Tasmania

Tasmanian Geological Survey

Record 2001/01

An investigation of land stability in the Taroona area

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Introduction

An area of land in the Taroona district of the Kingborough Municipality has been subject to land instability problems for a number of years. The area concerned is in the vicinity of Taroona High School and Taroona Primary School, and a continuing program of repairs to the adjacent Channel Highway has been necessary. Some buildings have also periodically required structural repairs.

Previous investigations in the area had indicated that the most likely causes of damage were landslide activity and expansive soils. These earlier investigations did not fully delineate the extent of the area affected by landslide movement.

Mineral Resources Tasmania commenced a study in March 1999 to further investigate the causes and extent of land instability in the area. The location of the study area is shown in Figures 1 and 2.

Previous studies

A number of investigations have been undertaken in the Taroona area since 1975.

The potential for landslide hazard in the area was acknowledged by Stevenson (1975), although some subsequent conclusions (Stevenson, 1976; Knights 1977) regarded expansive clays, combined with settlement and drainage problems, as the main cause of house damage in (at least) part of the area.

Investigation of road failure along the Channel Highway (Donaldson, 1977*a*) and of foreshore instability adjacent to the Taroona High School (Donaldson, 1977*b*) indicated that a major landslide problem was likely to exist within the area. These conclusions resulted in the establishment of a monitoring network along the Channel Highway.

Regular surveying of 'tell-tale' marker points along the Channel Highway by the Department of Roads and Transport commenced in 1977. This was discontinued in 1994, although subsequent analysis of the data revealed that the entire survey line, including reference benchmarks, was potentially mobile.

Inclinometers were installed in the affected area by the Department of Transport and the Department of Mines in 1991 and 1992, as part of a ground investigation for a proposed extension to the Taroona High School. Interpretation of these data suggested that the observed subsidence was the result of activity of a possibly deep-seated landslide, extending between the Channel Highway and the foreshore.

The current project

The current study commenced in the area in March 1999, with the aim of enlarging the existing monitoring network and re-establishing the regular monitoring program, as well as investigating the potential failure mechanism and extent of the landslide-affected area.

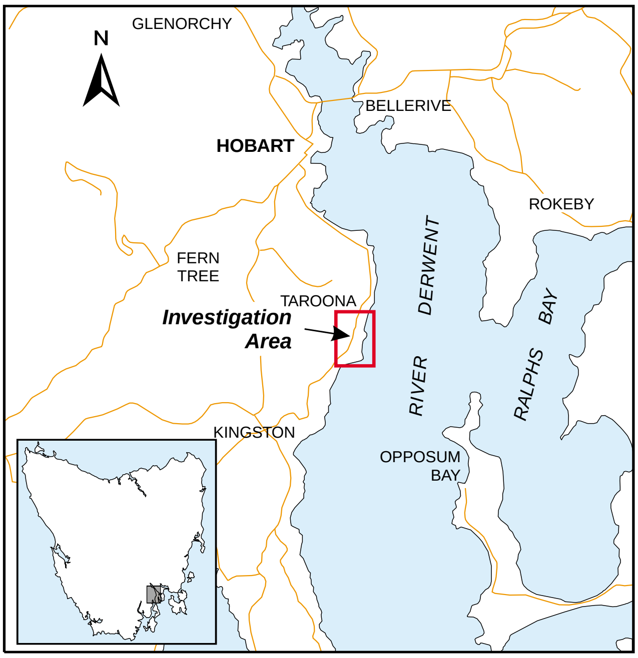


Figure 1

Location of investigation area

Fieldwork

Fieldwork comprised the monitoring of existing boreholes and inclinometer installations, precise surveying of surface reference points, geological mapping of the affected area, the drilling of three new boreholes and the establishment of inclinometers in those boreholes. Funding constraints resulted in a proposed bathymetric survey being postponed.

Existing boreholes (drilled 1991–1992)

Four boreholes were drilled in the area in 1991 by the Department of Mines with inclinometers (identified as I91-8 to I91-10) being installed in three of the holes. Monitoring of these instruments was undertaken by the Department of Roads and Transport. The fourth borehole (DDH1) was backfilled upon completion.

A further five boreholes were drilled within the grounds of Taroona High School in 1992. Four of these holes were used for inclinometer installations (numbered I92-11 to I92-14) while the fifth (BH92-11) had a piezometer installed at a depth of 18 metres.

The logs of these boreholes are summarised in Figures 3 and 4, with the borehole locations being shown on Figures 2, 5, 7 and 9.

Surveying

A number of established marker points along the Channel Highway, including existing boreholes, were surveyed by total station and referenced to benchmarks considered to lie outside the area affected by landslide. These observations are summarised in Table 3, and have been used in interpretation of the inclinometer data.

TAROONA BOREHOLE MONITORING NETWORK

Figure 2

New boreholes

Three additional monitoring boreholes were drilled in 1999 (fig. 2, 9) as part of this investigation, one by rotary core drilling and two by rotary percussion methods. These holes reached maximum depths of 70.7 metres (IBH1-99), 62 metres (IBH2-99) and 70 metres (IBH3-99).

The boreholes were surveyed by total station techniques. Details of the geology, AMG co-ordinates and elevation information are shown in the borehole logs (Appendix 1), together with core photographs of hole IBH1-99.

Geology

The geology of the Taroona area has been previously mapped by Leaman (1972) and Hofto (1990). A more detailed subdivision of Tertiary and Quaternary sediments was presented by Stephens (1988).

As part of this study, the geology of the area was remapped at 1:5000 scale (fig. 8). A number of locations mentioned in the following text are outside the area covered by this geological map, but are included because they provide the clearest illustration of relevant geological features in the vicinity of the study area.

Lower Parmeener Supergroup

Permian-aged sedimentary rocks of the Lower Parmeener Supergroup occur west of the Channel Highway, and are bordered to the south, west and north by Jurassic dolerite. The Permian rocks dip gently west to southwest. The western contact with dolerite is conformable, with the dolerite overlying the Permian rocks. The Permian rocks are bounded to the east by Tertiary and Quaternary sediments which conceal a major fault (the Taroona Fault).

The Deep Bay Formation is the oldest of the Permian units in the Taroona area, and can be seen in the disused quarry on the northern side of Cartwright Creek [529 000 mE, 5 246 650 mN]. The main rock types are interbedded fossiliferous pale green siltstone and fine-grained sandstone that dip gently west.

The Malbina Formation is the predominant Permian unit outcropping west of the Channel Highway. The most common rock type is a fine to medium-grained sandstone, interbedded with thinly bedded siltstone-mudstone. Quartz pebbles up to 50 mm diameter occasionally occur in the sandstone. The thickness of beds usually varies between 0.1–0.3 metres, with a maximum thickness of up to one metre. These rocks are slightly metamorphosed to hornfels and highly fractured (fracture opening 1–5 mm) along the western contact with dolerite, and dip southwest and west at angles of between 5° and 30°.

The presence of an isolated small outcrop of baked Permian siltstone and sandstone at 528 200 mE, 5 244 600 mN, separated from the main Permian outcrop area by dolerite, suggests the presence of stepped faults parallel to the highway.

Jurassic dolerite

Dolerite caps the hills west of Taroona and intrudes the Lower Parmeener Supergroup. The dolerite is usually coarse grained (2-4 mm), with a fine-grained variety occurring at contacts with Permian strata or as fine-grained dykes in coarse-grained dolerite (e.g. at Cartwright Point, approximately 400 m north of the boundary of the geological map). Dolerite is resistant to erosion and forms steep but apparently stable slopes above and around the Channel Highway.

Outcrops of weathered dolerite along the highway north of Stewart Crescent [528 700 mE, 5 245 800 mN] and at the southern end of Coolamon Road [528 300 mE, 5 244 900 mN] suggest that dolerite is continuous along the eastern boundary of the Malbina Formation, underneath surficial Tertiary and Quaternary deposits. The boundary between the Malbina Formation and the dolerite along the Channel Highway above the high school is mainly concealed by dolerite boulder deposits.

Tertiary sedimentary lithologies

Sedimentary lithologies of Tertiary age occur between the River Derwent and the Channel Highway and are separated from the older rocks by the NNE-trending Taroona Fault, formed about 60 million years ago. This fault can be seen just east of the Grange Quarry [529 100 mE, 5 246 700 mN]. The fault is concealed by Tertiary sediments in the high school area but further evidence of the fault can be seen near the Taroona shopping centre [528 300 mE, 5 244 700 mN], from where the fault continues seawards beyond the southern end of Hinsby Beach.

The Tertiary sedimentary rocks show considerable variation of lithology across the study area, both in a lateral sense and vertically as revealed in the boreholes. This variability is partly attributed to movement on the Taroona Fault during sedimentation. The west to southwest dipping fault block that lies east of the Taroona Fault is considered to have subsided and perhaps been tilted during deposition of the overlying Early Tertiary sediments. Boulders of dolerite and Permian siltstone and sandstone were deposited by a series of ancient landslides onto this lower block. Although fault movements periodically rejuvenated the system, over a period of time the slope gradients were reduced and sand, clay and gravel became the dominant deposits. These finer deposits eventually buried the boulder beds and extended over the uplifted (western) fault block as well.

Tertiary sedimentary rocks dip towards the west and southwest at up to 65°, consistent with continued fault movement during sedimentation. An east-trending fault was observed cutting Tertiary sediments at the

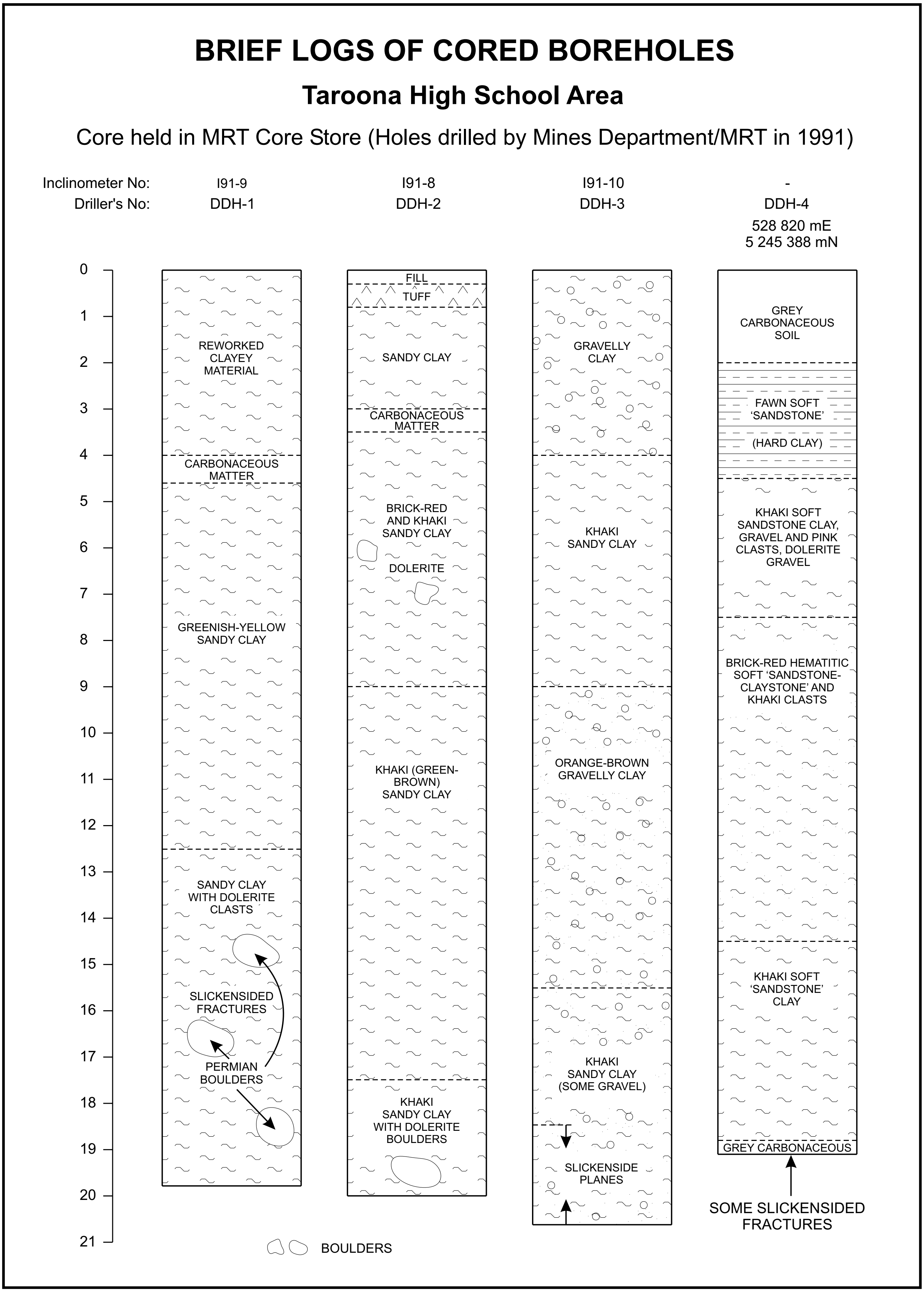
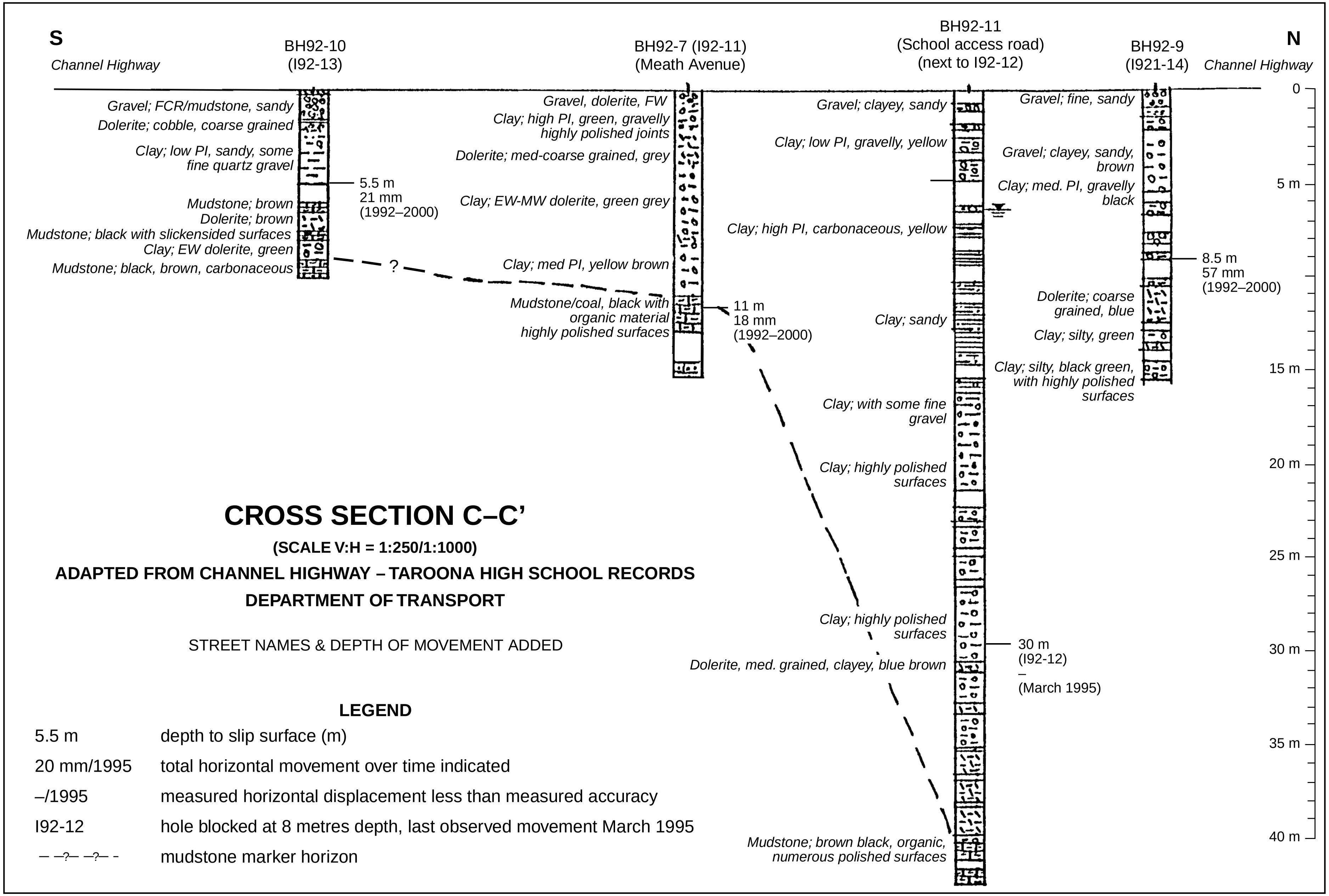

BRIEF LOGS OF CORED BOREHOLES
Taroona High School Area
Core held in MRT Core Store (Holes drilled by Mines Department/MRT in 1991)
Inclinometer No:
Driller's No:
I91-9
DDH-1
I91-8
DDH-2
I91-10
DDH-3
-
DDH-4
528 820 mE
5 245 388 mN
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
REWORKED CLAYEY MATERIAL
CARBONACEOUS MATTER
GREENISH-YELLOW SANDY CLAY
SANDY CLAY WITH DOLERITE CLASTS
SLICKENSIDED FRACTURES
PERMIAN BOULDERS
FILL
TUFF
SANDY CLAY
CARBONACEOUS MATTER
BRICK-RED AND KHAKI SANDY CLAY
DOLERITE
KHAKI (GREEN-BROWN) SANDY CLAY
KHAKI SANDY CLAY WITH DOLERITE BOULDERS
GRAVELLY CLAY
KHAKI SANDY CLAY
ORANGE-BROWN GRAVELLY CLAY
KHAKI SANDY CLAY (SOME GRAVEL)
SLICKENSIDE PLANES
GREY CARBONACEOUS SOIL
FAWN SOFT 'SANDSTONE'
(HARD CLAY)
KHAKI SOFT SANDSTONE CLAY, GRAVEL AND PINK CLASTS, DOLERITE GRAVEL
BRICK-RED HEMATITIC SOFT 'SANDSTONE-CLAYSTONE' AND KHAKI CLASTS
KHAKI SOFT 'SANDSTONE' CLAY
GREY CARBONACEOUS
SOME SLICKENSIDED FRACTURES
BOULDERS

Figure 3



CROSS SECTION C–C’

(SCALE V:H = 1:250/1:1000)

ADAPTED FROM CHANNEL HIGHWAY – TAROONA HIGH SCHOOL RECORDS

DEPARTMENT OF TRANSPORT

STREET NAMES & DEPTH OF MOVEMENT ADDED

LEGEND

5.5 m	depth to slip surface (m)
20 mm/1995	total horizontal movement over time indicated
–/1995	measured horizontal displacement less than measured accuracy
I92-12	hole blocked at 8 metres depth, last observed movement March 1995
– –?– –?– -	mudstone marker horizon

Figure 4

southern end of Cartwright Point [529 200 mE, 5 246 300 mN], and another is possibly present between the high school and Karingal Court [528 900 mE, 5 245 400 mN].

