (1.6 - 0 million years).

5. Recent (<10,000 years old) alluvial deposits including gravels, peat and sands restricted to stream valleys and within the fault angle depression.

3.3 PREVIOUS WORK

The Wairoa North Fault was first described by Hochsetter (1864), with some detailed field work by Mead (1930), Firth (1930) and Laws (1931). All workers recognised the prominent fault determining the eastern side of the Hunua Depression which extends from the Mangawheau River to the south to near Clevedon in the north and comprises a total distance of 24 kilometres. Mead (1930) identified a fault plane exposure at Cosseys Creek and this was noted in mapping by Schofield (1976) and elaborated by Cocks (1993).

Schofield (1976, 1979) mapped the geology of the fault at 1:63,360 scale and indicate that the fault is comprised of 3 segments each being progressively offset to the east. This report names these segments from north to south as: Clevedon, Hunua and Paparimu Segments. The Clevedon segment is the northern most segment and is shown as a concealed fault beneath Quaternary sediments as it parallels the Wairoa River. It passes into the Wairoa Gorge where Mesozoic greywacke lies to the west of the fault. Schofield (1976) observed the fault in this segment to dip 65^0E striking north-northwest.

Along the Hunua segment (middle segment) of the fault, Tertiary rocks are faulted against greywacke indicating an approximate throw of 100 m (Hull et al 1995). Greywacke and Quaternary alluvium also lie to the west of the fault with the alluvium being deposited within the fault angle depression. Schofield (1976) also shows basalt at Hunua Falls is located only on the downthrown side of the fault. These lavas are dated by Briggs et al (1994) at 1.30 million years. Schofield shows that these rocks are in faulted contact with Mesozoic greywacke and suggests that most fault displacement is post 1.30 million years. Tertiary aged sandstone is mapped on both sides of the fault and is also shown to have a faulted contact with greywacke. Cocks (1993) studied the Hunua segment of the fault in detail in an attempt to carry out a paleoseismic assessment of the fault. He found two exposures of the fault plane, one showing Tertiary rock faulted against greywacke with a 10 m wide shear zone dipping 72^0-74^0W. The second exposure shows greywacke on both sides of the fault with the fault gouge being preserved as an upstanding ridge in an eroding stream bed. It is recorded as being of a "similar orientation" to that seen at the first location ie approx. dipping 70^0W. Cocks (1993) carried out Scanning Electron Microscope (SEM) quartz grain surface texture analysis to suggest that there have been two or more phases of fault movement at both fault plane exposure sites. Using the surface texture results from his study Cocks compared these to results of similar studies by Kanaori et al (1985) who also utilised an absolute dating method of Electron Spin Resonance (ESR). The results suggest that the Hunua segment of the Wairoa North Fault has been active in the last 10 million years, probably active within the last 0.5 million years and possibly active more recently.

The Paparimu segment (southern segment) of the Wairoa North Fault has been named as the Wairoa South Fault by Schofield (1976). Here greywacke and Quaternary alluvium lie to the west of the fault. No exposure of the fault plane has been mapped.

Hull et al (1995) noted possible fault sag ponds, and an offset ridge and stream along all three segments of the fault which supports the idea of late Pleistocene activity. These features have prompted the commissioning of this study and will be discussed further in later sections of this report.

The Waikopua Fault may be the northward extension of the Wairoa North Fault (Firth 1930, Prebble 1991).

3.4 GEOMORPHIC EXPRESSION

As previously noted the Wairoa North Fault is seen as the prominent fault determining the eastern side of Hunua Basin. The regional geomorphic expression of the fault is the steep edge western margin of the Hunua Ranges. Typical slope angles are 1v:2h. Where the fault is bounded by greywacke the fault is observed as a distinctive lineation with offset ridges and spurs.

At a local level streams appear to have flowed along the fault trace eroding either the softer fault gouge material or Tertiary aged deposits. Hence it is common to find streams flowing parallel with the range front, for some distance, rather than flowing into the valley. Such stream flow paths give the impression that they have been displaced by strike-slip fault movement. This is not the case as fault movement is observed in the field as pure dip slip (ie. vertical movement). This evidence includes displaced greywacke rock, and fault plane exposures with vertical slickensides.

Often associated with these stream flow directions are the formation of swampy ground which may represent sag ponds formed by fault movement.

4.0 EVIDENCE FOR LATE QUATERNARY DEFORMATION

4.1 INTRODUCTION

The location of the fault as identified from this study is shown on the strip map given in Figure 3. Site specific description of all locations identified is presented in Appendix B. Also presented on the strip map is the location of any drilling information made available by ARC and the location of river terrace profiles drawn up for the Clevedon segment of the fault.

4.2 CLEVEDON SEGMENT

The Clevedon segment of the Wairoa North Fault is 9.5 km long commencing at Clevedon in the north and terminating at the southern end of the Wairoa Gorge. Schofield (1976, 1979) shows this segment to be located beneath Quaternary deposits in the north and within Greywacke to the south. It strikes 315^0 (grid north) near Clevedon and curves to strike 350^0 (grid north) at the Wairoa Gorge.

The review of aerial photography, field reconnaissance, review of borehole data and surveying of the Wairoa River terrace surfaces has revealed the following:-

1) No fault traces on any Quaternary surfaces were observed.
2) No fault plane exposures were observed.
3) Borehole information available was projected onto a single section in an attempt to assess displacements on discrete strata (Figure 4). The borehole logs lack accurate descriptions to enable confident strata correlation. Descriptions such as "sticky blue clays" could describe Quaternary alluvial deposits, Tertiary aged mudstones or highly weathered greywacke mudstones. Boreholes 1, 2, 4 suggest 45 to 50 m of Quaternary deposits (namely clays, gravels and peat) infilling the valley.

   A similar thickness of deposits between these boreholes suggests that no offset has occurred and that the fault is located either to the east or west of these boreholes.

4) The river terraces along the Wairoa River have been surveyed by GPS methods. The results are presented in Appendix C. The spot heights were taken across a variety of Quaternary terrace surfaces as mapped by Schofield (1979). These spot heights have been used to profile the terrace surfaces along the Wairoa River from the gorge to the coast by matching the heights of various surfaces. The resultant profile is presented in Figure 5. The surface nomenclature used in the profile follows the stratigraphy set up by Schofield (1979). This stratigraphy is subdivided according to the height of the terrace surfaces which are underlain by clays and gravels. The oldest and highest is labelled tq and represents alluvium underlying terraces 60 m and higher; followed by tb terraces which are greater than 25 m and less than 60 m; pb1 and pb2 surfaces are younger terraces at 15 m - 25 m high and 2-8 m higher respectively. The tq terraces are not present along the Wairoa River. The tb terraces are preserved as scattered remnants and were not recorded in the survey. Holocene sediments have been subdivided based on type of deposit such as beach (pr) and stream alluvium and swamp deposits (pa).

Figure 5 presents the heights of the terraces as surveyed against a longitudinal section along the Wairoa River. The location of this section is shown on Figure 3. Different symbols have been used for the various terrace surfaces. Where the terrace surfaces are observed from mapping to clearly extend down valley, the spot heights have been joined together by a solid line to represent a continuous terrace surface. Where the terrace surfaces have been mapped by Schofield (1979) as remnant surfaces the spot heights have not been connected together. River terrace systems can be expected to show a gradient downstream to sea level. Where a spot height is taken on a terrace surface close to the margins of the valley and a tributary stream, it is common to find that this height is greater than the similar surface in the middle of the valley. The reason is that the surface is a fan formed on the valley margin and grades into the valley centre. These spot heights are labelled with the associated stream names on Figure 5.

The pb 1 and pb 2 surfaces are the most extensively preserved surfaces along the Wairoa River. Since the Wairoa North Fault cuts across Wairoa River Valley almost at right angles it can be expected that any offset river terraces would have higher spot heights on the downstream side of the fault. The spot heights on the expected upthrown and downthrown sides of the fault have been differentiated to assist in identifying displacements.

Both the youngest surface (pa) of Holocene age and the pb 2 surface indicate smooth terrace profiles with downstream gradients that are not displaced by the fault.

The early Pleistocene pb 1 surface may be tilted by 3 m. This is only evident on the remaining pb 1 surface at Clevedon (see Figure 3). No distinctive fault trace is observed on these surfaces as the fault either falls on or to the West of the edge of the pb 1 surface where it parallels McNicol Road. There are insufficient surfaces remaining on the west side of the valley to provide a better location of the fault.

The ages of the Quaternary terraces in the Wairoa River Valley are unknown. There is no radiocarbon or other type of dates for these deposits. Schofield (1979) suggests that the pb 2 terrace is late Holocene in age and the pb 1 terrace is early Pleistocene. Waterhouse (1978) indicates that similar terraces in the Raglan area contain reworked ash from the Ahuroa Volcano which erupted after the 65-76 m sea level and before the 34-40 m seal level. The pb 1 terrace is certainly younger than the volcanic deposits (ie less than 0.5 million years) possibly about 400,000 years. Such tentative age correlations provide only a crude age estimate with considerable uncertainty.

5) Within greywacke the fault is observed to offset ridges and spurs and form geomorphic lineations. These locations are summarized in Appendix B.

Summary

There is no evidence for displacement on this segment of the fault in the last 10,000 years. Tentative survey results suggest the pb 1 terrace surface may be tilted by up to 3m. The age of this surface is not known but may be approximately 400,000 years old. This suggests that the fault may be a Class III active fault (Grant Taylor et al 1979).

4.3 HUNUA SEGMENT

The Hunua segment of the Wairoa North Fault is approximately 8 km long commencing at the southern end of the Wairoa Gorge and terminating at Moumoukai Road. Schofield (1976) maps the fault to juxtapose Greywacke against Tertiary and Quaternary aged deposits. The fault consistently strikes at 345^0 (grid north).

The review of aerial photography and drilling data, field reconnaissance, and surveying has revealed the following:-

1) Possible offset terrace surfaces and associated swampy ground (sag pond) on either side of Cosseys Access Road. As shown on Figure 6, a narrow terrace or fan surface remains immediately to the south of Cosseys Road Access. The surface slopes at 1v:50h towards the valley and is a fan surface with elevation varying from 60 m to 51 m a.s.l. There is no distinctive fault scarp across the surface however a survey profile suggests that the surface may be deformed by 1.5 m. This profile is presented as section C-C' in Appendix C. Cocks (1993) mapped this surface as the Cossey's Terrace level (T2) and noted that Waterhouse (1978) assigned a Holocene to early Pleistocene age (last 400,000 yrs). As discussed in the Clevedon segment there is no dating information available for these Quaternary deposits. Correlation with deposits described by Waterhouse (1978) and broad age classifications can only provide crude age estimates. The age of this surface is unknown but it is certainly higher and older than the adjacent Holocene surface. At the toe of this surface is swampy ground which may be a sag pond resulting from fault movement.

   Immediately north of Cosseys Access Road a Holocene aged surface may also be displaced. Surface survey suggests a displacement of 0.7 m (Section B-B, Appendix C). There is no swampy ground associated with this surface. A third slightly lower surface appears to be an erosional surface and does not show any clear sign of deformation (Section A-A', Appendix C). The age of this surface is not known.

   An alternative interpretation for these features is that all three surfaces and the swampy ground are the result of degradation of a constructional terrace surface due to changes in the river patterns.

If the apparent deformation features observed at this location are fault related then a likely fault history is one movement of 0.7 m pure dip slip, displacement in the last 10,000 years and perhaps another older event of similar magnitude possibly in the last 400,000 years.

These features need to be confirmed by trenching.

2) Two fault plane exposures have been identified on this fault segment. The northern most, mapped by Schofield (1976) and Cocks (1993), is still partly exposed although heavily covered with slope wash materials. This exposure shows Greywacke against Tertiary-aged sandstone and conglomerates. No Quaternary deformation is recognised at this site.

The southern exposure mapped by Cocks (1993) shows a fault plane within Greywacke dipping 84^0 NW and striking 324^0 (Magnetic North). The exposure has improved since the 1993 mapping and the relationship between the Greywacke and the overlying Quaternary deposits can be observed as shown in Figure 7. The unconformable contact is relatively flat and shows no evidence of displacement. Therefore, this fault has not ruptured since the deposition of these materials. Cocks (1993) reports on age of 330 ±60 years on this deposit. This is the only known date for any Quaternary deposit in the study area.

3) Drillhole data made available by ARC is all located on the downthrown side of the fault. This information together with geological mapping has been compiled onto Figure 8. A tentative correlation is made between the Tertiary limestone described by Schofield (1976) and the shells and white clays described in borehole 12. Cocks (1993) mapped an unconformable contact between limestone and greywacke (locations K, L) near Cosseys Access Road. These exposures are on the upthrown side of the fault. This correlation suggests a displacement of approximately 120 m in approximately 20 million years.

4) At localised locations stream flows follow the softer fault gouge materials and thus parallel with the range front. Often swampy ground is associated with this

geomorphic arrangement. These locations are shown on Figure 3 and listed in Appendix B.

5) Within the Greywacke the fault is seen as lineations or offset spurs as detailed in Appendix 2.

Summary

The fault is seen, in this segment, as a steeply dipping normal fault upthrown to the east. Drilling information suggests 120 m displacement in 20 million years. Possible offset terrace surfaces have been identified. If these features are fault related they suggest 2 movements up to early Pleistocene times (possibly in the last 400,000 years), with the most recent event being 0.7 m dip slip in the last 10,000 years. There has been no fault movement in the last 330 years. This suggests that this segment of the fault may be a Class II active fault (Grant-Taylor et al 1979).

4.4 PAPARIMU SEGMENT

The Paparimu segment of the Wairoa North Fault is equivalent to the Wairoa South Fault as mapped by Schofield (1976). It is approximately 9 km in length commencing at Moumoukai Road to the north and terminating about 1 km northeast of Mangatawhiri. Its termination is identified from aerial photograph interpretation. The fault consistently strikes at 350^0 (Grid North).

The review of aerial photography and drilling data, fielding reconnaissance and surveying has revealed the following:-

1. No fault plane exposures were observed.
2. A single fault trace crossing the Paparimu Terrace surface immediately east of Paparimu township is identified (as shown on Figure 3). The trace is 100 m in length and survey profiling shows it to be 4.5 m high (Section D-D' Appendix C). The Paparimu surface is believed to be early Pleistocene age (approximately 400,000 years) and is likely to represent a series of coalescing fans. As with the discussion of ages of terrace surfaces associated with the previous fault segments there are no known dates for these terraces. Very approximate ages have been

assigned in this discussion based on correlation with deposits described by Waterhouse (1978). Immediately north of the trace in the stream valley floor the Holocene aged Pa surface does not appear to be displaced (Figure 9). This lower surface has been disturbed by the formation of an access track into the small quarry in the valley floor. On the northern side of the stream is a well developed sag pond which extends about 300 m to the north.

3. At several locations along the range front distinctive breaks in slope are noted at the base of the Greywacke range (see Figure 3, Appendix B). These are interpreted to be fault traces which may represent the last faulting event.
4. Drillhole data made available by the ARC are all located on the downthrown side of the fault. Borehole 16 indicates about 100 m of Quaternary infill within the valley floor. Borehole 17 shows 25 m of Quaternary deposits overlying "rotten rock". Should this description be correct, it suggests that the downthrown block is tilted towards the east or that relief on the basement existed at the time of deposition.
5. As with the Hunua Segment streams are observed, at localised sites, to flow parallel with the range front. These locations are shown on Figure 3 and listed in Appendix B.
6. Within the Greywacke the fault is seen as lineations and offset spurs as detailed in Appendix B.

Summary

Along this segment a single fault trace displacing the Paparimu surface has been identified. The fault trace displaces this surface by 4.5 m, suggesting 4.5 m of movement possibly up to early Pleistocene times (in last 400,000 years) ie. an average slip rate of 0.01 mm/year. This suggests the fault may be a Class III active fault (Grant-Taylor et al 199).

5.0
FURTHER WORK

5.1 SUGGESTED SCOPE OF WORK

The area of greatest uncertainty within this study is the age of the Quaternary deposits that appear to have been displaced by the Wairoa North Fault. Such large uncertainties on these ages affects the ability of this study to assess, with any level of accuracy, the activity and recurrence interval of this fault. As a result mapping and dating of Quaternary surfaces together with trenching of fault traces to obtain recurrence intervals should be the top priority.

It is suggested that a three phase approach be used for further work and investigations of this active fault. These are mapping and dating of the Quaternary surfaces, trenching of fault traces and drilling. Quaternary mapping of the terraces around the Paparimu segment should be carried out in detail. Such mapping would confirm the terrace sequence and ensure that all possible exposures containing datable material are found. The ability to obtain accurate Quaternary ages on the displaced deposits may depend on such mapping. Mapping of the contact between the basalt at Hunua Falls and the greywacke may assist in understanding the relationship between these deposits. However, it is unlikely to provide any information on faulting recurrence in the late Quaternary. The possible tilted terrace sequence on the Clevedon segment should also be investigated further.