The Tertiary lithologies have been grouped into six mappable units.

☐ Probably the oldest unit, the *Lower Freshwater Unit*, shown as Tcg on the geological map (fig. 8), consists of boulder conglomerate interbedded with fine to coarse-grained sandstone of freshwater origin. The conglomerate contains large boulders (1–3 m^3) of predominantly dolerite, and fragments and pebbles of Permian origin. This unit is exposed along the cliffs south of Cartwright Point. The initial westerly dip of the beds at Cartwright Point gradually changes to southwesterly towards Karingal Court.

☐ The Lower Freshwater Unit gradually fines upward into an *Upper Freshwater Unit* (Tssl), which is exposed along the shore between Karingal Court and Taroona High School, and also 20–25 m above sea level in the cuttings of the sports grounds [528 800 mE, 5 245 500 mN]. The major rock types of this unit are fine to medium-grained sandstone and siltstone with minor conglomerate layers. The outcrop colour varies from pale yellow-green to light grey-white, but samples from boreholes are darker in colour. In borehole IBH3-99, this unit also contains dark grey-brownish clay from 12 to 24 m depth, and coalified wood and coal below 48 m depth. On the cliff below Karingal Court, beds dip west at 15–30° with steeper dips (up to 65°) on the beach at the northern end of the school. Steep (45–60°) east-dipping joints are present in the cliff face. Palynological evidence suggests an early or middle Eocene age for these sediments (Appendix 2).

☐ *Unit Tcba* consists of red sandy-silty clay with rare quartz pebbles, and is exposed along Flinders Esplanade between Belhaven Avenue and Seaview Avenue [528 750 mE, 5 244 900 mN]. This unit also contains large dolerite boulders that abruptly become more abundant in the lower part of this sequence at 30-65 m depth in borehole IBH2-99. The red colour of these sediments could be a consequence of warmer climatic conditions, or could be related to volcanic activity. At Crayfish Point the colour of the clay changes to yellow-orange, and large dolerite boulders (1–3 m^3) are exposed. It is unclear whether these boulders represent the lateral equivalent of the boulder beds in borehole IBH2-99, are the lower part of this unit, or are weathered dolerite bedrock.

☐ *Unit Tbat* is a highly porous, reddish-brown basaltic tuff that overlies unit Tcba just south of the high school, where the tuff dips northwest. It also crops out in the cutting above 'A' Block of the high school and at 14 Belhaven Avenue. The tuff may also be present in boreholes 13 and 18 further west (Knights, 1977). The tuff is probably Oligocene to early Miocene in age (Appendix 2).

☐ *Unit Tcbb* consists of green to orange-brown (khaki) sandy clay with pebbles and boulders, mainly of dolerite, and occasionally of Permian sandstone. Minor layers of very soft siltstone and sandstone, of the same colour as the clay, occur in this unit. Its maximum thickness of 65 m is recorded in borehole IBH1-99 where it is underlain by light grey-green siltstone, similar to siltstone of the Upper Freshwater Unit (Tssl). Unit Tcbb is most likely a mud-flow deposit.

☐ *Unit Tcbc*, of dolerite boulders in light brown clayey-gravel matrix, is exposed mainly along the Channel Highway, and is also evident in smaller areas on the middle slopes between the river and the highway. At Cartwright Point this unit overlies tuffaceous sediments (Tbat) similar to those at Taroona High School. These boulder beds are also probably of mudflow origin. Their age is uncertain, but is within the range middle to late Tertiary to Quaternary.

Quaternary sedimentary rocks

Quaternary sedimentary rocks include valley fill sediments, older and younger alluvial fans and man-made deposits.

During the last glacial period significant quantities of dolerite and sandstone pebbles and cobbles were deposited in the creek valleys. These sediments, shown as Qpv, are preserved west of Crayfish Point and northwest of the high school.

Older alluvial fans (Qafo) have been deposited on top of the valley-fill sediments and older rocks on both sides of the Channel Highway. The most prominent fan feature is between the primary school and St Luke's Church [528 600 mE, 5 245 200 mN]. The fan thickness varies from two to four metres in boreholes drilled along the highway. The older fans are composed of rounded and sub-rounded pebbles and sand (siltstone, sandstone and dolerite-derived) with a variable content of yellow and brown clay. Small springs usually occur along the lower contacts of these fans and create small intermittent streams further downslope.

The alluvial fan of Cartwright Creek, located some 300 m north of the study area, is the best preserved example of the younger alluvial fans (Qafy). This fan is up to ten metres thick and is composed mainly of well-rounded dolerite gravel and boulders (50–300 mm) with some fragments derived from Permian sedimentary rocks. South of Cartwright Point, the younger fans are either poorly preserved or completely absent. This may be due to more extensive marine erosion in this area, or these fans may have been submerged by rising sea levels after the last glacial period (10,000–20,000 years ago).

Man-made deposits (Qhmm) include different fill types such as road fill, playground excavations with fill areas and an area south of Karingal Court on Education Department property, where construction material debris has been dumped.

Engineering geology

The near-surface materials in the Taroona area have been the subject of a previous geotechnical investigation by Knights (1977). This investigation did not incorporate a study of materials occurring at more than 1.5 metres depth below the high school area.

In order to compare geotechnical properties of certain materials local to the high school area with the result of Knights' study, samples of materials extracted from the new boreholes were subjected to a program of laboratory testing. The results of this testing are shown in Appendix 3.

The results of both sets of tests are summarised for comparison in Table 2. These tests indicate that the Tertiary clays in the area of the high school have similar properties to some of the near-surface materials examined by Knights (1977). The low values of residual cohesion (3–4 kPa) and residual friction angle (10–13°) provide an indication of the degree of stability of slopes formed of these materials.

The results of mineralogical analyses by x-ray diffraction of materials from the three new boreholes are shown in Appendix 3 and summarised in Table 1. These analyses indicate that there is a high degree of vertical variation in the smectite content of the clay fraction of the Tertiary sedimentary rocks at Taroona. The lateral variation is less marked. The resulting reactivity of the clays to moisture changes, as well as variation in cohesion and friction angles, will have a bearing on the potential for landslide movement.

Field examination of the Upper and Lower Freshwater Units exposed in the cliff to the north of the high school indicates that the more lithified materials were generally within the low to medium strength categories as defined in Moon (1980).

Unweathered Permian sedimentary rocks and Jurassic dolerite

Where exposed at outcrop above the Taroona High School area, these rock types are characteristically stronger than the Tertiary sediments. They are moderately to highly fractured in places, dip to the west, and form stable slopes in the study area.

However in certain locations close to the study area, these rock types are known to exhibit instability under certain circumstances. Examples occur at Alum Cliffs, where several rockfalls were observed in Permian sedimentary rocks during reconnaissance mapping along the coastal cliffs east of the Shot Tower and Taronga subdivision in 1999. These falls affected an area along the shoreline of 450 m, extending inland up to 80 metres. A combination of the unfavourable orientation of the rock fracture systems (subvertical

Table 1

Clay mineral composition of Tertiary sedimentary rocks at Taroona

Borehole number	Sample depth (m)	Elevation (m ASD)	Smectite (wt %)	Kaolinite (wt %)	Halloysite (wt %)
P9*	0.70	not known	80	12	
P11*	1.00	not known	70	15	
P16*	0.74	not known	80	20	
P20*	1.49–1.79	not known	85	15	
IBH1-99	11.25	19.47	35	50	
IBH1-99	21.20	9.52	35	40	
IBH1-99	31.50	-0.78	90	5	
IBH1-99	43.20	-12.48	70	20	
IBH1-99	45.20	-14.48	75	20	
IBH1-99	51.60	-20.88	30		65
IBH1-99	55.10	-24.38	25	50	
IBH1-99	60.20	-29.48		65	
IBH1-99	65.80	-35.08	50	30	
IBH1-99	68.80	-38.08	15	75	
IBH1-99	70.50	-39.78	30	55	
IBH2-99	61.0–65.0	-37.1–-41.1	55	15	
IBH3-99	12.0–18.0	17.11–11.11	35	20	
IBH3-99	18.0–24.0	11.11–5.11	40	20	
Outcrop, Upper Freshwater Unit, Karingal Court	n/a	n/a	30	60	

Table 2

Geotechnical properties of Tertiary sedimentary rocks at Taroona

Location	Material	Depth (m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage	Residual Friction Angle	Residual Cohesion (kPa)	Peak shear strength (kPa)	Residual shear strength (kPa)
High School playground*	Dark brown CLAY	0.8	96	18	78	25				
High School playground*	Black organic CLAY	1.5	65	20	45	19.5				
Meath Avenue (Hole P9) *	Black organic CLAY	0.8	83	18	65	26.5				
Meath Avenue (Hole P9) *	Black organic CLAY	1							35	19.3
(Hole P5) **	Grey sandy CLAY	5.4–6.3	51	13	38	14				
Norwood Ave (Hole P11) *	Brown plastic CLAY	1.1	103	19	84	27				
Channel Hwy (Hole P14) *	Brown plastic CLAY	1.8–2.7	71	13	58	25				
Channel Hwy (Hole P15) *	Brown CLAY	1.45							59	24
Channel Hwy (Hole P16) *	Brown CLAY	1.6							67	31
Belhaven Ave (Hole P18) *	Lithic SAND (eroded tuff)	2.7	83	18	55	-				
High School Road (IBH 1-99)	Greenish brown silty CLAY	43.2–45.3	98	32	66	24	10	4		
Off Karingal Court (IBH 3-99)	Brownish grey CLAY	12.0–18.0	89	27	62	22				
Off Karingal Court IBH 3-99	Brownish grey CLAY	18.0–24.0	90	29	61	21	13	3		

* = From Knights (1977)
** = From Donaldson (1977*b*)

and steep, mainly easterly dipping joints) and marine erosion at the cliff base is probably the main driving force.

Further examples of soil creep and minor mass movement have occurred in the past on Jurassic dolerite slopes northeast of Bonnet Hill near the *Acton* property (Donaldson, 1976). Dolerite in the cliff north of the Cartwright Point towards the Lower Sandy is in places highly weathered and contains potentially dangerous steep (30–40°) easterly dipping joint set. Only one landslide has been recorded on this cliff at the mouth of the Folders Creek in autumn 1999.

Groundwater conditions

Only limited information is available on groundwater conditions within the Taroona district. No detailed examination of potentiometric surfaces within the Tertiary system or in materials to the west of the Channel Highway has been undertaken. Conceptually, the outcropping Permian sedimentary rocks and Jurassic dolerite are likely to act as fractured aquifers which recharge sandy layers acting as confined aquifers within the Tertiary sediments. Clay intercalations within the Tertiary sequence act as aquitards within the multi-layered Tertiary aquifer system.

Indications possibly confirming this general hydrogeological model were provided during the investigation works for this study. Borehole IBH3-99 encountered water at 25 m depth, at the contact between a siltstone and a clay, with further water strikes at 42 m and 60 m depth. This multi-layered aquifer system gave a standing water level at ten metres below ground level with a yield of 1.8 l/s.

Analysis of groundwater extracted from boreholes in the affected area (Appendix 4) indicates a chemistry corresponding to a Ca + Mg, Na + K, Cl and SO_4 facies (Freeze and Cherry, 1979). Total dissolved solids are high at 1840 mg/l. This chemical signature is typical of the Tertiary sedimentary rocks of the Hobart area, being previously recorded in a similar landslide area at Rosetta (Donaldson, 1991).

Seepage into inclinometers in the new boreholes and comparison with existing instruments indicates that all boreholes along the Channel Highway have somewhat similar average elevations of standing water level, relative to standard datum.

The probable shape of the local potentiometric surface, as indicated by available data, is illustrated in Figure 5. The elevation of water levels in all instruments under observation is shown in Figure 6. The apparent lack of water level variation in instruments at similar topographic levels reflects the fact that most were not designed as piezometers, and therefore would be expected to lack the sensitivity normal to such instruments. Only one piezometer has been installed (BH92-11).

The groundwater conditions can be summarised as follows:

- ☐ groundwater in the Tertiary sedimentary rocks between the River Derwent and the Channel Highway is subject to confined conditions and under moderate hydrostatic pressures;
- ☐ general groundwater flow is towards the east, with a steep hydraulic gradient below the primary school tennis courts and the River Derwent;
- ☐ the Tertiary sedimentary rocks form a multi-layered aquifer system, with probable large variations in lateral and vertical hydrogeological properties throughout the system. The permeability of the system as a whole may be relatively low, inhibiting drainage and maintaining high pore pressures within the system.

Rainfall and runoff

The long-term mean average annual rainfall for Taroona is 650 millimetres, with monthly averages between 41 millimetres and 68 millimetres.

Three exceptional rainfall events have been recorded since 1980:

December 1985–March 1986	412 mm for period
December 1995–April 1996	623 mm for period
April 1996	187 mm for month

In a location with reactive soils, such as Taroona, with open tension cracks and shrinkage cracks, there is a high potential for such exceptional events to produce rapid and deep infiltration and increase both pore pressures and hydrostatic pressures on discontinuities in the Tertiary materials.

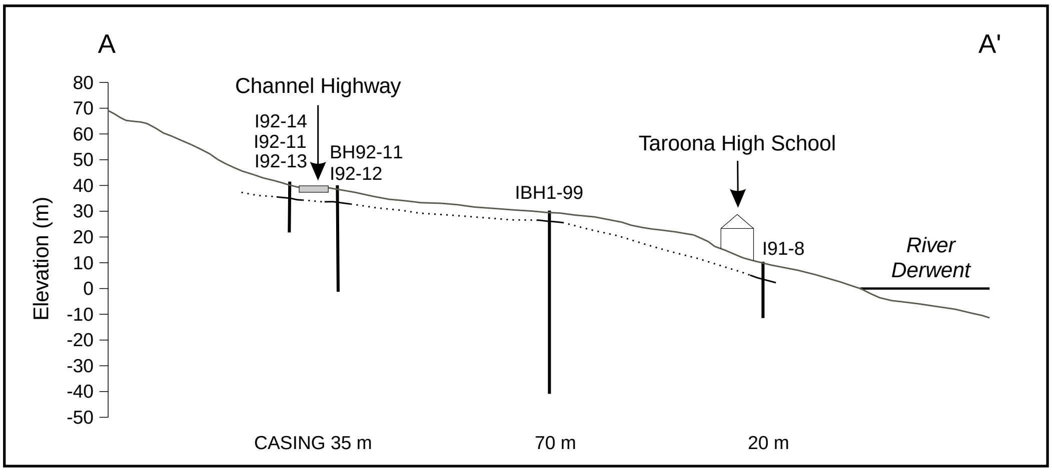
A number of streams have eroded small valleys into the cliff line in the Taroona area. These are unlined and are likely to act as a pathway for recharge to the Tertiary aquifer system. The most important of these is the stream immediately south of Karingal Court, which flows directly along the northern boundary of a possible landslide, and therefore may be contributing to locally high groundwater levels.

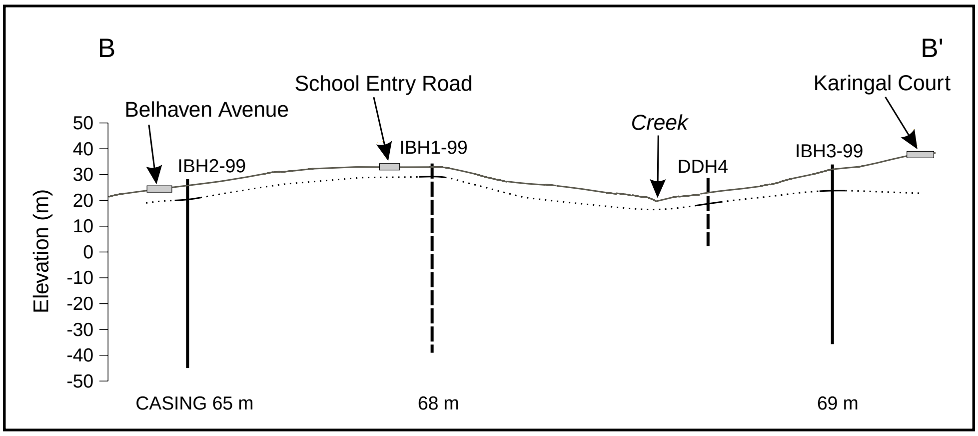
A number of flat-lying grassed areas occur within the high school boundaries. These represent areas of high potential infiltration, because of the negligible surface slope and lack of drainage. The potential for landslides to develop in such areas is suggested by the existence of slide MS1, encompassing the school archery ground.