This study has identified three locations that warrant trenching investigations. These are in order of priority:-

1. Fault trace on the Paparimu Segment with a maximum scarp height to 4.5 m.
2. Possible 1.5 m terrace surface deformation on the Hunua Segment at Cossey's Access Road.
3. Possible 0.7 m terrace surface deformation on the Hunua Segment at Cossey's Access Road.

The advantages of trenching would be to expose the fault plane in the side wall of a trench in order to identify various strata offset by the fault and obtain a fault displacement history.

The development of a fault displacement history is dependent on the definition of the ages of displaced strata. It may be possible to obtain samples for dating from the trench sites. Radiocarbon dating of carbonaceous materials will only date materials less than about 40,000 years of age. Accelerator Mass Spectrometry (AMS) radiocarbon dating is also available for very small samples of carbonaceous materials. This technique has similar age restrictions to standard radiocarbon dating. To obtain older chronology of fault movement it may be necessary to use other absolute dating methods such as fission track. Fission track dating requires glass shards from volcanic deposits and this is dependent on the preservation of volcanic deposits in the stratigraphic record. It is likely to take significant field time to locate such deposits, if they are at all preserved in the geological record.

Prior to any trenching it would be advisable to carry out detailed mapping of the Quaternary deposits. The advantage of this would be to provide a clear understanding of the Quaternary stratigraphy early in the project.

A drilling programme would be warranted where particular strata can be correlated across the fault to determine offsets of the strata. Drilling is unlikely to provide sufficient information on Quaternary recurrence intervals or significant material for dating. The Hunua Segment is probably the most appropriate portion of the fault for a drilling programme as Tertiary deposits are preserved on both sides of the fault. Exact locations of proposed drillholes should be confirmed following detailed mapping and trenching.

Should trenching provide insufficient strata or material for dating it would be prudent to supplement the trench site with stratigraphic drilling.

6.0
CONCLUSIONS AND RECOMMENDATIONS

The Wairoa North Fault is a normal fault forming the eastern margin of the Hunua Basin. It is divided into three discrete segments : Clevedon, Hunua and Paparimu.

Evidence of Quaternary fault movement on the Clevedon Segment is restricted to possible tilted terrace surface related to 15 m to 25 m high terrace surface, known as the pb 1 surface after Schofield (1979). This suggests about 3 m displacement on a terrace surface of unknown age (possibly 400,000 years from geological correlation).

Possible displaced terrace surfaces have been identified on the Hunua Segment. These suggest two fault events since the early Pleistocene (in the last 400,000 years) with the most recent being 0.7 m vertical movement in the last 10,000 years. There has been no movement in the last 330 years. This fault history needs to be confirmed by trenching.

A 4.5 m high fault scarp has been identified on the Paparimu Segment. It displaces the Paparimu Surface which has an approximate age of early Pleistocene (400,000 years).

Evidence of Quaternary fault movement has been identified on all segments of the fault. Dating of fault movements in this study is extremely tentative and is based on regional geological relationships. As a result it is evident that the Wairoa North Fault is an active fault. Based on the Grant-Taylor et al (1979) classification system it may be a Class III fault because it has a movement history in the last 50,000 to 500,000 years. As a result it is likely to present a relatively low hazard to the Auckland Region.

However, a possible faulting event is identified on the Hunua Segment in the last 10,000 years. This event would classify the fault as Class II and which would present a more significant hazard to the Auckland Region. Because there is such large uncertainties regarding the ages of faulted Quaternary deposits it is not possible to carry out detailed interpretation of the faulting history and associated hazard. Since it is evident that the Wairoa North Fault is an active fault, further investigations appear warranted and have been recommended.

Recommended further investigations include Quaternary mapping and dating, trenching and drilling. Three trench sites have been recommended for future work together with drilling investigations, targeting the Hunua and Paparimu Segments.

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APPENDIX A
AERIAL PHOTOGRAPHY USED

SN 5783	
Flown 24-10-80	Run R No 22-24
Scale 1:15000	Run S No 22-24
SN 5164	Run A No. 3-4
Flown 1977	Run B No 4-6
Scale 1:25000	Run C No 5-7
	Run D No 5-7
	Run E No 6-7
	Run F No 4-6

APPENDIX B
LOG OF LOCATIONS

Clevedon Segment

Grid Reference	Feature Type	Description
S11 26917080 E 6466200 N (Clevedon)	Possible tilted terrace surface	Identified from surveying of terraces. Pb 1 terrace surface tilted by approximately 3 m.
S11 2695000 E 6462400 N	Lineation	Lineation within greywacke determined to be fault trace.
S11 2695200 E 6461400 N	Offset spur	Greywacke spur offset by c.120 m. Upthrown to the east.
S11 2695300 E 6461000 N	Lineation	Lineation within greywacke

Hunua Segment

Grid Reference	Feature Type	Description
S12 2696180 E 6458190 N to 2696080 E 6458200 N (Cosseys Access Road)	Possible offset terrace sequence	Two separate surfaces possibly offset by 1.5m and 0.7m respectively. The higher surface may be 400,000 years of age and the lower surface of Holocene age.
S12 2696250 E 6457800 N (Cosseys Stream)	Fault Plane Exposure	Previously mapped by Schofield (1979) and Cocks (1993). Fault plane and gouge zone covered with slope debris. As described by Cocks (1993) Tertiary aged conglomerate, sandstone and limestone faulted against Greywacke Contact dips 75^0 S to SW.

Grid Reference	Feature Type	Description
S12 2696300 E 6457600 N	Lineation	Cossey's Creek probably flows along the fault plane parallel to the range front.
S12 2696400 E 6457300 N to 2696400 E 6456800 N	Lineation	Lineation within greywacke. Probable fault location
S12 2696500 E 6456620 N (East of Camp Adair)	Possible fault trace on two Quaternary Surfaces	Approximately 2m high fault scarp on a unidentified possibly Quaternary surface adjacent to approximately 1m high scarp on lower surface. Only 50m long and cannot be traced across the creek to similar surfaces. Strike of feature 320^0 MN
S12 2696650 E 6455700 N to 2696750 E 6455500 N (East of Camp Adair)	Possible sag ponds	Fault located at change in slope at base of Greywacke range. Well developed swamp identified with poor drainage (Possible sag ponds)
S12 2696700 E 645500 N to 2697050 E 6454500 N	Lineation	Lineation within greywacke. Probable fault location
S12 2697100 E 6454380 N	Fault Plane Exposure	Location of fault plane exposure in creek previously mapped by Cocks (1993). Fault plane displaces Greywacke, strikes 324^0 MN and dips 84^0SW. Unconformity between greywacke and overlying alluvium is not displaced. No evidence of Quaternary deformation.

Grid Reference	Feature Type	Description
S12 2697100 E 6454300 N to 2698200 E 6452000 N	Lineations	Lineations within greywacke. Probable fault location.

Paparimu Segment

Grid Reference	Feature Type	Description
S12 2699700 E 6451300 N	Possible fault scarp	Note: unable to find landowner to gain entry permission. Site not investigated further.
S12 2699650 E 6451000 N	Possible Sag pond	Swampy area in valley floor where streams flowing along fault plane join.
S12 2699800 E 6450600 N	Lineation and swampy ground	Stream flows along a linear valley which probably represents the fault plane located within greywacke. The localised swampy ground exists in the valley floor.
S12 2700160 E 6448820 N (East of Paparimu)	Fault scarp displacing Quaternary Surface	4.5 m high fault scarp displacing Paparimu surface, striking 322^{0}MN. Paparimu surface is late Pleistocene in age (Schofield 1979). Recent alluvium in stream to north has been modified by work in the local quarry and it is not possible to identify any deformation. Well developed swampy ground to the northeast of fault scarp in stream floor.
S12 2700400 E 6448500N to 2700480 E 6447840 N	Possible fault scarp	Possible fault traces approximately 1 m high, traverses base of slope of edge of Greywacke range. Cannot be traced continuously along the foot of the hill. Located swampy ground where streams cross the fault.

Grid Reference	Feature Type	Description
S12 2700500 E 6447800 N to 2701000 E 6443300 N	Lineation	Lineation within greywacke. Probable fault location

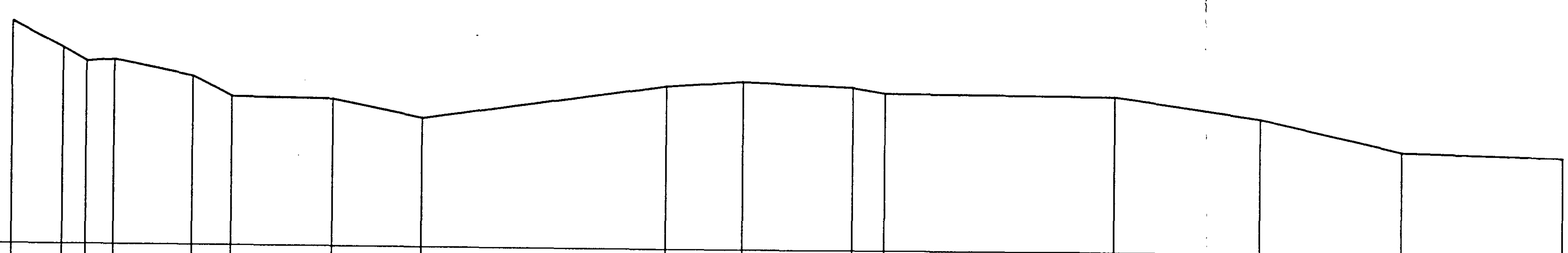
APPENDIX C
SURVEYING RESULTS

CKL surveyors of Hamilton carried out spot height surveys of the river terrace surfaces associated with the Wairoa River on the Clevedon segment of the Wairoa North Fault. This company also surveyed the profiles of possible fault traces. The results of these surveys are presented in this Appendix.

The spot heights are presented as a 1:25,000 overlay on geodetic grid. A series of points have been converted to NZ map grid to assist in the overlay. This points are presented below should readers wish to carry out any overlay work.

	Circuit (metres)		NZMG (metres)	
Pt Name	Northing	Easting	Northing	Easting
1	687483.93	324942.63	6465872.92	2692369.53
2	686409.86	323677.86	6464824.97	2691082.95
1129	691049.41	326140.88	6469413.22	2693640.70
1008	690367.94	328926.91	6468674.71	2696412.27
1108	685277.02	322921.99	6463707.82	2690303.99
1096	683801.38	327454.50	6462139.52	2694805.44
100	675924.88	327933.89	6454254.64	2695123.25

95811



Datum R.L. 37.000

Natural surface	43.52	42.74	42.35	42.42	41.94	41.36	41.31	40.78	41.78	41.94	41.79	41.63	41.57	40.94	39.99	39.84
Chainage Hz scale 1:500 Vt scale 1:100	0.00	7.41	10.83	14.86	26.23	31.92	46.58	59.69	95.19	106.42	122.42	127.10	160.45	181.50	201.93	225.27

Longitudinal section of A'–A

Amendments	Date

CKL SURVEYS Land & Engineering Surveyors
Land Development Consultants

Carter Keucke & Latham Ltd. Members of the Consulting Surveyors of N.Z.

HAMILTON TE AWAMUTU COROMANDEL

WOODWARD CLYDE

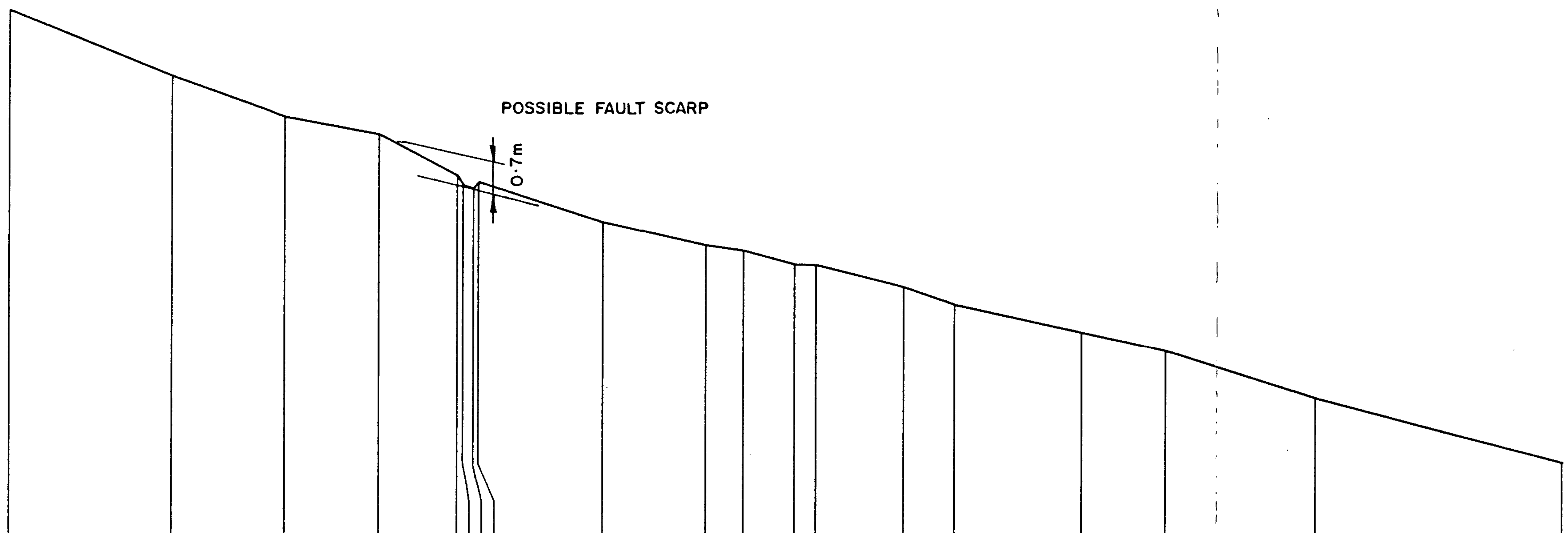
GPS FIX

Prepared for

WOODWARD CLYDE

DRAWN B.F.ENDRES | CHECKED | SCALES H 1:500 V 1:100
TRACED | DATE 18 MAR 1996

SHEET
SERIES OF
COMP No. A112
JOB REF 95811



Datum R.L. 40.000

Natural surface	54.22	52.45	51.35	50.88	49.76	49.54	49.44	49.62	48.55	47.91	47.77	47.40	47.38	46.79	46.31	45.56	45.06	43.80	42.09
Chainage Hz scale 1:500 Vt scale 1:100	0.00	21.64	36.84	49.44	59.83	60.62	61.91	62.63	79.12	93.18	98.26	105.09	107.94	119.62	126.48	143.59	154.73	174.89	207.82

Longitudinal section of B'–B

Amendments	Date
POSSIBLE FAULT SCARP DETAIL ADDED	23/4/96 (SCG)

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Land Development Consultants

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HAMILTON TE AWAMUTU COROMANDEL