Surface evidence for landslide activity

Certain key physical features indicative of current, or perhaps Pleistocene, landslide activity exist or have previously been observed in the area surrounding the Taroona High School. These consist of:

TAROONA HIGH SCHOOL AREA
STANDING WATER LEVELS
Cross Sections A–A' and B–B'





SCALE: $\frac{\text{V } 1:2500}{\text{H } 1:5000}$

LEGEND

▬	Borehole

STANDING WATER LEVELS (March–July 2000):

──	SWL measured in bore.
┈┈	SWL inferred.

NOTE: BH92-11 is the only piezometer installation (response zone 12–18 m)

Figure 5

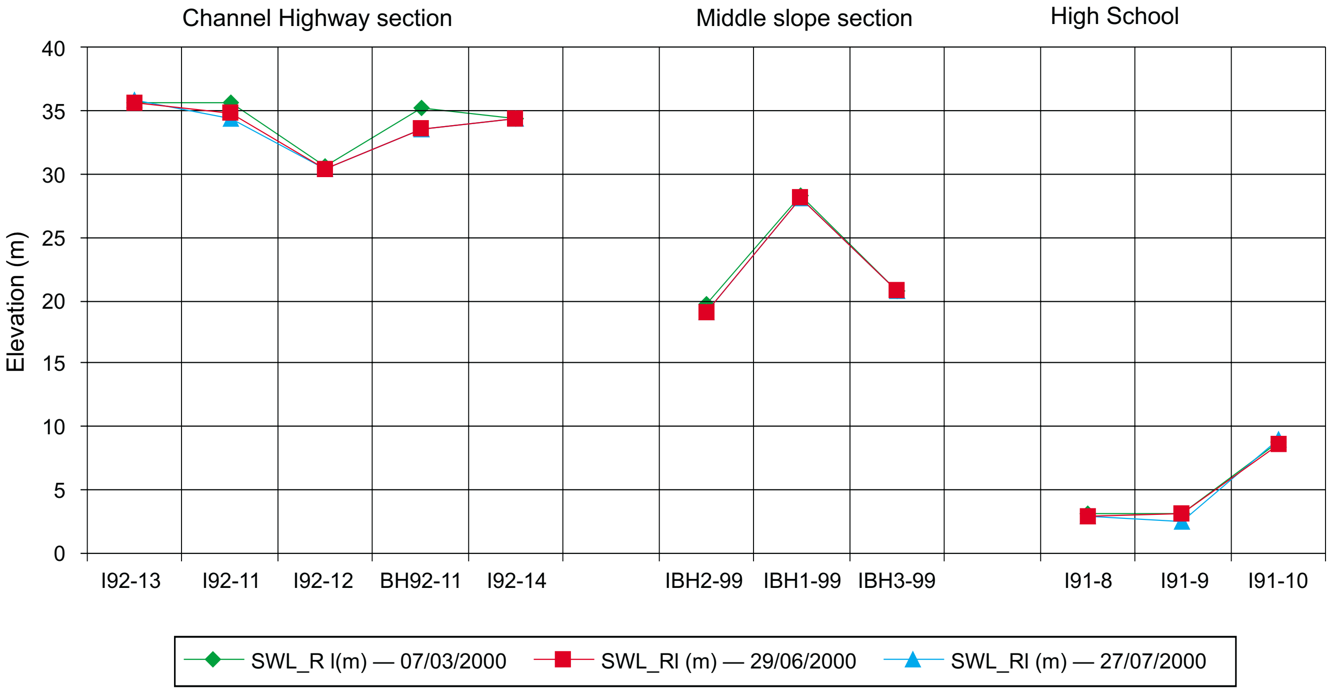


Figure 6

Reduced Standing Water Levels (m), Taroona High School inclinometer boreholes — March to July 2000

- ☐ the formation of transverse cracks and scarp features, particularly along the alignment of the Channel Highway and in the vicinity of the high school archery ground;
- ☐ the presence of sudden changes of slope, likely to be fossil headscarps, in some of the properties along Flinders Esplanade;
- ☐ a history of infrastructure damage along a section of the Channel Highway, and damage to structures in the school complex;
- ☐ the presence of hummocky ground at some locations across the area; and
- ☐ backscars associated with landslides along the sea cliff line.

Movement monitoring

Previous monitoring regimes have been established in part of the area, using a combination of precise surveying and down-hole instrumentation. Fieldwork and interpretation was carried out both by the then Department of Roads and Transport and Pitt and Sherry Pty Ltd.

Surface surveying

This initially consisted of a survey of four surface stations and the surface collars of all existing inclinometers, carried out at intervals by the Department of Roads and Transport over the period from 1977 to 1988.

Over this time, the overall distance from all surveyed points was measured to have increased by approximately 90 millimetres. This movement was clearly observable along a ten metre length at Station 3 (R. Rallings, pers. comm.). However, between 1988 and 1991, the overall spacing between the same points was found to have decreased by 30 millimetres. This apparent contradiction in the data may be due to movement of the reference points.

A further period of regular surveying of the surface capping of all new and existing monitoring boreholes was carried out from February 2000, to provide new baseline data. Initial locations and levels of the monitoring boreholes, as calculated at the commencement of the second survey period, are shown in Table 3. Small variations observed during 2000 are summarised in Table 4.

Inclinometer monitoring

Monitoring of inclinometer installations was carried out over the period from December 1991 to June 2000, and provided evidence for landslide-related ground instability in the area. The existence of reactive clays within the soil and subsoil profile is likely to have influenced ground behaviour to approximately 2.5 m below ground level. The inclinometer data above that depth may therefore be discounted as a recorder of major landslide movement.

The inclinometer data (Appendix 5) indicate that translational movement occurred in three of the four installations along the Channel Highway (I92-11, I92-13 and I92-14), with the maximum horizontal displacement (40 mm) being recorded in borehole I92-14 between 1991 and July 1997.

Inclinometer data also indicate a variation in the level of horizontal displacement over the period that

Table 3

Summary results of surface surveying, March 2000

Borehole Number	Easting (m)	Northing (m)	Elevation of ground level (m)	Elevation of top of instrumentation casing (m)	Elevation of borehole cover plate (m)
I91-8	528950.093	5245180.097	9.980	11.022	n/a
I91-9	528979.614	5245306.604	8.110	9.004	n/a
I91-10	528907.418	5245342.977	13.910	14.923	n/a
I92-11	528551.433	5245174.249	40.740	41.820	n/a
I92-12	528621.693	5245197.329	38.590	39.580	n/a
I92-13	528537.640	5245129.664	41.529	41.519	41.529
I92-14	528626.508	5245255.096	40.866	40.690	40.866
IBH1-99	528785.509	5245198.896	30.723	30.723	30.780
IBH2-99	528757.345	5245024.675	23.902	23.875	23.902
IBH3-99	528781.549	5245523.540	29.114	29.068	29.114
BH92-11	528622.536	5245200.489	38.670	39.204	n/a

monitoring was carried out. The range of displacements observed between 1997 and 2000 (9–13 mm) represents approximately 50% of the total displacement recorded in Holes I92-11 and I92-13 since the start of monitoring along the Channel Highway in 1991. This may indicate increased and more uniform movement in the landslide area above the primary school for this period.

Evidence of movement in the area surrounding the high school is also provided by the existence of buckles in the casings of certain inclinometers. The relationship between inclinometers and movement zones is indicated in Table 5.

Recorded displacement appears to involve shear within three types of geological material which are part of the landslide deposits formed during the Tertiary. All overlie the Tertiary Freshwater Units described on Page 8:

- the first is a variably sandy or silty clay, generally orange-brown in colour, containing coarse gravel to boulder size clasts of dolerite, Permian sedimentary rocks and quartz, as well as occasional fragments of carbonaceous material. This lithology forms part of Unit Tcbb in the stratigraphy outlined on Page 8;
- the second material consists of a grey-green to brown coloured high plasticity clay and exhibits evidence of shear, including a slickensided fabric. This material also forms part of unit Tcbb.
- the third material, a red-brown sandy clay containing dolerite boulders, was encountered in borehole IBH2-99. This material probably corresponds with unit Tcba, described on Page 8, and may underlie or laterally interdigitate with the other two materials.

These materials are likely to have the lowest shear strengths of those forming the Tertiary sedimentary rocks.

Interpretation

Factors

A number of factors may influence land instability in the Taroona area. These may be summarised as:

- the presence of reactive soils;
- current and Pleistocene landslide activity;
- high rainfall periods;
- groundwater levels;
- drainage;
- rock fracturing;
- marine erosion; and
- soil creep.

The reactive soils in the area, derived from the weathering of Tertiary sedimentary rocks, have been recognised as a cause of structural damage in the area south of the high school (Knights, 1977). This is also likely to be the case elsewhere in the district where Tertiary sedimentary rocks containing a high proportion of reactive smectite clays are present at outcrop.

Landslide activity has historically been recognised in the area (Stevenson, 1975; 1976). The lithology and mineralogy of the Tertiary sedimentary rocks in the area makes them susceptible to landslide activity under certain conditions.

The topographic slopes throughout the area are generally at an angle of between 5° and 10°, in an overall easterly direction, with steeper angles at some locations. The slope profile is shown on Figure 9.

Table 4

Survey results to the end of 2000

Parameter	Hole Number										
	I91-8	I91-9	I91-10	I92-11	I92-12	I92-13	I92-14	IBH1-99	IBH2-99	IBH3-99	BH92-11
Easting February 2000	528950.093	528979.614	528907.418	528551.433	528621.693	528537.640	528626.508	528785.509	528757.345	528781.549	528622.536
Easting October 2000	528950.098	528979.605	528907.440	528551.449	528621.707	528537.652	528606.518	528785.493	528757.345	528781.493	528622.555
Difference (m)	0.005	-0.009	0.022	0.016	0.014	0.012	0.010	-0.016	0.000	-0.056	0.019
Northing February 2000	5245180.097	5245306.604	5245342.977	5245174.249	5245197.329	5245129.664	5245255.096	5245198.896	5245024.675	5245523.540	5245200.489
Northing October 2000	5245180.071	5245306.573	5245342.949	5245174.247	5245197.326	5245129.668	5245255.102	5245198.880	5245024.670	5245523.496	5245200.493
Difference (m)	-0.026	-0.031	-0.028	-0.002	-0.003	0.004	0.006	-0.016	0.005	-0.044	0.004
Estimated accuracy (± m)	0.033	0.045	0.046	0.028	0.033	0.033	0.029	0.019	0.033	0.059	0.028
Elevation of casing top Feb 00	11.022	9.004	14.923	41.820	39.580	41.519	40.690	30.723	23.875	29.068	39.204
Elevation of casing top Oct 00	11.017	9.005	14.919	41.827	39.586	41.528	40.702	30.712	23.873	29.072	39.205
Difference (m)	0.005	0.001	-0.004	0.007	0.006	0.009	0.012	-0.011	-0.002	0.004	0.001
Estimated accuracy (± -m)	0.021	0.023	0.024	0.017	0.017	0.018	0.016	0.019	0.022	0.013	0.017

Table 5

Summary of inclinometer data

Inclinometer number	Length of inclinometer casing (m)	Base of inclinometer (elevation in metres)	Depth to movement zone (m bgl)	Depth to movement zone (elevation in metres)	Geology	Notes
I91-8	21.0	-0.02	11	0.02	not known	
			18	-6.98	not known	possible indications of movement*
I91-9	20.5	-1.00	8	1.00	not known	probable indications of movement*
			15	-6.00 top	not known	possible indications of movement*
			20	-11.00 base		
I91-10	21.0	-14.92	none detected	none detected		
I92-11	15.0	-29.82	11	29.82	Yellowish brown CLAY	movement of 18 mm at 68° magnetic
I92-12	35.0	-39.58	-	-	Brown CLAY within dolerite?	blocked
I92-13	8.5	-36.52	5.5	36.52	Greenish grey CLAY	movement of 21 mm at 51° magnetic
I92-14	15.0	-32.19	8.5	32.19	not known	movement of 57 mm at 64° magnetic
IBH1-99	68.0	23.28	54	-23.28	Dark green silty CLAY	possible indications of movement*
IBH2-99	65.0	12.13	36	-12.13	Reddish brown silty CLAY	possible indications of movement*
IBH3-99	69.0	-29.07	none detected	none detected		

* movement observed in these instruments is currently less than the accuracy/reliability of measurement.

A threshold slope angle for Tertiary clays in Tasmania, as indicated earlier, may be between 7° and 8°. The topographic information shown in Figure 9 indicates that the steeper slopes in the area are at, or exceed, this threshold angle. The laboratory data in Appendix 3 indicate that the residual friction angle for the local Tertiary clay is approximately 10°. This, combined with high pore pressures and distinctive properties of the Tertiary clay, suggests that there is some potential for landslide development.

Wave action undercutting the cliff line through the area may contribute to the potential for instability. The discontinuity patterns in the Tertiary sedimentary rocks have resulted in the development of a number of cliff failures along the cliff line northwards from Karingal Court and at the southern end of Hinsby Beach. The primary cause of these failures is likely to have been marine erosion undercutting the cliff, but stormwater discharge has also influenced the situation in some of cases.

Infrastructure and property damage

Damage to the Channel Highway, where it passes through the area, is occurring. Coring of the road pavement in 1988 showed a maximum thickness of 400 mm of bituminous pavement in the area, resulting from periodic resurfacing. Fractures are present in a concrete drain which crosses the Channel Highway adjacent to Karingal Court and which carries the water of a creek. The local water supply main, which previously followed the alignment of the highway, has been relocated to a location upslope of the road to prevent continuing damage.

Local property access roads have been disturbed by ground movement, with the development of laterally extensive cracks producing a need for continuous re-patching.

Structural damage to A Block of Taroona High School has been reported since the early 1970s. An examination of the high school in 1999 revealed the existence of cracks up to 10 mm wide and disruption in ceilings, internal and external walls. The cracks were located near the supporting structural elements, were orientated parallel with the slope direction, and were invariably wider in the upper storeys of the building. Services supplying the school buildings have also fractured. The cracking may have been caused by expansive soils, differential settlement or landslide activity, or a combination of all of these.

Knights (1977) examined certain houses in the area between Norwood Avenue and Meath Avenue, and found structural damage which was regarded as being caused by expansive soils (from 46 houses examined, 15 had major damage and 22 had light damage). An external examination during the current study confirmed that structural damage was present in other houses at locations between Meath Avenue and Seaview Avenue. The repairs to properties, signs of which were obvious during fieldwork, tend to obscure the true extent of structural damage in the area. It is possible that there may also be damage to underground services.

The properties in this area are on slopes with a much shallower angle than the slopes within the grounds of the two schools, which may indicate that landslide movement is a lesser cause of structural damage in this part of Taroona. The existence of subsurface drains (as shown in Figure 9) may have also had a stabilising effect on the land south of the high school. However, the influence of landslide activity on this part of the area cannot be ruled out.

Landslide in the vicinity of Taroona High School

The area east of the Channel Highway, between Karingal Court and Meath Avenue, is characterised by a hummocky topography with sharp breaks in slope adjacent to flat-lying areas, typical of landslide areas. It appears likely that this area is affected by landslide, with a number of discrete, more active slides occurring. The relative activity of each has been assumed from the currently available monitoring data. The locations of these landslides are indicated on Figure 9.

Possible extent of landslide

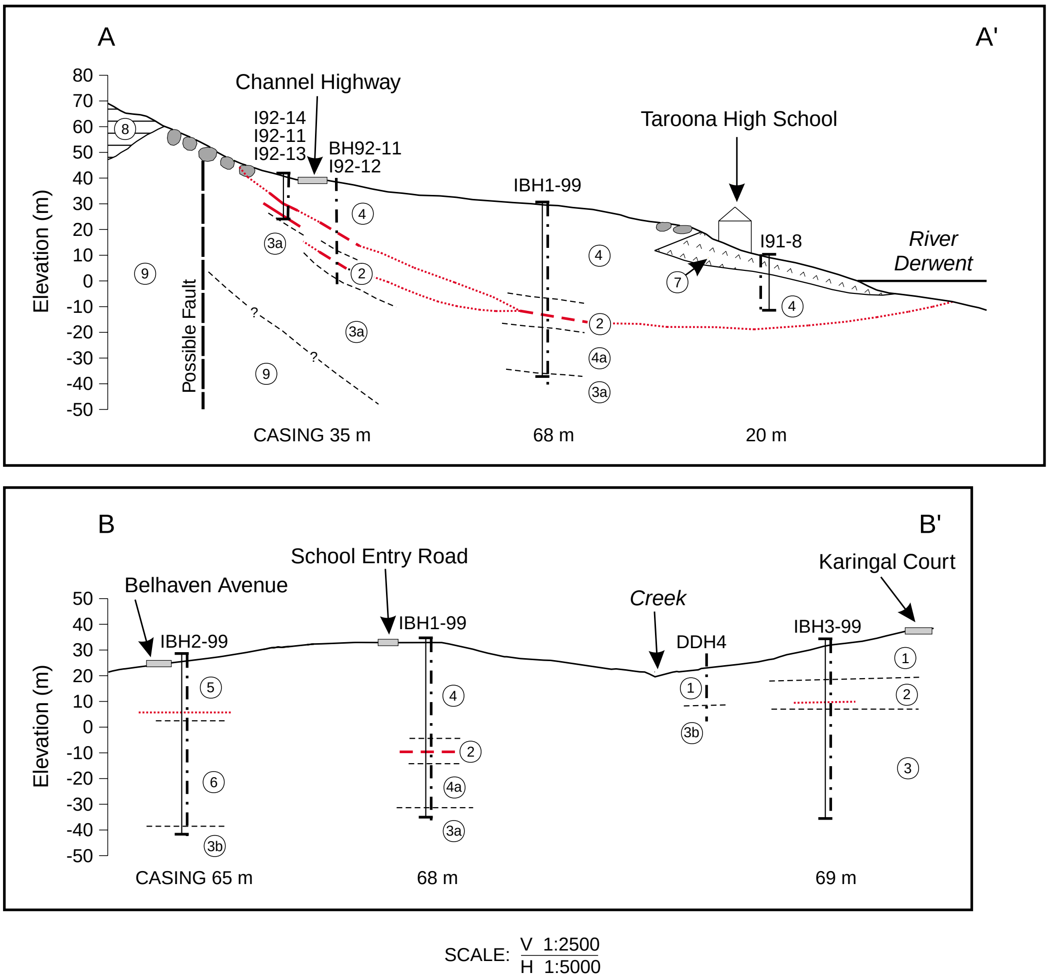
From existing data, it is possible that there is a complex landslide (Cruden and Varnes, 1996) extending from the Channel Highway to the cliff line of the River Derwent. The head and western boundary is approximately along the alignment of the Channel Highway, although locally extending a short distance west of the road. The northern flank, as far as can be determined from available data, may be approximately coincident with the southernmost section of Karingal Court. However this is not certain, and requires to be confirmed by subsurface investigation north of the northern boundary of the high school grounds. Extension of the main scarp south of the junction of the Channel Highway with Norwood Avenue could not be determined because of the modification of topography and the very limited amount of subsurface information.

Between Karingal Court and Belhaven Avenue, topographic expressions of landslide activity are now mostly obscured by repair works along the Channel Highway. The magnitude of recent movement on the headscarp is indicated by the substantial thickness of road pavement encountered in coring works prior to highway repairs along the Channel Highway between the junctions with Seaview Avenue and Karingal Court (as noted above). The continuing nature of movement is suggested by the records from inclinometers located close to the Channel Highway (see Table 5 and Appendix 5).

The upslope limit of the slide is composed of *in situ* dolerite and Permian sedimentary rocks. The slip surface (or surface of rupture) appears to dip steeply

TAROONA HIGH SCHOOL AREA

GENERALISED CROSS SECTIONS A-A' and B-B'



LEGEND

LANDSLIDE FEATURES:

— Depth of movement measured in inclinometer boreholes

– – – Depth to possible slip zone observed in cored borehole

······ Depth to possible slip zone

BOREHOLES:

— · — · · Borehole

├──┤ Inclinometer casing

GEOLOGICAL UNITS:

1. Sandstone and siltstone, light grey to yellowish
2. Plastic clay, grey-green to brown
3. Olive siltstone with dolerite boulders and carbonaceous matter

3a. Light grey-green siltstone with carbonaceous matter

3b. Soft siltstone/sandstone or clay

4. Orange-brown to greenish silty-sandy clay with pebbles-boulders (mainly dolerite, some Permian sediments and quartz), minor yellow-brown clay with carbonaceous matter

4a. Similar to No.4, increased number of dolerite boulders up to 1.5–2.0 m diameter

5. Red-brown sandy clay
6. Red-brown sandy clay with dolerite boulders
7. Tuff (Oligocene?) ^^^
8. Permian sandstone (Malbina Formation)
9. Jurassic dolerite

●●● Dolerite boulders

N.B. Units grouped by material properties

Figure 7

eastwards, and can be tentatively traced from the existence of steeply dipping shear zones in boreholes and significant displacements observed at shallow depth in inclinometers I92-11, I92-13 and I92-14. An interpreted headscarp feature is also present along the Channel Highway between 5 245 010 mN and 5 245 170 mN. The current topographic orientation of this feature may imply a certain degree of structural control on its formation.

To the east of this headscarp feature, subsurface indications of the main slip surface (or surface of rupture) are less obvious. The data from the deep inclinometers in boreholes IBH1-99 and IBH2-99 indicate that possible signs of movement may be being detected at depths of 54 m and 36 m (elevations –26.7 m and –17.9 m ASD respectively). Other inclinometers in the main body of the landslide are presumed to terminate above the main slip surface. The form of this slip surface is assumed, from borehole data, to be rotational (fig. 7). It is probable that the toe of this landslide extends beyond the shoreline. The southern limit is not known.

The area involved in this landslide may be as much as 25–30 ha. The variable distribution of movement and intermittent nature of its activity is typical of large landslides in Tasmania.

Active minor landslides

Landforms and inclinometer data suggest that a number of minor landslides may occur within the area. These are comparatively shallow and are likely to have developed where the geomorphological setting, lithological contrasts and hydrogeological regime predispose the materials to the formation of landslides.

The possible boundaries of these minor slide features are shown on Figure 9. These slides have been subjectively graded according to observed levels of activity, with MS1 currently having the highest activity level and MS6 being the least active. Minor slides MS1, MS2 and MS3 have noticeable surface expressions of current activity. There are only limited monitoring datasets for MS4, MS5 and MS6 and these slides have less surface expression.

MS1

This probably translational slide is the most obviously active of the minor slides, and has been in existence for at least 30 years (Donaldson, 1977*b*). An extensive transverse crack, 5 mm wide and 0.7 m deep, was observed along the minor scarp in 2000. Horizontal and vertical movements since 1977 are of the order of 0.15 to 0.3 metres. Recently-moved material was observed to have fallen from the cliff line within the area of this slide in 2000.

The location of this slide in relation to the schools and cliff line suggests that its formation may be due to a combination of elevated groundwater pressures, marine erosion and locally increased infiltration associated with the flat-lying land forming the school archery ground.

MS2

This shallow, probably rotational slide was possibly initiated by the dumping of excavated material on the steep slopes between the school car park and the beach. An extensive crack was present in the crown of this slide in 1998. The landslide was reported to be 10 m wide and 20–30 m long, with a one metre high headscarp (R. Rallings, Department of Transport, 1998). Another possible headscarp with continuous tension crack was observed some 35 m further upslope (beyond the inclinometer I91-10). Evidence of pre-existing failure planes and seepage faces was visible in the toe area during 1999.

MS3

This is a shallow, probably translational slide on a steep (>20°) slope, and is likely to have been initiated by runoff from the Channel Highway onto the adjacent slope. The additional loading caused by the placing of fill materials on the head of the slide is likely to have exacerbated the situation.

MS4

The only remnant topographic expressions of this possible slide are variations in the slope profile close to A Block of the high school, and a minor scarp to the east and downslope from Flinders Esplanade, which is coincident with the outcrop of a unit of tuff. Traces of a similar feature exist immediately to the west of the High School buildings. There are indications of movement associated with this slide in inclinometer I91-8 at moderate depth (11 m and 18 m below ground level). The main factors influencing its activity are likely to be stormwater infiltration and marine erosion.

The volume of water draining into the basement of Block A of the high school from this tuff outcrop after rain events was sufficient to result in the construction of a stormwater drain in the basement. This is not directed to the cliff or a lined sewer and is thus an obvious source of high infiltration. Service lines into the school also suffer regular damage.

MS5

This surrounds MS2, on an area of steep slopes dipping towards the cliff line. Apparent activity is significantly less than MS2, with possible minor indications of displacement being recently recorded at a depth of eight metres in inclinometer I91-9 on the southern flank, where shear stresses would be expected to be greatest. No indications of movement have been noted to date in inclinometer I91-10, situated in the body of this possible minor slide. Any activity which may be occurring is likely to be influenced by possible infiltration from the creek on its northern flank, and erosion of the cliff line.

MS6

This possible minor slide has a characteristically hummocky surface topography. The borehole immediately adjacent (IBH3-99) confirmed the existence of high plasticity clay between +17.07 m ASD and +5.02 m ASD, and significant hydrostatic pressures, indicating a high potential for instability. This is likely to have been increased by the loading of the crown area of this probable slide by dumped construction waste. There is also a marked development of shrinkage cracks in the ground surface in this area, which will allow more rapid infiltration of a greater volume of runoff.

Possible landslide mechanism

Syndepositional landslide activity along the Taroona Fault formed a highly heterogeneous sequence of deposits during the Tertiary. The variation in thickness of the Tertiary landslide deposits across the Tertiary main scarp is indicated by the depth of a carbonaceous mudstone marker horizon present in boreholes along section line C–C^l.

The present topography may have developed as a rotational slide, by partial reactivation of an ancient landslide, to form a complex landslide with a main scarp generally following the Channel Highway between Karingal Court and Meath Avenue. Subdivision of the Tertiary lithologies by material properties has been used to construct cross-sections in east–west (A–A^l) and north–south (B–B^1) directions across the landslide. These are shown in Figure 7.

Section A-A^1 suggests that movement is occurring in the clay lithologies which overlie the siltstone of the freshwater units. The differences in apparent dip of slickensides and polished surfaces in borehole samples, from 25–50° close to the Channel Highway to subhorizontal in the mid-line of the landslide (borehole IBH1-99), suggest that the surface of rupture may have the form indicated in Figure 6. The deepest section of the surface may be at 42 m to 44 m, or possibly 63 m to 65 m depth, in borehole IBH1-99. The lateral configuration of the surface of rupture has been less easy to determine. The toe of this possible landslide is likely to be offshore.

Areas of risk

The rate of movement of the entire area is not known. The areas of strain close to the boundaries of the active minor slides are characterised by significant differential movements (e.g. along the Channel Highway) and the risks to property and infrastructure in these areas is higher than other parts of the area.

The limited evidence of damage and the topographic indicators suggest that the area south of Meath Avenue may not be involved in movement, but subsurface investigation and monitoring is recommended to confirm this hypothesis.

Rate of movement

The data from the inclinometers along the Channel Highway, when averaged over the period 1991–2000, indicate that displacement in that area is occurring at between 2 mm and 6 mm per year, depending on location. The rate of movement falls into Class 1 of the landslide velocity scale of Cruden and Varnes (1996). This rates it as an extremely slow moving landslide, with a velocity of less than 16 mm per year. In this respect, it is generally typical of deep seated slides in Tasmania. It should also be noted that the above are average speeds, and do not imply that the rate of movement of the slide could not increase beyond these figures if conditions were to alter.

Other possible minor slide areas

South of the area regarded as possibly within the slide, certain zones exhibit features which may be attributable to ground movement, but the local ground surface has been extensively modified by urban development and it was not possible to recognise features indicative of landslides. Field mapping of the area in 1999 identified a number of zones in which brick buildings were observed to have experienced some damage. These are indicated as areas D1–D3 in Figure 9.

These zones are mostly south of the point at which the transverse crack along the main scarp of the major slide could be detected on the ground. Because of the lack of monitoring information in this area, definite linking of the damage within the zones to landslide movement is not possible.

Other landslides in the area

A small number of minor landslides (fig. 9) exist in the area.

At Hinsby Beach, to the south, a number of shallow debris slides have been caused by a combination of marine erosion and apparent concentration of stormwater discharge points close to the cliff edge, leading to the destruction of a footpath at the eastern end of the beach.

A number of cliff failures occur along the cliff line to the north of Karingal Court. These occur in areas where the geology consists of relatively undisturbed weak rocks of the Tertiary Upper and Lower Freshwater Units which have a shallow west or southwest dip. Marine erosion, weathering and the relationship between the bedding, the east-dipping joint pattern and the orientation of the cliff line has influenced the stability of cliffs formed of these rocks.

Most are relatively small features (1–2 m thick) and have been caused primarily by weathering and marine erosion, but one (SL1) is considerably larger than the rest, and its formation may also involve other major factors.

SL1

SL1 is likely to have been initiated by an interaction of marine erosion, joint orientation (within the weak rocks of the Tertiary Upper Freshwater Unit) and a rapid rise in pore water pressures, to produce failure. The rise in pore water pressure was probably caused by high rainfall and discharge of stormwater over the cliff edge.

Conclusions

An area of approximately 25–30 ha that may be affected by landslide has been identified. This landslide appears to be an at least partially reactivated, extremely slow-moving, complex rotational slide in Tertiary sedimentary formations, with several subsidiary minor slides. The toe structure of the main slide may exist offshore. Whilst part of the western boundary of the slide has been tentatively located and a possible trace of the northern boundary identified, this could not be done for the remainder of the western boundary or the southern boundary. The greatest degree of shallow landslide activity is occurring in areas with the steepest topographic slopes.

Slow average movements of between 2 and 6 mm per year have been confirmed by inclinometer monitoring in the vicinity of the main slide headscarp along the Channel Highway.

Groundwater within the landslide is probably confined, with the Tertiary sedimentary rocks operating as a multi-layered aquifer system with probably generally low permeabilities. Infiltration in the area is enhanced by existing transverse cracks and shrinkage cracks present in the ground surface, creeks flowing on the lines of rupture surfaces, and damaged services.

A section of the Channel Highway, Taroona High School, Taroona Primary School and certain areas of residential development to the south of the school grounds appear to be affected by landslide. One block of the high school and certain properties adjoining Flinders Esplanade and Melinga Place are wholly or completely on minor more active slides. The affected high school building has noticeable structural damage. Infrastructure damage has continued to occur in a number of areas.

Properties in certain areas of Seaview Avenue, Norwood Avenue and Belhaven Avenue have been subject to damage, but it was not possible to definitely ascribe this to landslide activity.

It is not possible to establish more precisely the boundaries of the deep-seated landslide using the available information.

Recommendations

The area affected by deep-seated landslide is poorly defined. In order to be able to more clearly establish the limits of landslide activity, the following actions are recommended.

Mapping

☐ The area should be geomorphologically mapped to interpret the overall landslide mechanism.

☐ Palynology analysis should be undertaken on available core and outcrops.

Monitoring network

☐ Further subsurface work and the extension of the monitoring network should be carried out to include areas in which there is currently no information. This could be achieved by drilling boreholes, using rotary coring techniques, in areas suggested as likely to be useful following geomorphological mapping, and the installation of inclinometers within these holes. The depth of such boreholes would need to be similar to the deep holes drilled in 1999 (70 m), to ensure the intersection of a possible slip surface.

☐ If regarded as likely to be useful following geomorphological mapping, a deep borehole should be drilled between the high school and the cliff line, using rotary core drilling techniques, to intersect the probable main slip surface. An inclinometer should be installed in this borehole and regularly monitored, as part of the local monitoring regime.

☐ A number of piezometers should be installed in deep drillholes in the crown and main body of the landslide and regularly monitored, especially where placed to intersect the main slip surface or other probable failure planes.

☐ The blocked inclinometer (I92-12) should be either unblocked, or if this is not possible, sealed and a substitute installed close by.

☐ A structural survey of buildings in the area of the main slide should be performed by a structural engineer, and cracking in affected buildings and other structures monitored using fixed ‘tell-tale’ markers. Correlation with inclinometer data might allow ‘noise’ caused by movements due to expansive soils to be filtered out from those caused by landslide movement, thereby allowing more accurate determination of the boundaries of the landslide area.

☐ An overall surface monitoring network, consisting of surveying pegs set in pavement surfaces or structures, should be constructed and regularly monitored by a licensed surveyor.

☐ An offshore bathymetric survey should be carried out to check for the presence of any submarine landforms which may be associated with the deep-seated landslide.

To reduce the impact of the landslide the following actions are recommended:

Infrastructure

- ☐ All services present (water, stormwater, sewerage, surface drains etc.) within the area bounded by the Channel Highway, Harrow Place, Karingal Court and Nubeena Crescent should be regularly inspected for signs of damage by the responsible authority. An examination of services along that area of the Channel Highway is particularly recommended. Reconstruction using materials more appropriate to the ground conditions may be necessary in some cases.

- ☐ Any existing cracks in the Channel Highway between Karingal Court and Nubeena Crescent should be sealed and discharge from the roadway directed either into the stormwater system, or into a piped drainage system for discharge to the foreshore.

- ☐ The creek between Karingal Court and the high school grounds should be contained using a lined channel or pipe, and directed to the foreshore, to prevent recharge to the Tertiary aquifer and erosion of its own banks.

- ☐ Stormwater drainage should be directed to the municipal system.

Possible remedial measures

- ☐ Surface runoff should be diverted away from critical areas of infiltration, such as the crown of the landslide or from the flat-lying recreation areas. Any services observed to be leaking water should be repaired as soon as possible after inspection.

- ☐ Active and passive dewatering systems could be set up within the main body of the landslide. These would have the potential to reduce landslide activity considerably, but would be unlikely to completely prevent it. They may also result in damage by the effect of dewatering on reactive clays.

- ☐ Further minimisation of infiltration could be achieved, if deemed necessary, by controlling irrigation of gardens and lawns in the affected area.

- ☐ Any existing transverse cracks, other tension cracks or fissures in the ground surface should be plugged or re-modelled to prevent infiltration.

- ☐ Erosion of the cliff line and foreshore, in areas regarded as being affected by high rates of erosion, could be reduced by the construction of a breakwater or similar systems.

- ☐ A system should be set up within Council to record and investigate reports of structural damage to buildings in the area. A structural engineer should carry out the investigations and report findings to Council. Where necessary, a program of long-term monitoring of damage should be initiated.