WOODWARD CLYDE

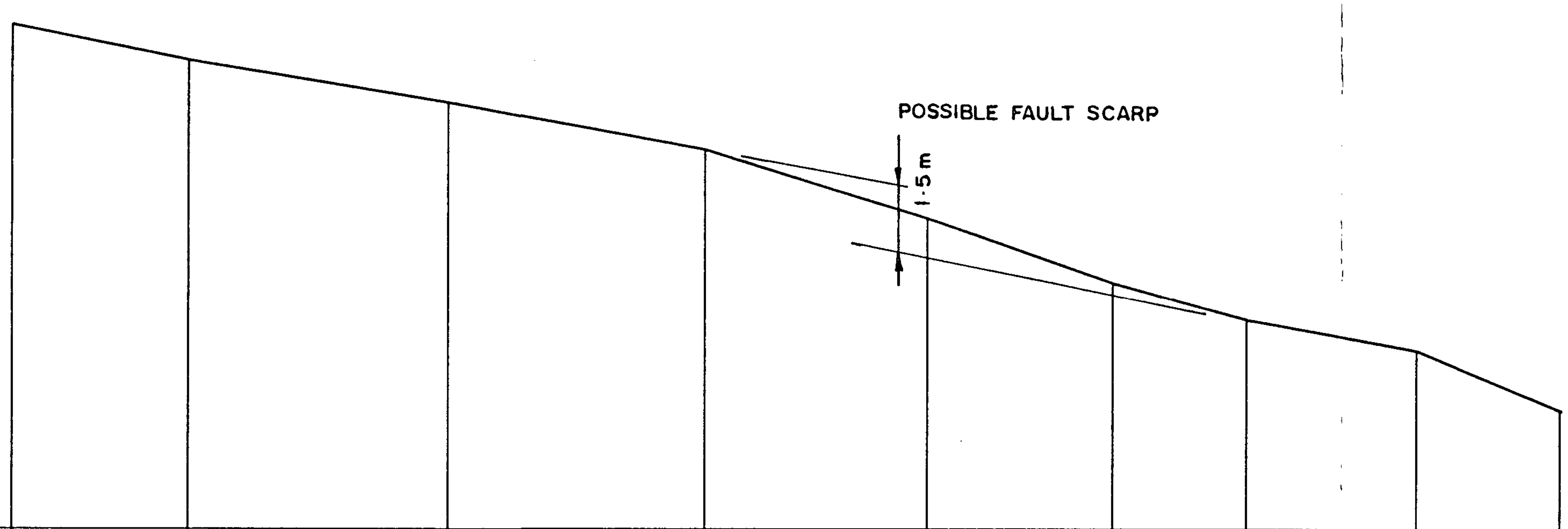
GPS FIX

Prepared for

WOODWARD CLYDE

DRAWN B.F. ENDRES	CHECKED	SCALES H 1:500 V 1:100	SHEET
TRACED	DATE 18 MAR 1996		SERIES OF
			COMP No. AMS
			JOB REF 95811

95811



Datum R.L. 49.000

Natural surface	60.27	59.48	58.54	57.49	55.94	54.50	53.68	52.99	51.66
Chainage Hz scale 1:500 Vt scale 1:100	0.00	19.52	48.25	76.94	101.50	122.18	136.94	155.84	171.62

Longitudinal section of C'–C

Amendments	Date
POSSIBLE FAULT SCARP DETAIL ADDED	23/4/96 (SCG)

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Land Development Consultants

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HAMILTON TE AWAMUTU COROMANDEL

WOODWARD CLYDE

GPS FIX

Prepared for

WOODWARD CLYDE

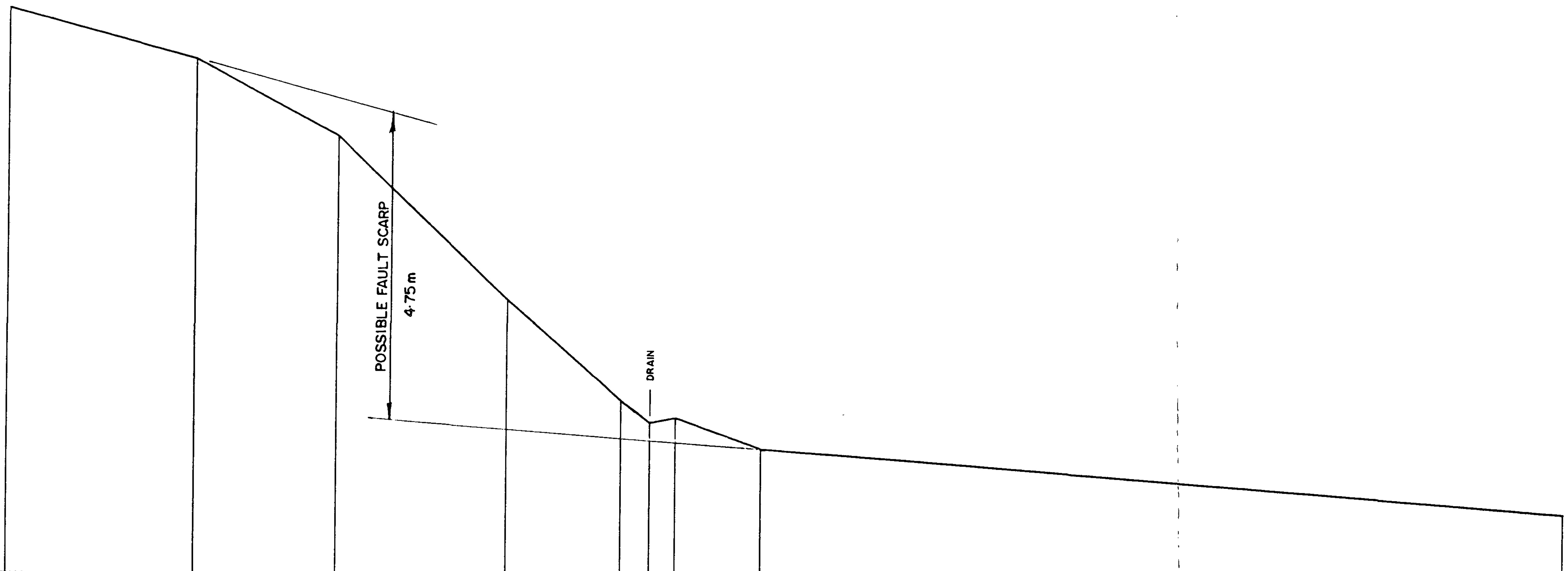
SHEET

SERIES OF

DRAWN B.F.ENDRES | CHECKED | SCALES H 1:500 V 1:100 | COMP No. AHZ

TRACED | DATE 18 MAR 1996 | JOB REF 95811

95811



Datum R.L. 133.000

Natural surface	141.77	141.00	139.82	137.30	135.75	135.41	135.49	135.02	134.11
Chainage Hz scale 1:250 Vt scale 1:50	0.00	14.46	25.42	38.53	47.33	49.50	51.50	58.10	119.82

Longitudinal section of D'–D

Amendments	Date
FAULT SCARP DETAIL ADDED	23/4/96 (SCG)

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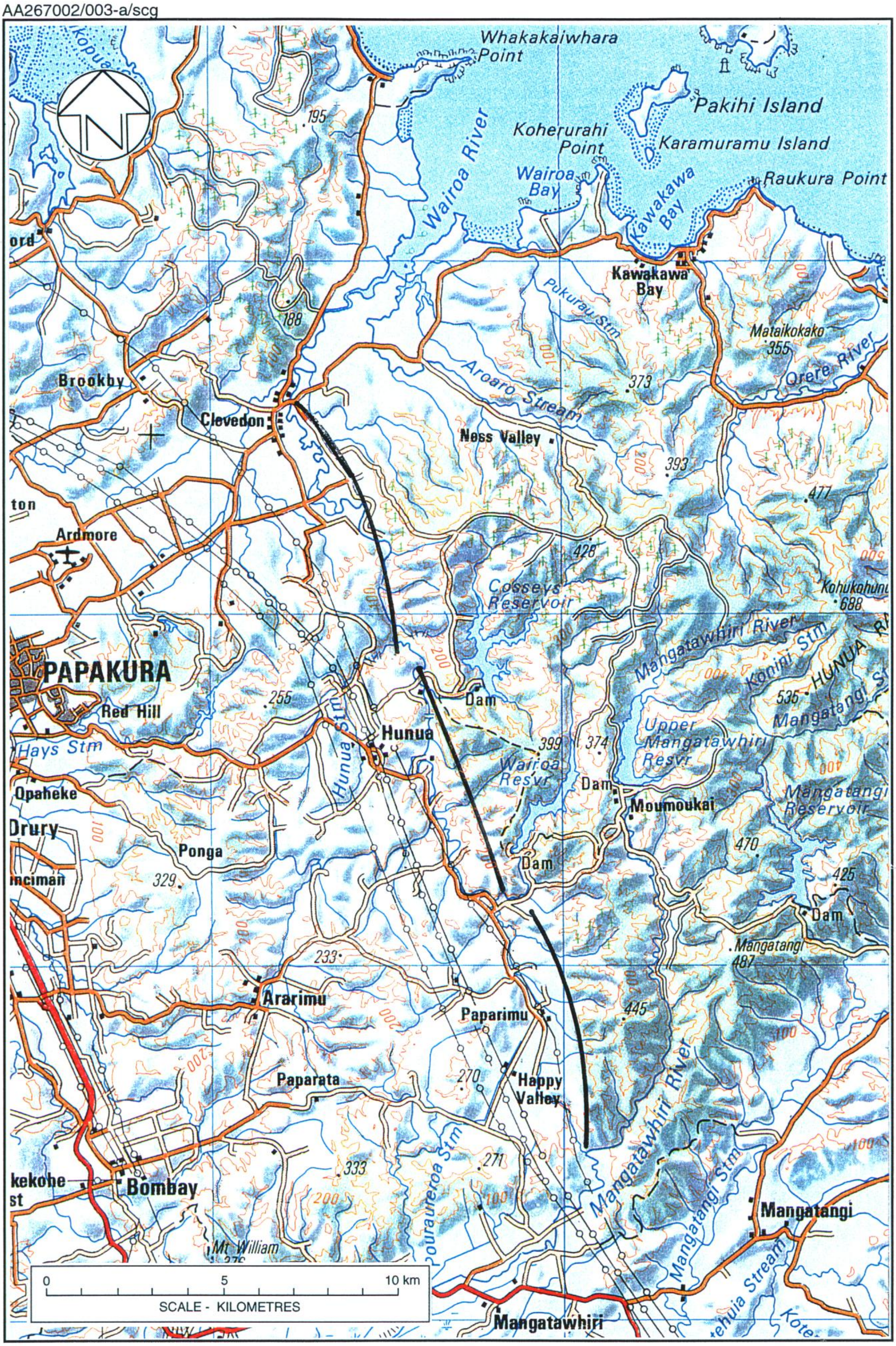
HAMILTON TE AWAMUTU COROMANDEL

WOODWARD CLYDE
GPS FIX

Prepared for
WOODWARD CLYDE

DRAWN B.F.ENDRES | CHECKED | SCALES H 1:250 V 1:50
TRACED | DATE 18 MAR 1996
SHEET
SERIES OF
COMP No. AN2
JOB REF 95811

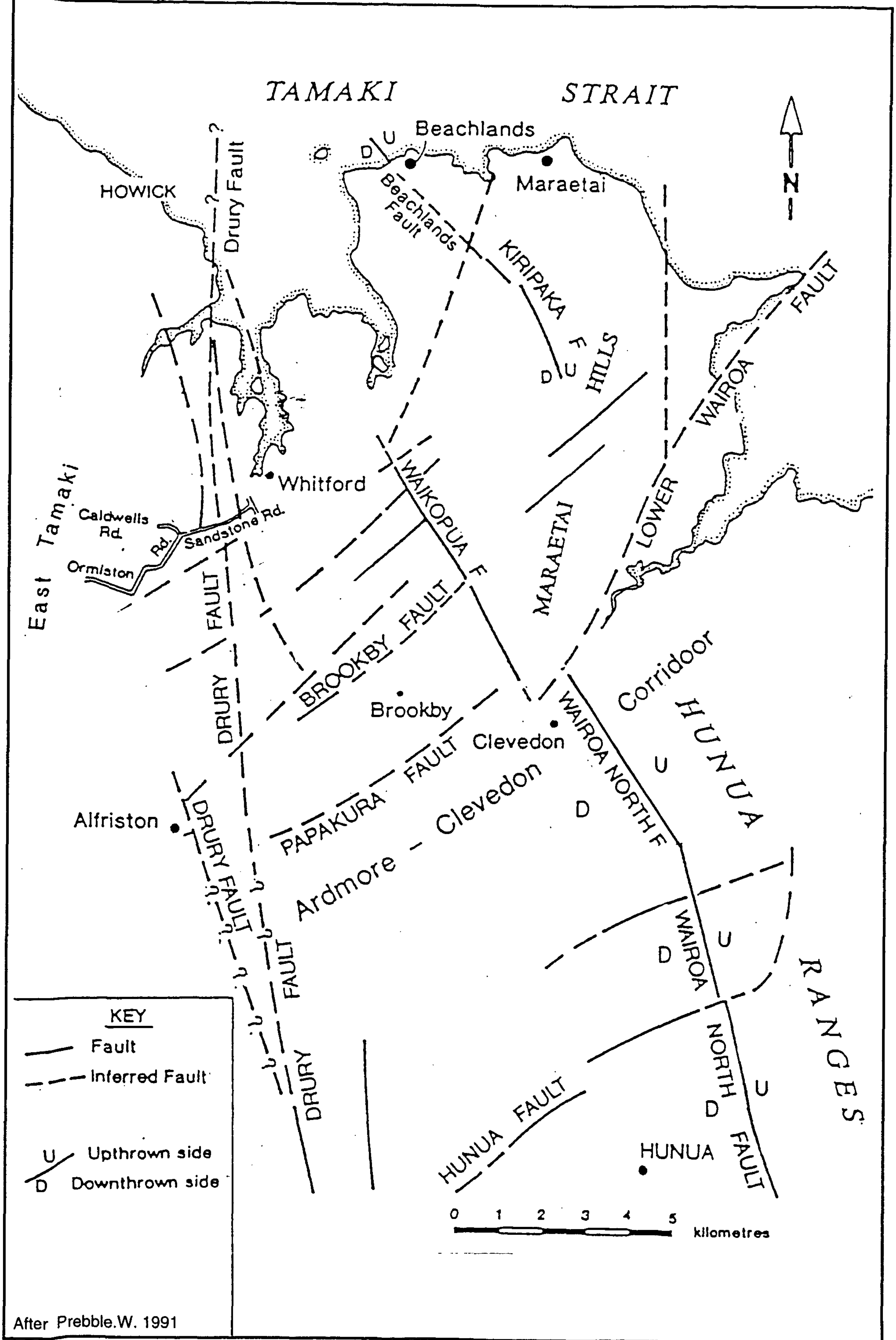
AA267002/003-a/scg



SITE LOCATION

Figure 1

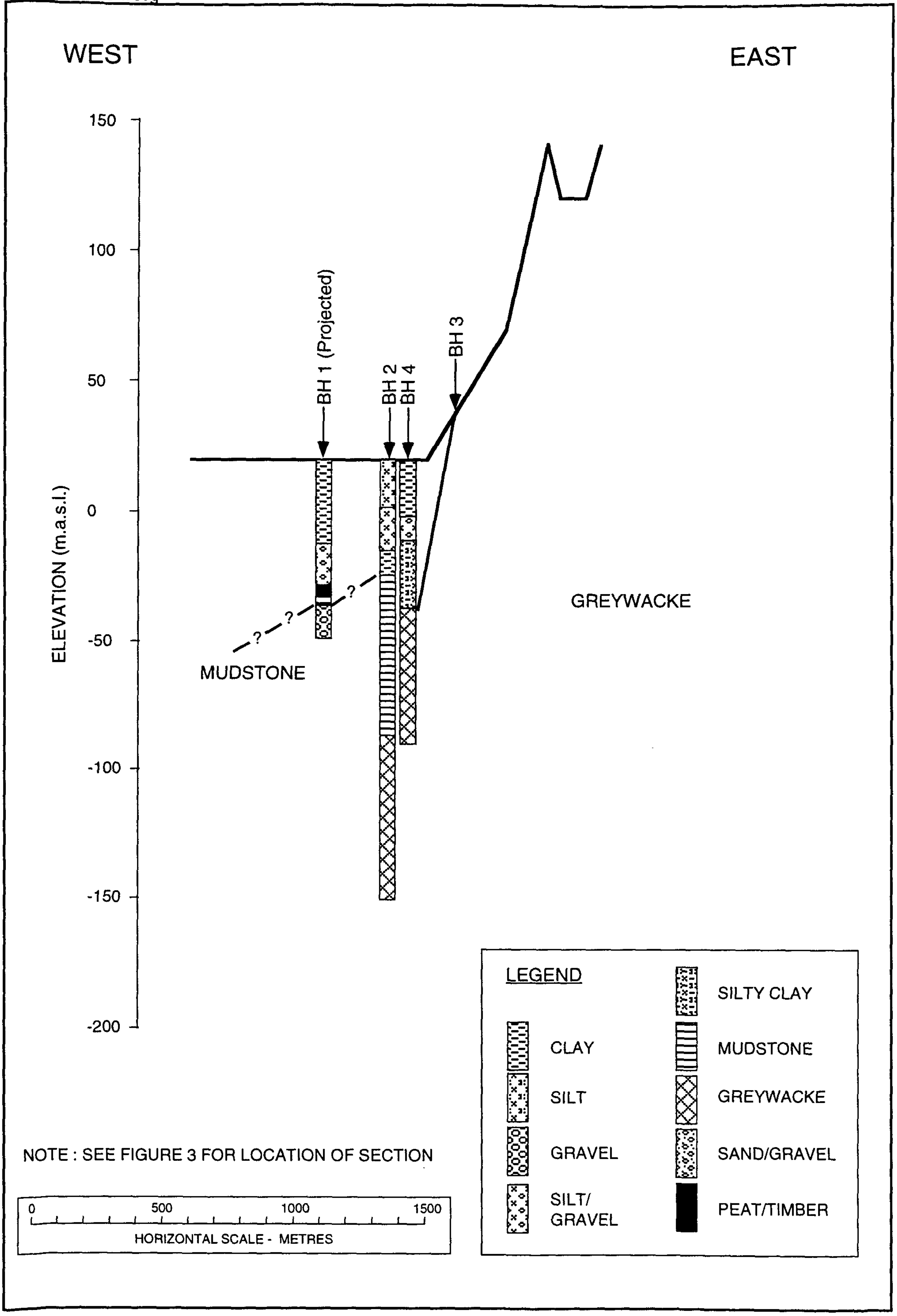
AA267002/001-a/scg



FAULTS IN SOUTH EAST AUCKLAND

Figure 2