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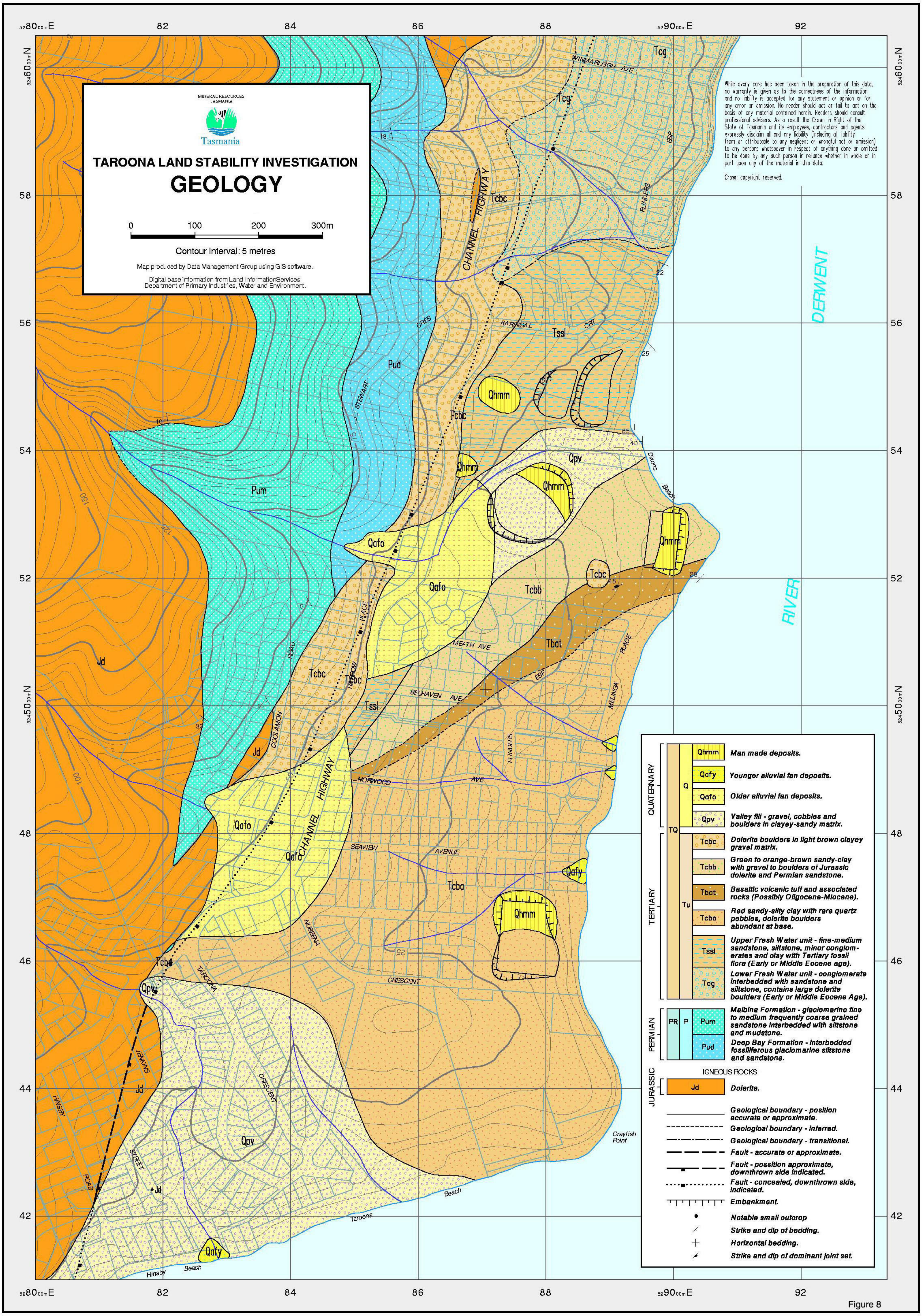
[10 August 2001]



MINERAL RESOURCES TASMANIA

Tasmania

TAROONA LAND STABILITY INVESTIGATION

GEOLOGY

0 100 200 300m

Contour Interval: 5 metres

Map produced by Data Management Group using GIS software.

Digital base information from Land InformationServices, Department of Primary Industries, Water and Environment.

QUATERNARY	TQ	Q	Qhmm	*Man made deposits.*
			Qafy	*Younger alluvial fan deposits.*
			Qafo	*Older alluvial fan deposits.*
			Qpv	*Valley fill - gravel, cobbles and boulders in clayey-sandy matrix.*
TERTIARY		Tu	Tcbc	*Dolerite boulders in light brown clayey gravel matrix.*
			Tcbb	*Green to orange-brown sandy-clay with gravel to boulders of Jurassic dolerite and Permian sandstone.*
			Tbat	*Basaltic volcanic tuff and associated rocks (Possibly Oligocene-Miocene).*
			Tcba	*Red sandy-silty clay with rare quartz pebbles, dolerite boulders abundant at base.*
			Tssl	*Upper Fresh Water unit - fine-medium sandstone, siltstone, minor conglomerates and clay with Tertiary fossil flora (Early or Middle Eocene age).*
			Tcg	*Lower Fresh Water unit - conglomerate interbedded with sandstone and siltstone, contains large dolerite boulders (Early or Middle Eocene Age).*
PERMIAN	PR	P	Pum	*Malbina Formation - glaciomarine fine to medium frequently coarse grained sandstone interbedded with siltstone and mudstone.*
			Pud	*Deep Bay Formation - interbedded fossiliferous glaciomarine siltstone and sandstone.*

IGNEOUS ROCKS

JURASSIC	Jd	*Dolerite.*

Geological boundary - position accurate or approximate.

Geological boundary - inferred.

Geological boundary - transitional.

Fault - accurate or approximate.

Fault - possition approximate, downthrown side indicated.

Fault - concealed, downthrown side, indicated.

Embankment.

● *Notable small outcrop*

Strike and dip of bedding.

+ *Horizontal bedding.*

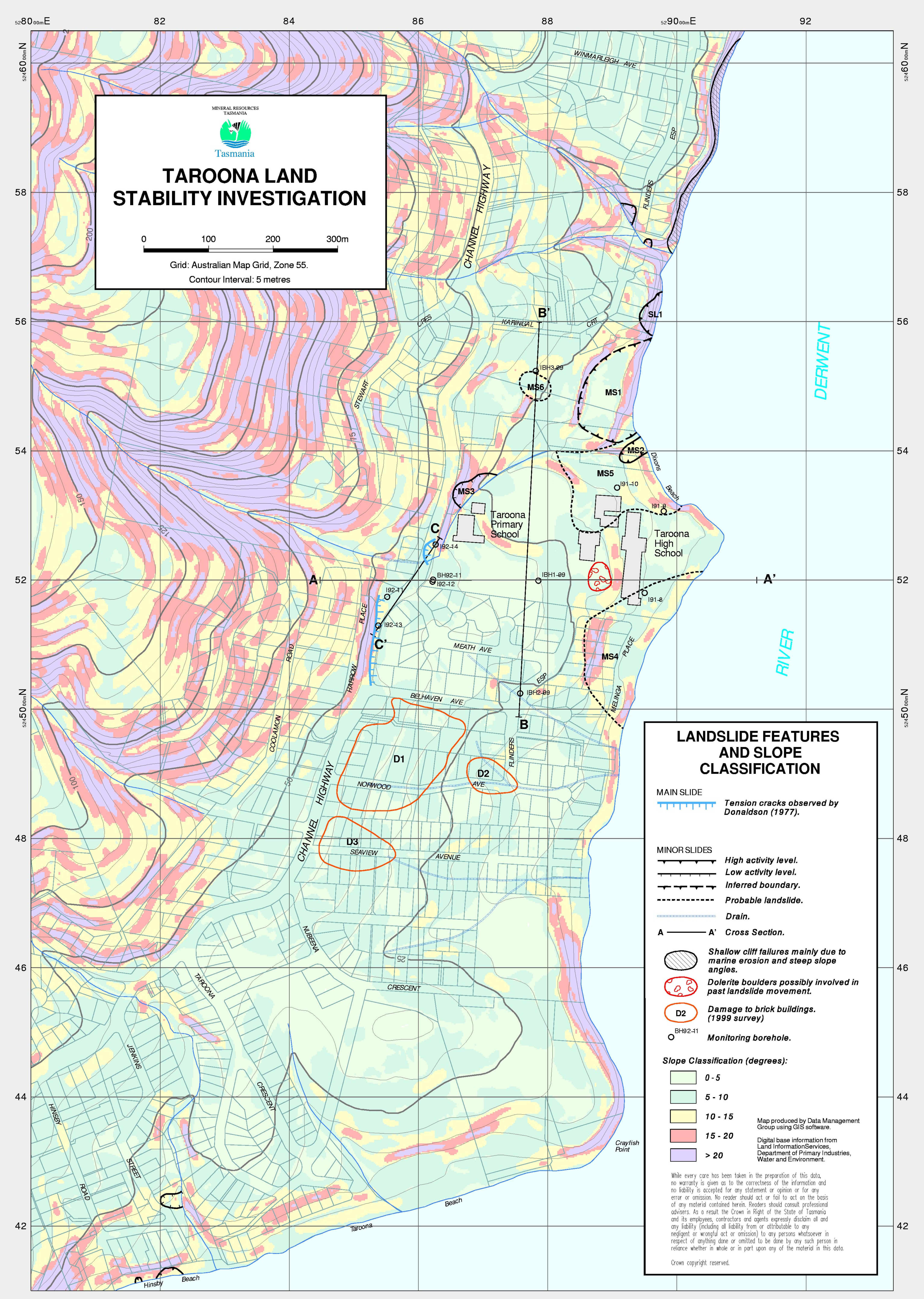
Strike and dip of dominant joint set.

Figure 8

MINERAL RESOURCES
TASMANIA

Tasmania

TAROONA LAND STABILITY INVESTIGATION



Grid: Australian Map Grid, Zone 55.

Contour Interval: 5 metres

LANDSLIDE FEATURES AND SLOPE CLASSIFICATION

MAIN SLIDE

Tension cracks observed by Donaldson (1977).

MINOR SLIDES

High activity level.

Low activity level.

Inferred boundary.

Probable landslide.

Drain.

A —— A' *Cross Section.*

Shallow cliff failures mainly due to marine erosion and steep slope angles.

Dolerite boulders possibly involved in past landslide movement.

D2 *Damage to brick buildings. (1999 survey)*

BH92-11 *Monitoring borehole.*

Slope Classification (degrees):

🟩	***0 - 5***
🟩	***5 - 10***
🟨	***10 - 15***
🟥	***15 - 20***
🟪	***> 20***

Map produced by Data Management Group using GIS software.

Digital base information from Land InformationServices, Department of Primary Industries, Water and Environment.

Figure 9

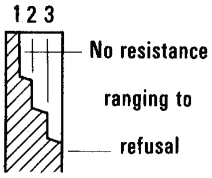
APPENDIX 1

Borehole logs

EXPLANATION SHEET FOR ENGINEERING LOGS

Borehole and excavation log

Penetration



Water

22 Jan, 80 Water level on date shown.

Water inflow.

Water outflow.

Notes - samples and tests

U50	Undisturbed sample 50mm diameter.
D	Disturbed sample.
N	Standard penetrometer blow count for 300mm.
N *	SPT + sample.

Material classification

Based on Unified Soil Classification System.
In Graphic Log materials are represented by clear contrasting symbols consistent for each project.

Moisture content

D	Dry, looks and feel dry.
M	Moist, no free water on hand when remoulding.
W	Wet, free water on hand when remoulding.
LL	Liquid limit.
PL	Plastic limit.
PI	Plasticity Index.

eg. M > PL - Moist, moisture content greater than the plastic limit.

Consistency

		hand penetrometer (kPa)
VS	Very soft.	< 25
S	Soft.	25 - 50
F	Firm.	50 - 100
St	Stiff.	100 - 200
VSt	Very stiff.	200 - 400
H	Hard.	> 400
Fb	Friable.	

Notes: X on log is test result
— is range of results.

Density index

		%
VL	Very loose.	0 - 15
L	Loose.	15 - 35
MD	Medium dense.	35 - 65
D	Dense.	65 - 85
VD	Very Dense	85 - 100

Fracture description

RP	Rough planar
RI	Rough irregular
SP	Smooth planar
SI	Smooth irregular

Cored borehole log

Case - lift

Casing used.

Barrel withdrawn.

Fluid loss

No loss

50% loss

100% loss.

Lugeons

Lugeon units (μL) are a measure of rock mass permeability. For a 46 to 74mm diameter borehole 1 Lugeon is defined as a rate of loss of 1 litre per metre per minute. 1 Lugeon is roughly equivalent to a permeability of 1×10^{-4} mm/sec.

Graphic log

No core.

Rock substances represented by clear, contrasting symbols consistent for each project.

Weathering

Fr	Fresh.
SW	Slightly weathered.
HW	Highly weathered.
EW	Extremely weathered.

Strength

		point load strength index $I_{s(50)}$ (MPa)
EL	Extremely low.	< 0·03
VL	Very low.	0·03 - 0·1
L	Low.	0·1 - 0·3
M	Medium.	0·3 - 1
H	High	1 - 3
VH	Very high.	3 - 10
EH	Extremely high.	>10

Note: X on log is test result.

Significant defects

Significant defects shown graphically.

Joint.

Sheared zone.

Crushed seam.

Infill seam.

Extremely weathered seam.

c:\data\geology\eng_log.cdr

MINERAL RESOURCES TASMANIA

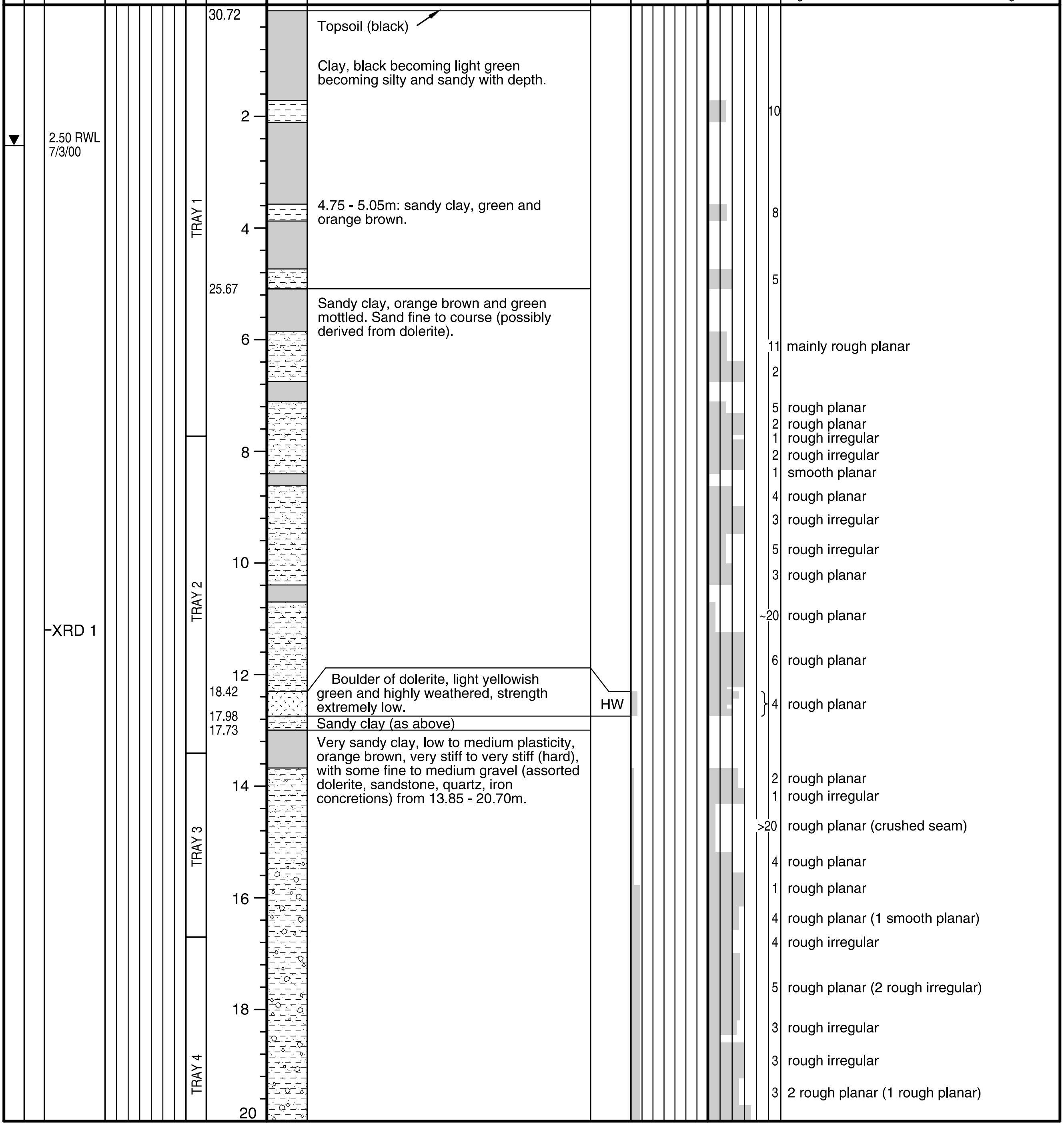
ENGINEERING LOG - CORED BOREHOLE

borehole no. IBH1/99
sheet 1 of 4

project	TAROONA LANDSLIP INVESTIGATION			location	TAROONA HIGH SCHOOL
co-ordinates	528 785.51mE 5 245 198.90mN	drill type		hole commenced	22/3/99
R.L.	30.72m	drill method	Rotary coring	hole completed	26/3/99
		drill fluid	Water	drilled by	KMR
inclination	Vertical	casing diameter	70mm	logged by	ML
bearing				checked by	RCD
Casing length	68 m				

drilling information | **rock substance** | **rock mass defects**

water | samples | notes | lugeons (0.3, 1, 3, 10, 30, 100) | tray no. | metres (R.L., depth) | graphic log | **substance description** rock type: grain characteristics, colour, structure, minor components. | weathering | **strength** (EL, VL, L, M, H, VH, EH) | **defect spacing (mm)** (30, 100, 300, 1000, 3000) | **defect description** thickness, type, inclination, planarity, roughness, coating. significant / general



Water: ▼ 2.50 RWL 7/3/00

Samples: XRD 1

Tray no.: TRAY 1, TRAY 2, TRAY 3, TRAY 4

R.L.: 30.72, 25.67, 18.42, 17.98, 17.73

Depth: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Topsoil (black)

Clay, black becoming light green becoming silty and sandy with depth.