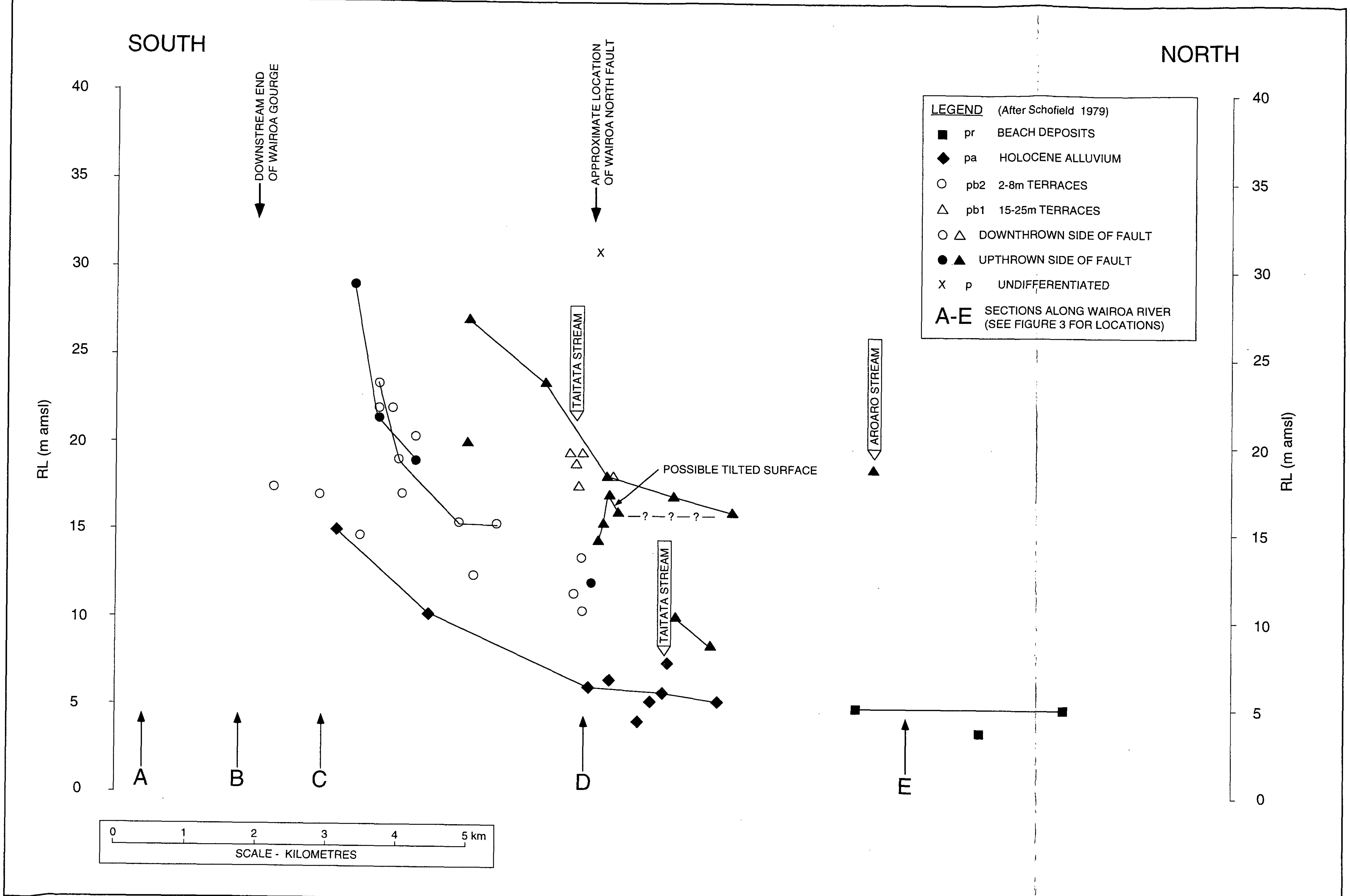
AA267002/002-a/scg



GEOLOGICAL SECTION ACROSS CLEVEDON SEGMENT OF WAIROA NORTH FAULT

Figure 4

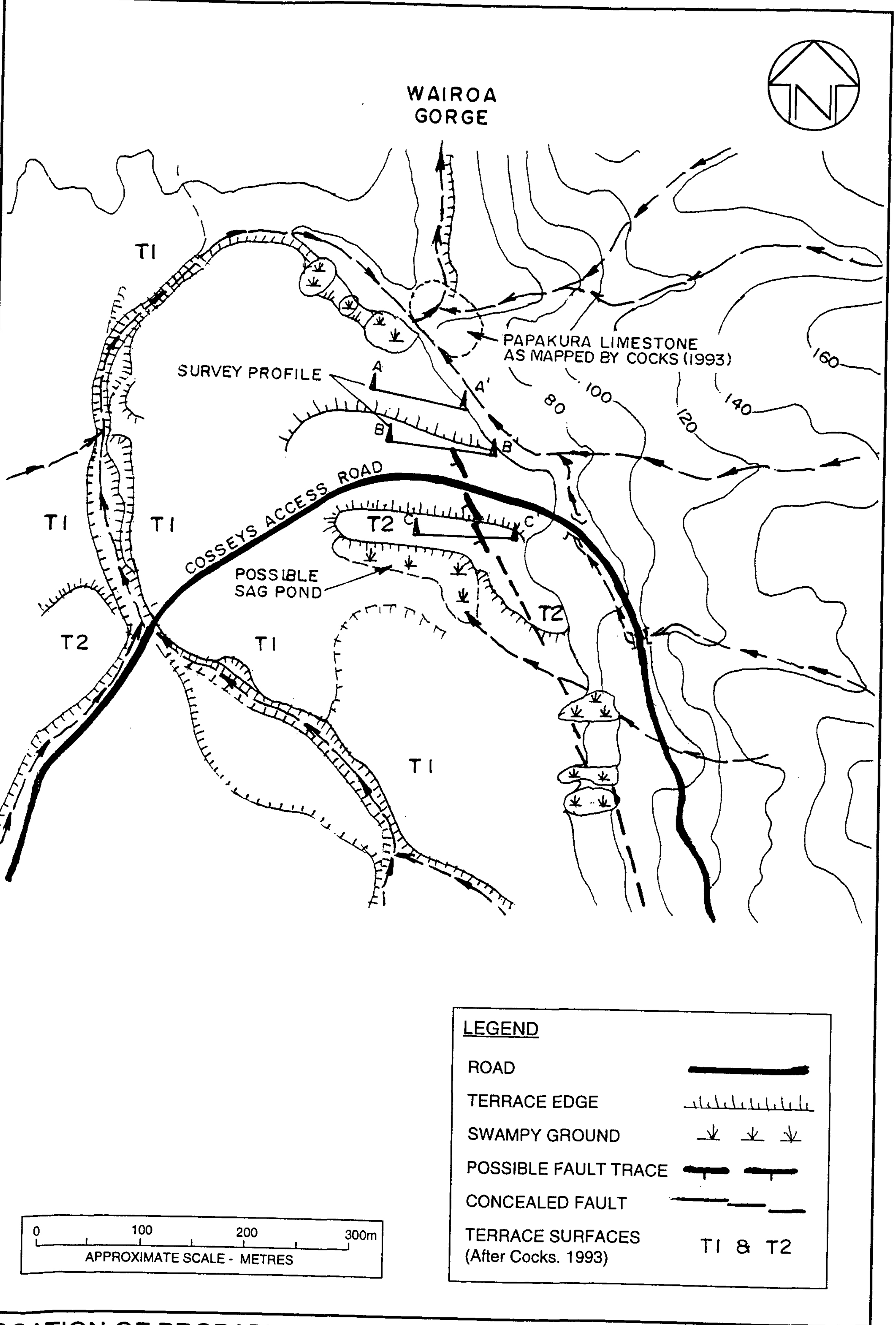
AA267002/005-b/scg



WAIROA RIVER TERRACE PROFILES ALONG CLEVEDON SEGMENT OF WAIROA NORTH FAULT

Figure 5

AA267002/006-a/scg

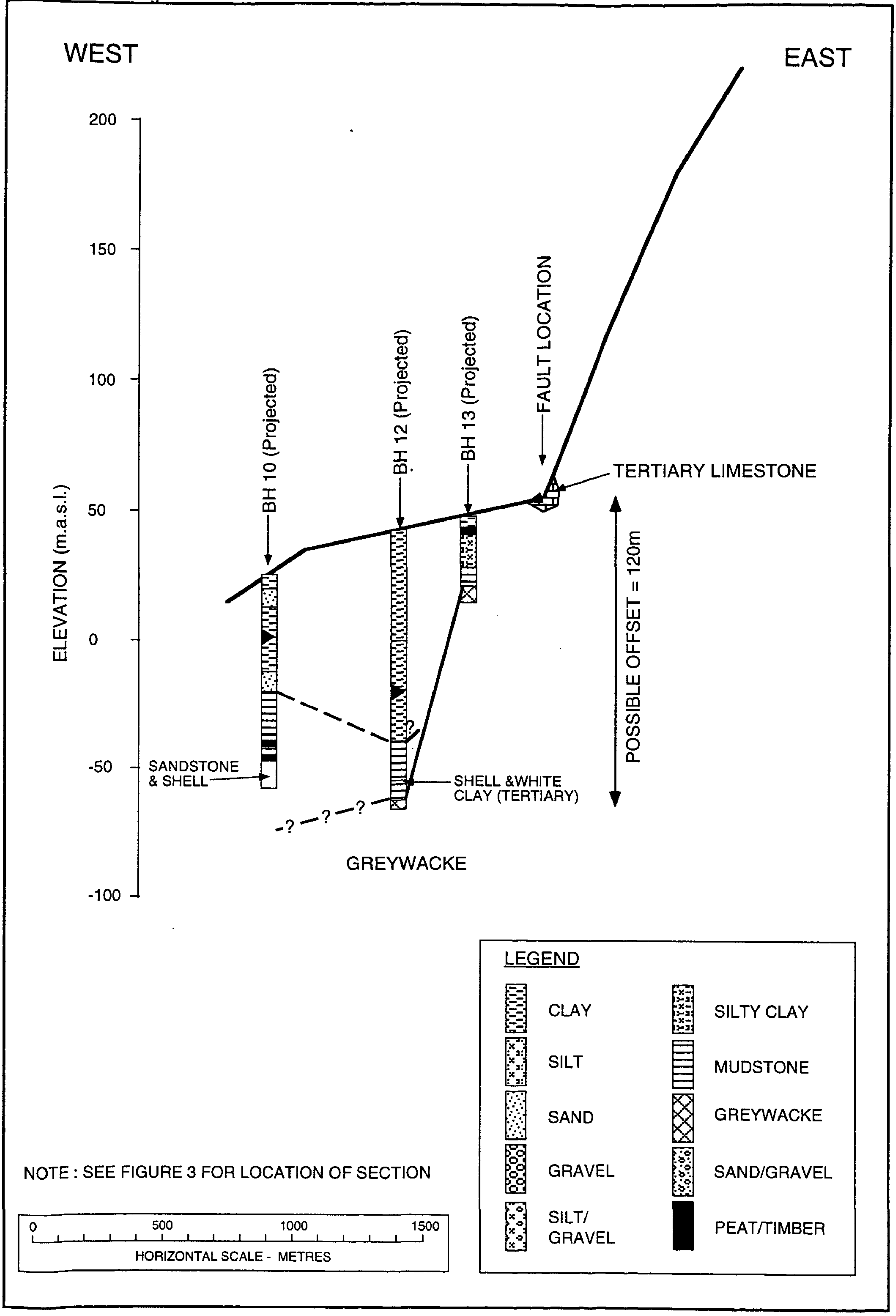