4.75 - 5.05m: sandy clay, green and orange brown.

Sandy clay, orange brown and green mottled. Sand fine to course (possibly derived from dolerite).

Boulder of dolerite, light yellowish green and highly weathered, strength extremely low. | HW

Sandy clay (as above)

Very sandy clay, low to medium plasticity, orange brown, very stiff to very stiff (hard), with some fine to medium gravel (assorted dolerite, sandstone, quartz, iron concretions) from 13.85 - 20.70m.

10	
8	
5	
11	mainly rough planar
2	
5	rough planar
2	rough planar
1	rough irregular
2	rough irregular
1	smooth planar
4	rough planar
3	rough irregular
5	rough irregular
3	rough planar
~20	rough planar
6	rough planar
4	rough planar
2	rough planar
1	rough irregular
>20	rough planar (crushed seam)
4	rough planar
1	rough planar
4	rough planar (1 smooth planar)
4	rough irregular
5	rough planar (2 rough irregular)
3	rough irregular
3	rough irregular
3	2 rough planar (1 rough planar)

MINERAL RESOURCES TASMANIA

ENGINEERING LOG - CORED BOREHOLE

borehole no. IBH1/99
sheet 2 of 4

project TAROONA LANDSLIP INVESTIGATION
location TAROONA HIGH SCHOOL

co-ordinates	528 785.51mE 5 245 198.90mN	drill type		hole commenced	22/3/99
		drill method	Rotary coring	hole completed	26/3/99
R.L.	30.72m	drill fluid	Water	drilled by	KMR
inclination	Vertical	casing diameter	70mm	logged by	ML
bearing				checked by	RCD
Casing length	68 m				

drilling information — water; samples; notes; lugeons (0.3, 1, 3, 10, 30, 100); tray no.; metres (R.L., depth)

rock substance — graphic log; **substance description** (rock type: grain characteristics, colour, structure, minor components.); weathering; **strength** (EL, VL, L, M, H, VH, EH)

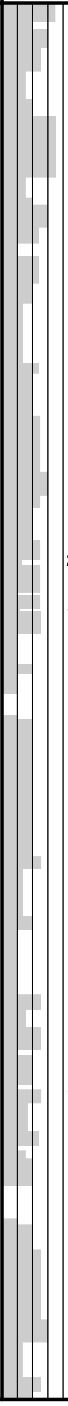
rock mass defects — **defect spacing (mm)** (30, 100, 300, 1000, 3000); **defect description** (thickness, type, inclination, planarity, roughness, coating.) significant / general

Notes: XRD 2 (at about 21 m depth); XRD 3 (at about 31.6 m depth)

Trays: TRAY 4; TRAY 5; TRAY 6; TRAY 7; TRAY 8; TRAY 9

Depth (m): 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40

R.L.	substance description	weathering
	Very sandy clay (as sheet 1)	
10.05	Sandy clay, greenish brown, (sand is fine to coarse and possibly derived from dolerite).	
3.22	Cobble size fragment of dolerite boulder.	
3.02	Sandy clay, greenish brown. 27.80m: with gravel size angular fragment derived from Permian siltstone.	
1.72	Sandy clay, reddish brown with some gravel (coarse, of weathered dolerite).	
0.52	Slightly silty clay, dark green.	
-0.58	Dolerite, light greenish brown, stained red.	HW
-0.88	Sandy clay, reddish brown locally mottled green, with some fine to medium gravel (dolerite, iron concretions, Permian rocks).	
-2.48	Silty clay, green occasionally brown, with rare cobbles (dolerite).	
-3.68	Sandy clay, reddish brown and greenish brown with occasional fine to medium gravel (iron concretions).	
-4.58	Sandstone recovered. Strength extremely low.	
-4.78		
-5.48	Sandstone recovered. Strength extremely low.	
-5.78		
-6.28	Boulder, light green to white, low strength (dolerite).	HW
-6.73	Silty clay, high plasticity, greenish brown, in parts sandy, with rare gravel and cobbles (dolerite, extremely weathered)	



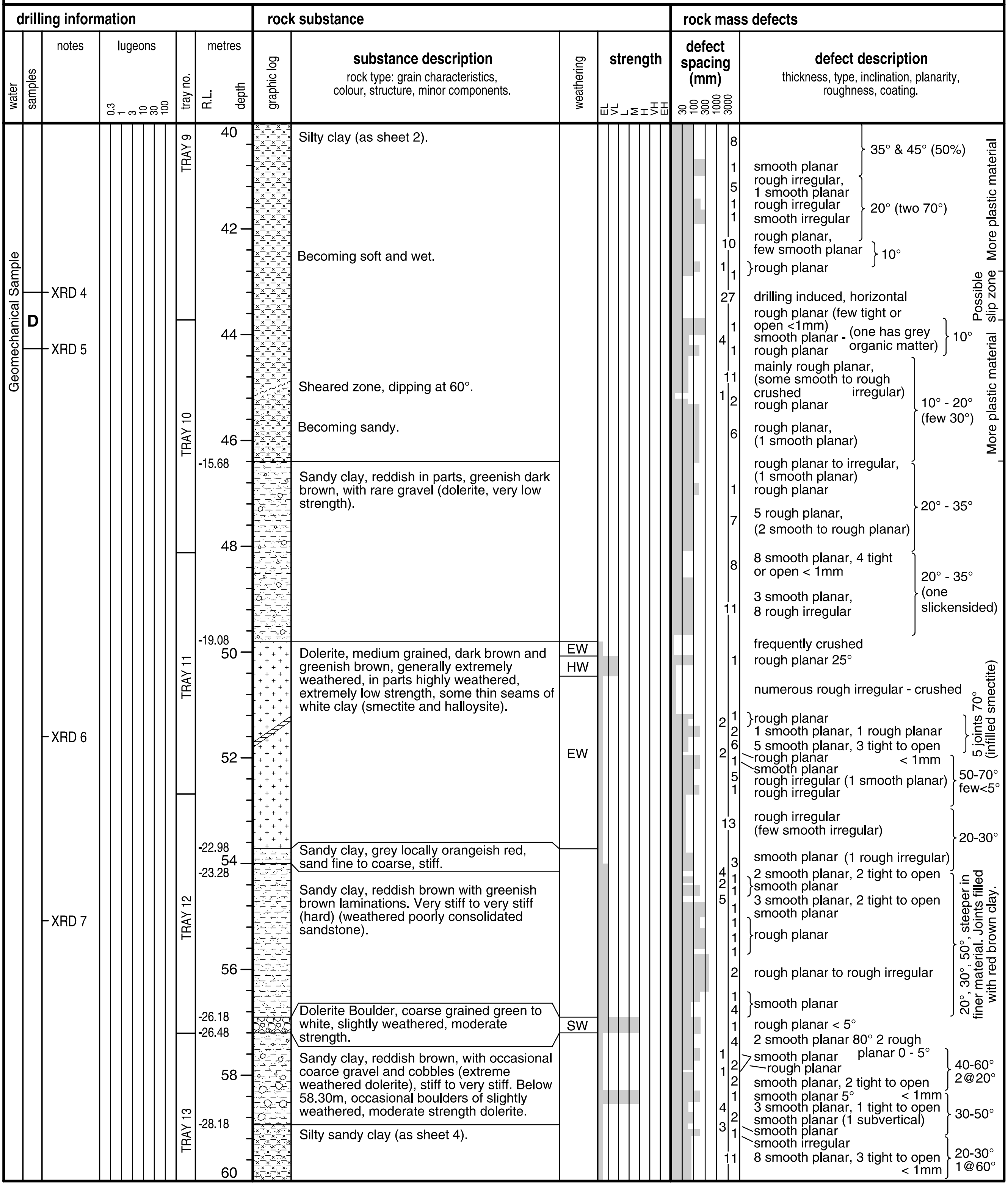
		significant	general
1	1 1	rough planar	
	1	smooth planar	
	2	smooth planar	
	6	smooth planar	
	2	1 rough planar & 1 smooth planar	
	2	1 rough irregular & 1 smooth irregular, 10° & 85°	
1	4	smooth planar	20°
	1	rough planar	
1		rough irregular	
	7	subvertical 85 - subhorizontal (several systems)	
	2	smooth planar	
	3	planar - slickensided rough	
	15	1 long 75° (joint) slickensided, others planar (smooth & rough) 20° - 30° some 5°	
	1	smooth planar	
	8	mainly planar, some irregular, 20° - 30°, one 70°	
	3	smooth planar	
	1 1	rough planar	
	5	2 longitudial smooth planar 3 rough planar	
2	1	rough planar	
	2	smooth planar	
1 3	1	rough planar	
	1	rough planar 55°	
	8 1 8	mainly rough planar (5° - 40°)	
		smooth planar (slickensided) 20° - 30° (one 55°)	
	27		
		mainly semi-open 0° - 10°	
	1		
	14	smooth planar	15° - 30°
	2		
		smooth planar	45°-55°
	1		
	4		
	2	rough irregular	
	4	smooth planar	
	4	smooth planar - rough planar	
5		smooth planar - 1 rough planar	
	1	rough planar	15°-30°
	6	smooth planar	
	1		
4	2	smooth planar - smooth irregular	
		rough irregular	
	3	smooth planar - smooth irregular	
	6	smooth planar - (one inferred ???)	20° - 35°
	5	smooth planar	
	5	smooth planar - slickensided	
	1	smooth planar	
	18	smooth - planar; irregular	20°
	1	rough irregular	

MINERAL RESOURCES TASMANIA

ENGINEERING LOG - CORED BOREHOLE

borehole no. IBH1/99
sheet 3 of 4

project	TAROONA LANDSLIP INVESTIGATION			location	TAROONA HIGH SCHOOL
co-ordinates	528 785.51mE 5 245 198.90mN	drill type		hole commenced	22/3/99
		drill method	Rotary coring	hole completed	26/3/99
R.L.	30.72m	drill fluid	Water	drilled by	KMR
inclination	Vertical	casing diameter	70mm	logged by	ML
bearing				checked by	RCD
Casing length	68 m				



R.L.	substance description rock type: grain characteristics, colour, structure, minor components.	weathering
	Silty clay (as sheet 2).	
	Becoming soft and wet.	
	Sheared zone, dipping at 60°.	
	Becoming sandy.	
-15.68	Sandy clay, reddish in parts, greenish dark brown, with rare gravel (dolerite, very low strength).	
-19.08	Dolerite, medium grained, dark brown and greenish brown, generally extremely weathered, in parts highly weathered, extremely low strength, some thin seams of white clay (smectite and halloysite).	EW HW EW
-22.98	Sandy clay, grey locally orangeish red, sand fine to coarse, stiff.	
-23.28	Sandy clay, reddish brown with greenish brown laminations. Very stiff to very stiff (hard) (weathered poorly consolidated sandstone).	
-26.18	Dolerite Boulder, coarse grained green to white, slightly weathered, moderate strength.	SW
-26.48	Sandy clay, reddish brown, with occasional coarce gravel and cobbles (extreme weathered dolerite), stiff to very stiff. Below 58.30m, occasional boulders of slightly weathered, moderate strength dolerite.	
-28.18	Silty sandy clay (as sheet 4).	

defect spacing	defect description thickness, type, inclination, planarity, roughness, coating.		
8		35° & 45° (50%)	More plastic material
1	smooth planar		
5	rough irregular, 1 smooth planar	20° (two 70°)	
1	rough irregular		
1	smooth irregular		
10	rough planar, few smooth planar	10°	
1 1	rough planar		
27	drilling induced, horizontal		Possible slip zone
1	rough planar (few tight or open <1mm)	10°	
4	smooth planar - (one has grey organic matter)		More plastic material
1	rough planar		
11	mainly rough planar, (some smooth to rough irregular) crushed	10° - 20° (few 30°)	
1 2	rough planar		
6	rough planar, (1 smooth planar)		
	rough planar to irregular, (1 smooth planar)	20° - 35°	
1	rough planar		
7	5 rough planar, (2 smooth to rough planar)		
8	8 smooth planar, 4 tight or open < 1mm	20° - 35° (one slickensided)	
11	3 smooth planar, 8 rough irregular		
	frequently crushed		
1	rough planar 25°		
	numerous rough irregular - crushed		
2 1	rough planar	5 joints 70° (infilled smectite)	
2	1 smooth planar, 1 rough planar		
6	5 smooth planar, 3 tight to open < 1mm		
2 1	rough planar smooth planar	50-70° few<5°	
5	rough irregular (1 smooth planar)		
1	rough irregular		
13	rough irregular (few smooth irregular)	20-30°	
3	smooth planar (1 rough irregular)		
4 1	2 smooth planar, 2 tight to open	20°, 30°, 50°, steeper in finer material. Joints filled with red brown clay.	
2 1	smooth planar		
5	3 smooth planar, 2 tight to open		
1	smooth planar		
1 1 1	rough planar		
2	rough planar to rough irregular		
1 4	smooth planar		
1	rough planar < 5°		
4	2 smooth planar 80° 2 rough planar 0 - 5°		
1 2	smooth planar rough planar	40-60° 2@20°	
1 2	smooth planar, 2 tight to open < 1mm		
1	smooth planar 5°	30-50°	
4	3 smooth planar, 1 tight to open		
2	smooth planar (1 subvertical)		
3 1	smooth planar smooth irregular		
11	8 smooth planar, 3 tight to open < 1mm	20-30° 1@60°	

MINERAL RESOURCES TASMANIA

ENGINEERING LOG - CORED BOREHOLE

borehole no. IBH1/99
sheet 4 of 4

project TAROONA LANDSLIP INVESTIGATION
location TAROONA HIGH SCHOOL

co-ordinates	528 785.51mE 5 245 198.90mN	drill type		hole commenced	22/3/99
R.L.	30.72m	drill method	Rotary coring	hole completed	26/3/99
inclination	Vertical	drill fluid	Water	drilled by	KMR
bearing		casing diameter	70mm	logged by	ML
Casing length	68 m			checked by	RCD

drilling information

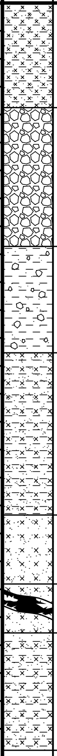
notes: XRD 8; XRD 9; palynology (P1079); XRD 10; XRD 11

lugeons: 0.3 1 3 10 30 100

tray no.: TRAY 13; TRAY 14; TRAY 15; TRAY 16

metres (depth): 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80

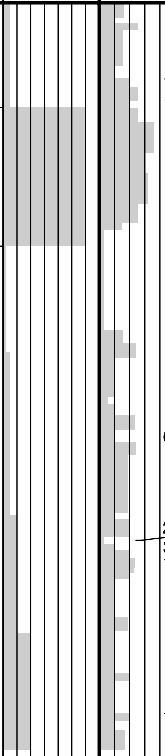
rock substance



R.L.	substance description rock type: grain characteristics, colour, structure, minor components.	weathering
	Silty sandy clay, reddish brown, in parts greenish brown, stiff to very stiff. (Weak Mudstone).	
-30.78	Dolerite boulder, coarse gravel, dark and light grey spotted, fresh very high strength.	FR
-32.78	Slightly sandy clayey gravel and cobbles, greenish brown and reddish brown, composed of green sandy sily clay (weathered siltstone), angular fragments of Permian sandstone, and subrounded iron concretions.	
-34.28	Siltstone, sandy, clayey light green with orange brown banding, massive, extremely low strength.	
-36.58	Siltstone, sandy, light green and light grey, some organic material, very low strength.	
-37.58	Siltstone, sandy, grey, carbonaceous, low strenght. 68.40 - 68.60m: coal seam.	
-38.28	Siltstone, sandy (fine to coarse), clayey, light green to brown, massive with rare angular fine to medium gravel, very low to low strength.	
-39.98		

strength: EL VL L M H VH EH

rock mass defects



defect description
thickness, type, inclination, planarity, roughness, coating.

		} 20° - 30° (one 60°)
1 4		
12	smooth planar	
5		
1 1		
1 2		30°, 35°
1	rough planar	55°
1		20°
1	smooth planar	(clay infill ~ 1mm coating) 45°
1	rough planar 30°	
2	rough planar	
	numerous joints < 1cm mainly smooth planar, some smooth irregular, few core pieces 7 - 12cm tight to open, all the rest broken completely.	possible slip zone
5	4 rough planar, 1 smooth planar, few tight to open	
1	rough planar, few tight to open	
20	rough planar, 5 smooth planar	15° (few 20° - 30°)
1	rough planar	
6 2	} smooth planar	20°
10	smooth planar, few tight to open < 1mm	
5	} smooth planar	60°
2	numerous	few tight to open,
3 2	smooth to rough planar	<1mm, 30°
1	} smooth planar	30° - 35°
1		
11	8 smooth planar & 3 coal seams 1 - 2cm	15° - 20° (few 30°)
3	} smooth planar	
6		
17	smooth planar, few tight to open, < 1mm	30°
2		
12	} smooth planar	40° - 60° others 20°
1 5	rough irregular	
4	} smooth planar	15° - 20° (few 30°)
8		

BH1/99

0.0
to
13.45 m

BH1/99

13.45
to
16.70 m

BH1/99

16.70
to
21.20 m

BH1/99

21.20
to
25.70 m

BH1/99

25.70
to
30.20 m

BH1/99

30.20
to
34.50 m

BH1/99

34.50
to
39.20 m

BH1/99

39.20
to
43.70 m

BH1/99

43.70
to
48.10 m

BH1/99

48.10
to
52.70 m

BH1/99

52.70
to
57.20 m

BH1/99

57.20
to
61.50 m

BH1/99

61.50
to
65.70 m

BH1/99

65.70
to
70.70 m

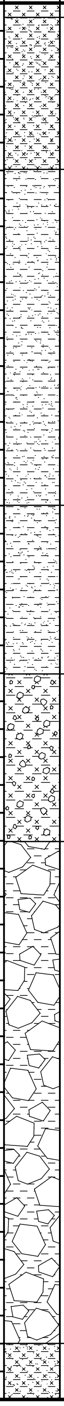
MINERAL RESOURCES TASMANIA

ENGINEERING LOG - BOREHOLE

borehole no. IBH2/99
sheet 1 of 2

project TAROONA LANDSLIP INVESTIGATION location CORNER OF BELHAVEN AVE & FLINDERS ESP.

co-ordinates	528 757mE 5 245 025mN	drill type		hole commenced	30/03/1999
R.L.	23.90	drill method	Rotary to 30m DTH 30m - 48m	hole completed	01/04/1999
inclination	Vertical	drill fluid	air	drilled by	KMR
bearing		casing diameter	70mm	logged by	ML
casing length	65m			checked by	AW



sample	water	notes samples, tests	metres R.L.	metres depth	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	structure, geology
			23.40	0	Silty clay.	M		Topsoil
	▼	RWL 7/3/2000		5	Sandy silty clay, mottled brownish red and green, with some fine to coarse gravel (slate, siltstone). Some gravel sized fragments of extremely weaksiltstone at base.			
			17.90	10 15	Sandy clay, dark red, with rare fine to coarse sand (quartz).	D		
	▶	WS (possibly)	5.90	20	Sandy clay, reddish light brown, with some fine to coarse gravel (extremely weak, greenish white) and rare fine sand (quartz).	W		Possible slip zone.
			-0.10	25	Gravel, fine to medium, occasionally coarse, with a little silt and clay. Gravel consists of angular to sub-rounded fragments of dolerite, slate and siltstone.			
			-6.10	30 35 40 45	Boulders with some interbeds of silty clay (reddish brown). 41m - 43m: Boulder size increase.			
			-24.10	50	Sandy sily clay (as sheet 2).			

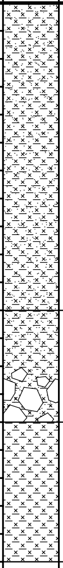
MINERAL RESOURCES TASMANIA

ENGINEERING LOG - BOREHOLE

borehole no. IBH2/99
sheet 2 of 2

project	TAROONA LANDSLIP INVESTIGATION	location	CORNER OF BELHAVEN AVE & FLINDERS ESP.

co-ordinates	528 757mE 5 245 025mN	drill type		hole commenced	30/03/1999
R.L.	23.90	drill method	Rotary to 30m DTH 30m - 48m	hole completed	01/04/1999
inclination	Vertical	drill fluid	air	drilled by	KMR
bearing		casing diameter	70mm	logged by	ML
casing length	65m			checked by	AW



sample	water	notes samples, tests	metres R.L.	metres depth	graphic log	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	structure, geology
			-26.10	50		Sandy silty clay, reddish brown and light brown mottled, with some fine, occasionally medium, gravel (angular to subangular, dolerite).			
				55					
				60					
		XRD1	-37.10			Sandy silty clay, light orange brown (possibly weathered siltstone). 63m - 65m: some boulders of dolerite.			
			-41.10	65		Silty clay, light orangish grey to green mottled with some fine gravel (angular, dolerite).			
			-46.10	70					

MINERAL RESOURCES TASMANIA

ENGINEERING LOG - BOREHOLE

borehole no. IBH3/99
sheet 1 of 2

project TAROONA LANDSLIP INVESTIGATION
location CORNER OF BELHAVEN AVE & FLINDERS ESP.

co-ordinates	528 782mE 5 245 524mN	drill type		hole commenced	19/04/1999
R.L.	29.07	drill method	Rotary drilling 0 - 50m DTH drilling 50 - 70m	hole completed	19/04/1999
inclination	Vertical			drilled by	KMR
bearing		drill fluid	water/air	logged by	ML
casing length	69m	casing diameter	70mm	checked by	AW

sample	water	notes samples, tests	metres R.L.	metres depth	graphic log	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	structure, geology
			29.00	0		Sandy clay. Sandstone and siltstone fine grained, light grey becoming light yellowish green and grey below 6m, extremely lo strength.			Topsoil
				5			D		
	▼	RWL 20/4/1999		10					
		XRD1 geomech 1	17.07			Clay, moderite plasticity becoming high plasticity below 18m, brownish dark grey mottled orange.			
D				15			M		
		XRD2 geomech 2 palynology (P1079)							Possible slip zone
D				20			W		
	▶	WS (0.63 l/s)	5.07	25		Siltstone, olive green, recovered as low strength gravel, with some gravel of dolerite (fine to coarse, light grey). Occasional pyrite coatings on siltstone gravel. Occasional conglomerate interbeds.			
						24m - 30m: Fine fraction contains mostly clay, with some fine to medium sand of quartz and feldspar.			
				30					
				35					
						36m - 42m Much fine to medium dolerite gravel, with fine fraction mostly of clay and some sand (quartz, pyroxene, feldspar).			
				40					
	▶	WS (0.1 l/s)							
				45		42m - 48m Much fine to coarse gravel (dolerite and siltstone) with some clay and fine to medium sand (quartz, pyroxene, feldspar, siderite).			
						48m - 54m Occasional gravel-sized fragments of wood and tree roots.			
				50					

MINERAL RESOURCES TASMANIA

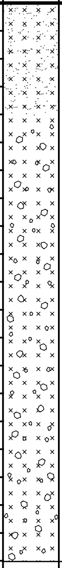
ENGINEERING LOG - BOREHOLE

borehole no. IBH3/99
sheet 2 of 2

project TAROONA LANDSLIP INVESTIGATION

location CORNER OF BELHAVEN AVE & FLINDERS ESP.

co-ordinates	528 782mE 5 245 524mN	drill type		hole commenced	19/04/1999
		drill method	Rotary drilling 0 - 50m DTH drilling 50 - 70m	hole completed	19/04/1999
R.L.	29.07			drilled by	KMR
inclination		drill fluid	water/air	logged by	ML
bearing		casing diameter	70mm	checked by	AW
casing length	69m				



sample	water	notes samples, tests	metres R.L.	metres depth	graphic log	material soil type: plasticity or particle characteristics, colour, secondary and minor components.	moisture condition	consistency density index	structure, geology
				50		Siltstone, sandy, with some fine to medium dolerite gravel.			
		palynology (P1080)		55		54m - 60m: Much fine siltstone gravel.			
	▶	WS (1.09 l/s) continuous water inflow		60					
				65		60m - 70m: Some fine dolerite gravel.	W		
			-40.93	70					

APPENDIX 2

Palynology report on three samples from Taroona bores IBH 1-99, IBH 3-99

S. M. Forsyth.

INTRODUCTION

During 1999 several boreholes were drilled in the Taroona school area as part of a geological investigation undertaken by Mineral Resources Tasmania. One sample from a diamond cored bore and two samples of cuttings from a second bore were selected for palynological study.

The samples are identified below.

Paly. No.	*Bore*	*Depth (m)*	*Type*	*Sample description*
P1078	IBH 1-99	~67	Core	Fractured dark grey siltstone
P1079	IBH 3-99	18-24	Sludge	Grey clay with rock chips
P1080	IBH 3-99	54-60	Chips	Olive coloured siltstone chips

Sample preparation

The samples were all prepared with standard hydrofluoric and hydrochloric acid treatment followed by ten minutes nitric acid (sample P1078) or ten minutes Schultz solution (samples P1079 and P1080) and then potassium carbonate solution. Permanent slides were prepared.

Results and discussion

The results presented below are based on a non-exhaustive study of the slides and without direct comparisons to similar microfloras. It is expected that additional scanning would add to the microflora lists, but perhaps not alter the interpretation.

Bore IBH 1-99

Although the core sample P1078 seemed a promising lithology the probable Tertiary microflora obtained was found to be very meagre and thin walled and no diagnostic palynomorphs have been found in the limited scanning undertaken to enable a more specific zone assignment. The poor preservation may indicate some weathering associated with fluids passing through the fractures and it could prove fruitful to select additional samples from the less fractured, but less carbonaceous core from other horizons within the bore.

Bore IBH 3-99

The samples from IBH 3-99 yielded better preserved microfloras, particularly the upper sample P1079, but diagnostic palynomorphs were not common.

Some palynomorphs are found in both samples, these include:

Nothofagidites flemingii (Couper) Potonie 1960
Nothofagidites goniatus (Cookson) Stover and Evans 1973.

Based on their ranges in the Gippsland Basin (Stover and Partridge, 1973) and Bass Basin (Partridge, 1973) (see Figure 10), the presence of *Nothofagidites goniatus* suggests a zone assignment from the Lower *Malvacipollis diversus* Zone to into the *Proteacidites tuberculatus* Zone. The maximum age estimate may be supported in the lower sample P1080 by an imperfect specimen probably of *Beaupreaidites elegansiformis* Cookson 1950, which first appears (i.e. oldest occurrence) in the Middle *Malvacipollis diversus* Zone (Partridge, 1973).

The upper sample P1079 differs from the lower sample P1080 (and also P1078) by containing an abundance of horned dinoflagellates. Some of the pollen species present provide contradictory evidence of age. In addition to *Nothofagidites goniatus*, three other species present support a *Malvacipollis diversus* Zone or younger age. These are:

Triporopollenites ambiguus Stover 1973
Cupanieidites orthoteichus Cookson & Pike 1954
Intratriporopollenites notabilis (Harris) Stover 1973.

Three other specimens present of the form genus *Gambierina*, including *G. rudata* Stover 1973 and a form close to *G. edwardsii* (Cookson & Pike) Harris 1972, suggest a pre-*Malvacipollis diversus* Zone assignment.

Some possible interpretations of the contradictory results are:

1. The sludge sample interval 18–24 m contains both pre-*M. diversus* Zone and post-*Lygistepollenites balmei* Zone strata in superposition or reversed order.
2. *Gambierina* spp. have been recycled as grains or in clasts into post-*L. balmei* Zone strata.
3. The ranges of *Gambierina* spp. and/or other species may differ in southern Tasmania.
4. The drilling process may have artificially contaminated the sludge sample.

Recycling of *Lygistepollenites balmei* Zone fossils into younger Tertiary strata is well known from the Bass Basin (Partridge, 1973). Species such as *Gambierina rudata* also occur above their normal range in on-shore Tasmania, although through intervening intervals the

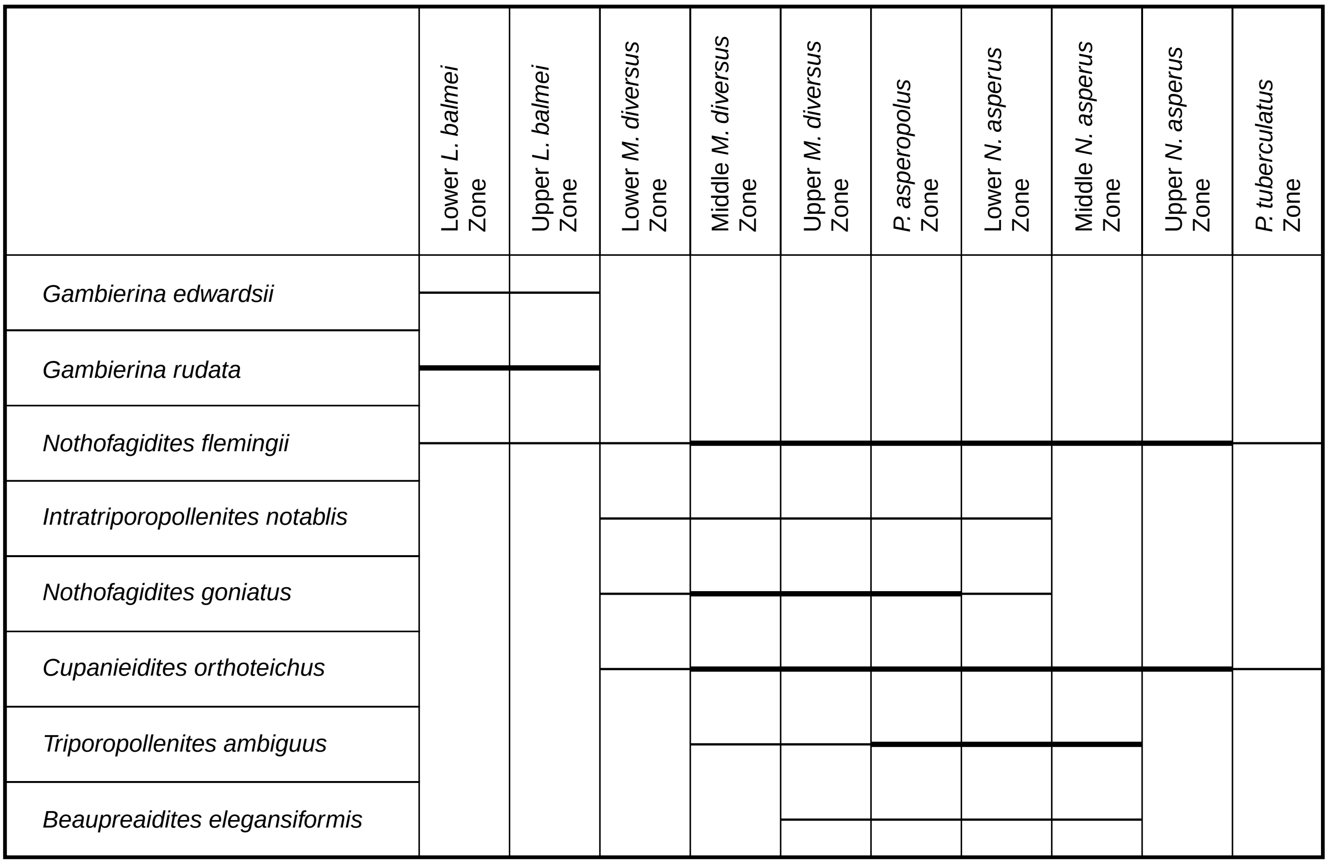


Figure 10

Ranges of selected palynomorphs in the Bass Basin after Partridge (1973), including formal and informally defined zones

species appears to be entirely absent. In some cases different states of preservation strongly support a recycled origin for the specimens. A recycled origin for the *Gambierina* spp. appears quite possible for the Taroona sample.

Four taxa suggest a post-*Lygistepollenites balmei* Zone choice for the P1079 microflora. A possible fifth taxa, *Malvacipollis diversus* (which could probably be confirmed with additional study of the slides), would also support this result. Overall the evidence suggests the presence of post-*Lygistepollenites balmei* Zone strata in the interval 18–24 metres.

Gambierina spp. were not recorded from the single deeper and apparently older strata interval from 54–60 m as might be expected if the species was distributed continuously throughout the sequence. Although the evidence is slight, it does not support an upward extension of *Gambierina* spp. or the *Lygistepollenites balmei* Zone towards the interval 18–24 m from any hypothetical deeper occurrences below 60 metres.

A microflora similar to that of sample P1079 was previously obtained from an unknown bore drilled after 1990 near Taroona High School. This microflora also contains *Intratriporopollenites notabilis* and additional indicators of a post-*Lygistepollenites balmei* age not found in P1079, but *Gambierina* spp. are absent. This microflora indicates that non-ambiguous post-*L. balmei* Zone microfloras are locally present.

The upper zone limit for P1079 is indicated by *Triporopollenites ambiguus*, *Intratriporopollenites notabilis* and *Nothofagidites goniatus*. In the Bass Basin the first taxon does not range above the Middle *Nothofagidites asperus* Zone and the latter two taxa do not range above the Lower *Nothofagidites asperus* Zone. There are no taxa present such as the usually ubiquitous *Cyatheacidites annulatus* that would suggest the *Proteacidites tuberculatus* Zone, nor indicators of the *Nothofagidites asperus* Zone which usually occur with some reliability in northern Tasmania. Consequently P1079 is probably older than the Lower *N. asperus* Zone, or if within that Zone then towards the base before the characteristic species had become well established.

In P1079 *Triporopollenites ambiguus* defines the lower Zone limit as the Middle *Malvacipollis diversus* Zone.

If the tentative occurrence of *Beaupreaidites elegansiformis* in P1080 was confirmed and if the stratigraphic sequence between the samples is unfaulted, then the P1079 microflora is most likely from the Upper *Malvacipollis diversus* Zone or the *Proteacidites asperopolus* Zone. At this stage such a refinement is probably unwarranted, as the evidence is not strong and the sample P1079 represents a six metre interval.

Based on the revised correlation of the Gippsland Basin zones with the geological time scale (Partridge, 1973) and the informal Bass Basin definitions of some

Zones (Partridge, 1976) the P1079 microflora is of early or middle Eocene age. Such an age determination is somewhat independent of precise zone assignment as the early Eocene age equivalents include most of the Middle *M. diversus* Zone, the Upper *M. diversus* Zone and part of the *P. asperopolus* Zone. The middle Eocene age equivalents include the remainder of the *P. asperopolus* Zone and the Lower *N. asperus* Zone.

Previous palynological investigations of samples from near Taroona High School have been reported by Harris (1968) and Warren (1969). Harris (1968) reported that sample S1291 (= University of Tasmania Geology Department 87598), from the shore below the rotary camp, yielded microplankton that indicated a marine or brackish water environment during sedimentation and indicated a Palaeocene age.