LOCATION OF PROBABLE FAULT TRACE ON THE HUNUA SEGMENT OF THE WAIROA NORTH FAULT

Figure 6

PHOTOGRAPH OF FAULT PLANE EXPOSED ON THE HUNUA SEGMENT OF WAIROA NORTH FAULT.

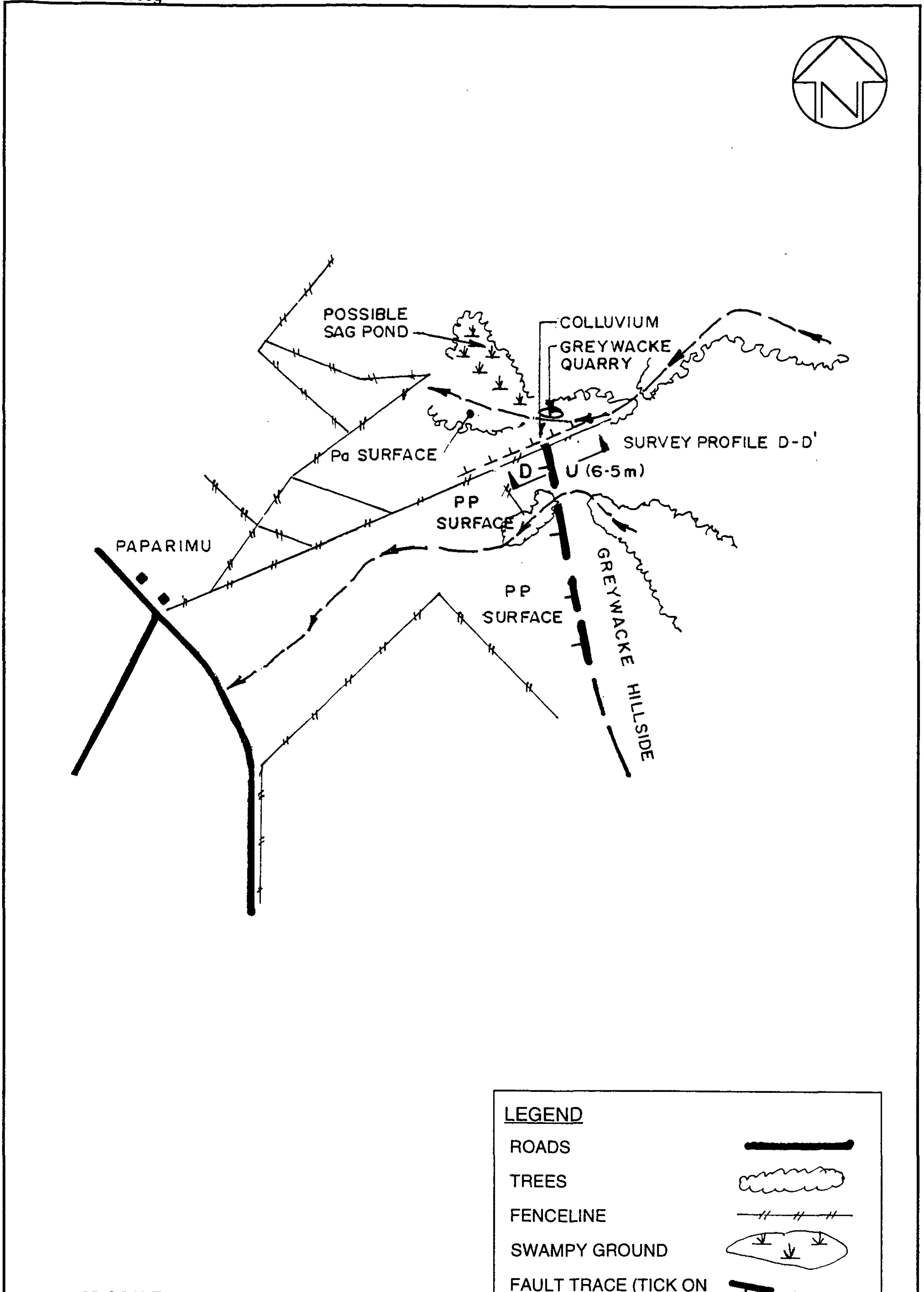
Figure 7



GEOLOGICAL SECTION ACROSS HUNUA SEGMENT OF WAIROA NORTH FAULT

Figure 8

AA267002/009-a/scg



SKETCH PLAN OF FAULT TRACE ON THE PAPARIMU SEGMENT OF THE WAIROA NORTH FAULT

Figure 9