Harris (1968) did not describe the particular microflora, but listed typical species from Tasmanian 'Palaeocene' microfloras in general. Of the species listed by Harris (1968) only the 'rather rare' *Triorites* (=*Gambierina*) *edwardsii* would now be used to indicate the *Lygistepollenites balmei* Zone. Other listed species, *Tiliaepollenites* (= *Intratriporopollenites*) *notabilis* and *Anacolosidites acutullus*, indicate a post-*Lygistepollenites balmei* Zone and in the latter example an Eocene age.

Warren (1969) described fossil turtle specimens from the foreshore 100 metres north of the Taroona High School and assigned them to the living Australian freshwater turtle family Chelidae. Warren (1969) also noted that pollen analysis of the turtle matrix carried out by S. Duigan indicated a flora of *Nothofagus*, Proteaceae, Myrtaceae, conifers of the *Podocarpus* type and possible Araucariaceae. Some palynomorphs, considered then to be characteristic of Palaeocene–Eocene beds further north in Tasmania, were not found and it was surmised that the beds were probably of Oligocene or Miocene age.

The fossil groups found by Duigan are all present in samples P1079 and P1080 and there is no compelling evidence presented in Warren (1969) to suggest that the fossil turtles are necessarily younger than the current bore hole samples.

In summary, the available palynological evidence suggests that early or middle Eocene strata are present near Taroona High School. Older strata may be present, previously present or within the provenance area during the early to middle Eocene.

The occurrence of basaltic tuff at Taroona High School suggests some associated and overlying rocks could be younger than middle Eocene.

The radiometric ages of Tertiary basalt occurrences in Tasmania range from Palaeocene to late Miocene (59–8 Ma) (Sutherland, 1989), but most lie within the Oligocene–Miocene range. Determinations of basalt ages in the Hobart area, summarised by Sutherland and Wellman (1986), of 30.2 Ma at Risdon Brook, 26.5 Ma at Sandy Bay, and a minimum age of 23.0 Ma at Geilston Bay are within the mid-Oligocene to early Miocene range. It is probable that the age of the tuff at Taroona High School is also within an Oligocene–Miocene range.

Summary

A sludge sample from the interval 18–24 m in borehole IBH3-99 contains an early or middle Eocene microflora, together with *Gambierina* spp. probably derived from older strata. The microflora from cuttings between 54 and 60 m in the same bore is probably of similar age.

The microflora in borehole IBH1-99 at ~67 m is poorly preserved but probably of Tertiary age.

References

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APPENDIX 3

Mineralogical and geochemical testing

Whole sample XRD (approx. wt. %), borehole IBH1-99

Sample	Quartz	Smectite	Kaolinite	K-feldspar	Goethite	Ilmenite	Magnetite	Halloysite	Rhabdophane[1]	Pyrite
1-IBH1/99, 11.25 m	5	35	50	2	5	*				
2-IBH1/99, 21.20 m	15	35	40	2	5					
3-IBH1/99, 31.50 m	*	90	5		*		2			
4-IBH1/99, 43.20 m	10	70	20		2	*				
5-IBH1/99, 45.20 m	5	75	20		*	*				
6-IBH1/99, 51.60 m	2	30						65	5	
7-IBH1/99, 55.10 m	15	25	50	2	5	2				
8-IBH1/99, 60.20 m	10		65	*	25					
9-IBH1/99, 65.80 m	15	50	30	5						*
10-IBH1/99, 68.80 m	5	15	75	*						2
11-IBH1/99, 70.50 m	10	30	55	*	5					

* Trace

1. Rhabdophane-type mineral (hydrated rare-earth phosphate) — slightly expanded lattice?
   (peaks at approximately 6.07Å, 4.42Å, 3.51Å, 3.05Å, 2.85Å, 2.37Å, 2.27Å, 2.17Å, 1.93Å, 1.87Å)

Peak overlap may interfere with identifications (e.g. K-feldspar and rutile)

Amorphous minerals, or minerals present in trace amounts, may not be detected

Mechanical properties tests

Sample	LL (%)	PL (%)	LS (%)	∅' (º)	c' (kPa)
1-IBH1/99, 43.2–45.3 m	98	32	24	10	4

Analyst: R. N. Woolley, 1 June 1999

Whole sample XRD (approx. wt. %), boreholes IBH2-99 and IBH3-99

Sample	Quartz	Smectite	Kaolinite	K-feldspar	Mica	Plagioclase	Clinopyroxene	Ilmenite	Zeolite	Halite
1-IBH3/99, 12–18 m	30	35	20	2	2	2	2	2	2	2
2-IBH3/99, 18–24 m	30	40	20	2	2			2		2
1-IBH2/99, 61–65 m	25	55	15	2				2		
Siltstone, Karingal Court	10	30	60	2						

Peak overlap may interfere with identifications

Amorphous minerals, or minerals present in trace amounts, may not be detected

Mechanical properties tests

Sample	LL (%)	PL (%)	LS (%)	∅' (°)	c' (kPa)
1-IBH3/99, 12–18 m	89	27	22		
2-IBH3/99, 18–24 m	90	29	21	13	3

Analyst: R. N. Woolley, 26 May 1999

APPENDIX 4

Groundwater analysis

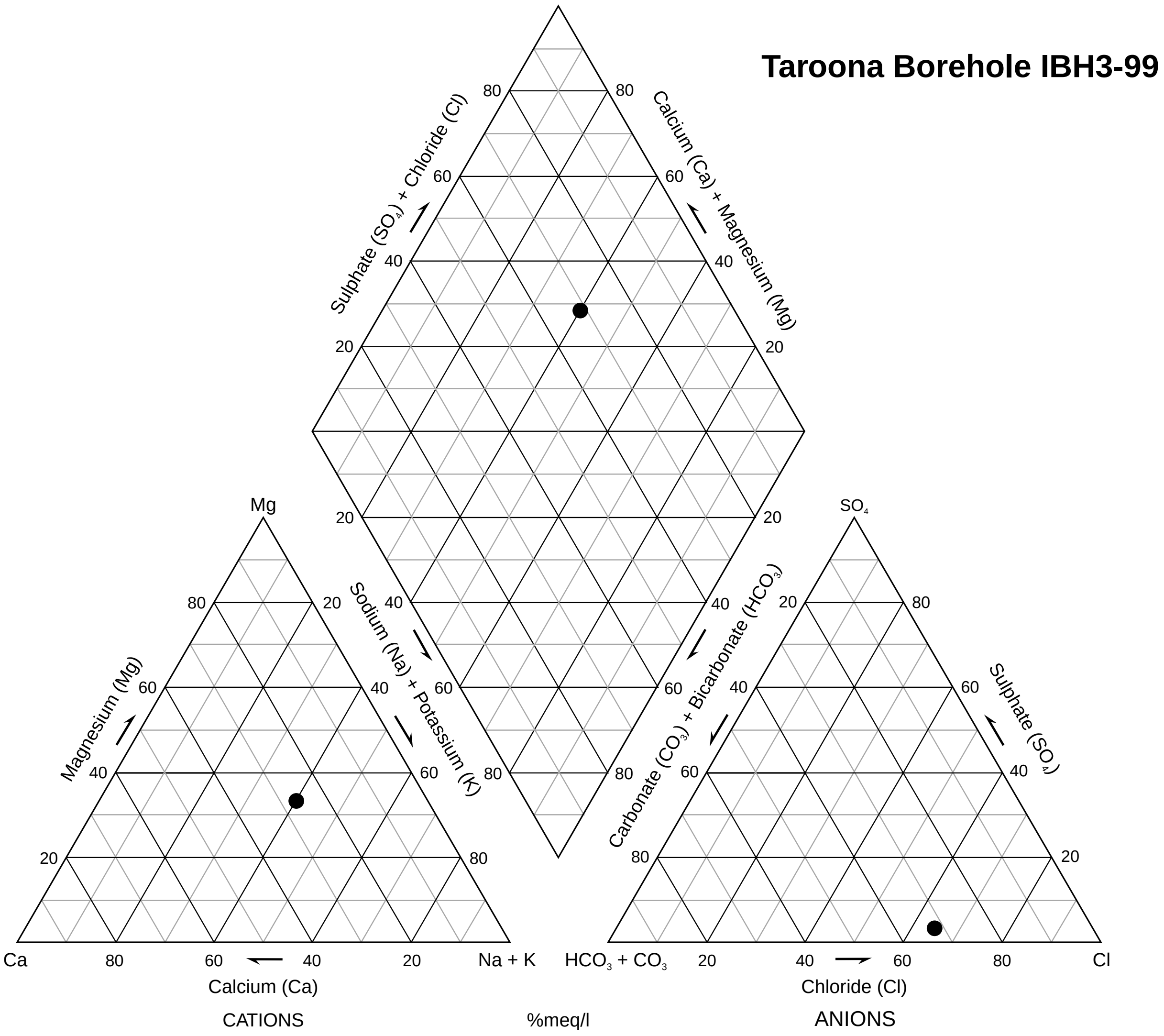
Borehole IBH3-99, Karingal Court, Taroona

Date sampled	20/04/1999
Date of analysis	29/04/1999
pH:	7.5
Conductivity	2520 µS/cm

Analysis (mg/L)

CO_3	-n/a	Ammonia as NH_4	n/a
HCO_3	530	F	<0.3
Cl	650	NO_3	<0.5
SO_4	43	Nitrite	n/a
SiO_2	n/a	TDS	1840
Ca	155	TSS	n/a
Mg	120	Total	880
Fe	n/a	Permanent hardness	450
Al	<0.2	Temporary hardness	430
K	6.4	Alkalinity	430
Na	270	DOC	n/a

n/a — not analysed



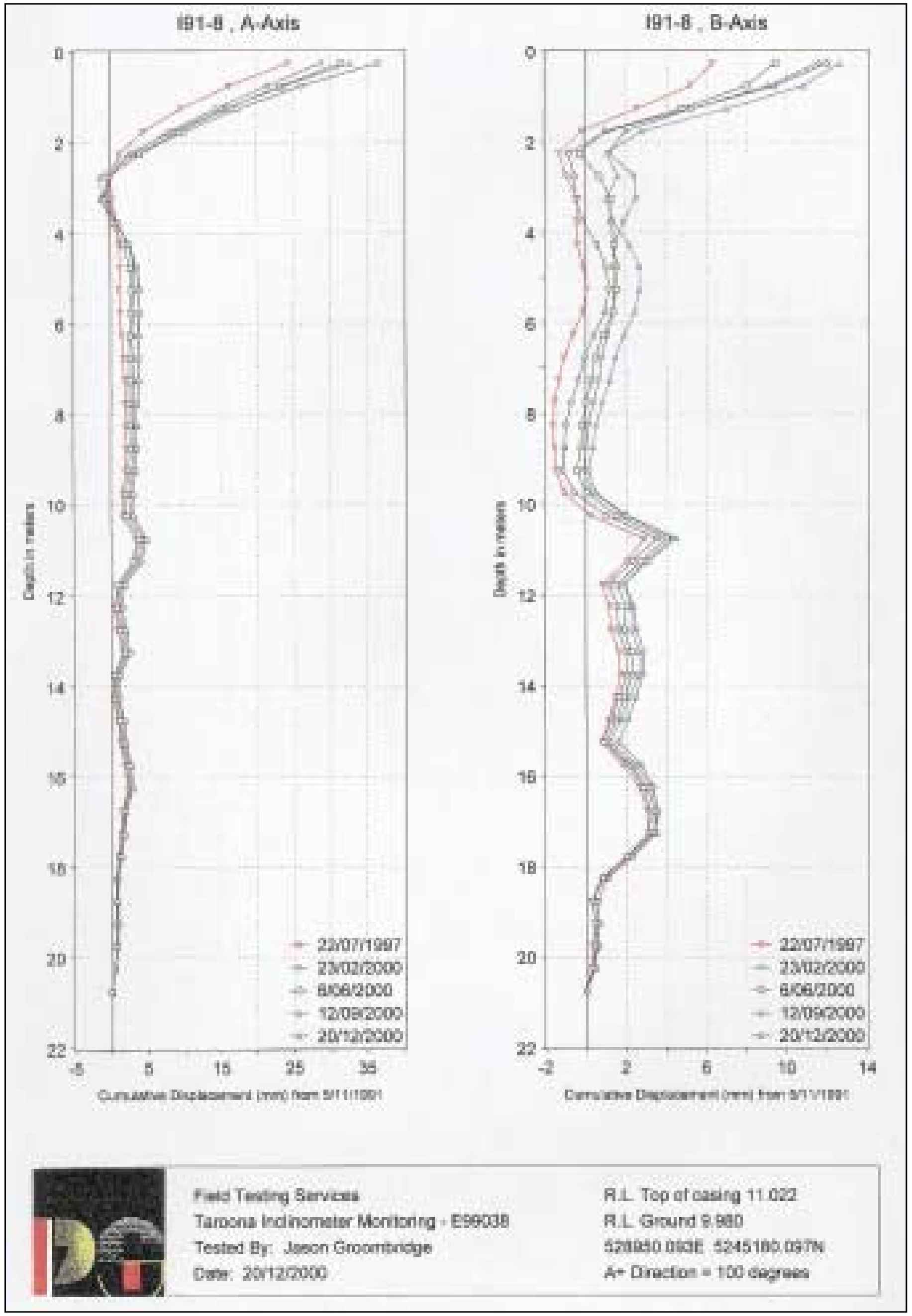
APPENDIX 5

Inclinometer monitoring data

Taroona Inclinometer Monitoring — E99038
Monitoring round 20 December 2000
Checksum statistics

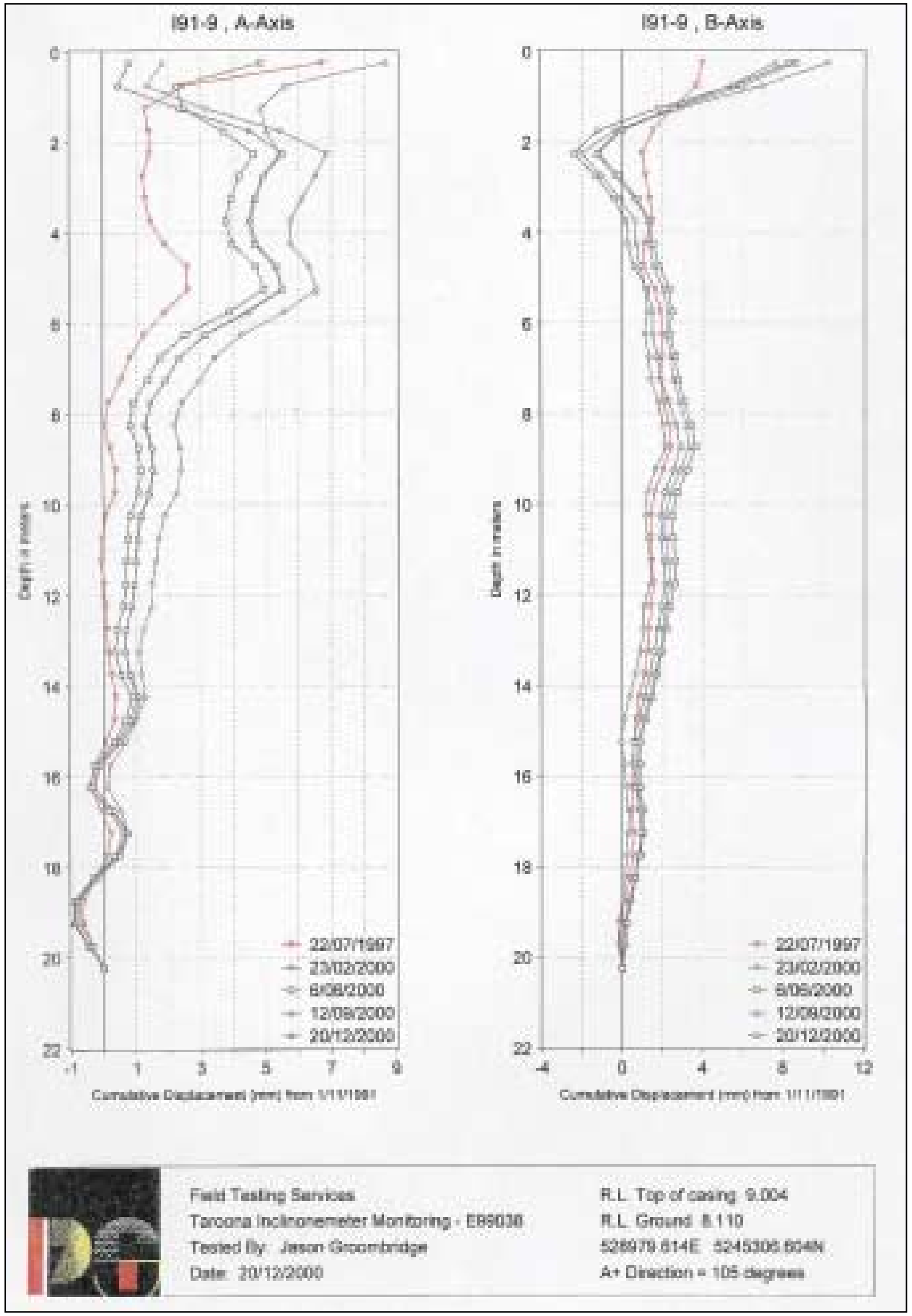
Borehole No.	Mean 'A'	SD 'A'	Mean 'B'	SD 'B'
I91-8	22.0240	5.1061	47.8780	12.5430
I91-9	14.2250	3.1344	37.7250	11.4560
I91-10	14.1420	2.8332	41.3800	11.1410
I92-11	22.0660	1.5261	47.1330	9.6979
I92-13	22.5620	2.6213	54.6250	5.3136
I92-14	23.5170	3.4403	50.3100	11.1880
IBH1-99	22.6370	5.9624	36.9700	10.7300
IBH2-99	24.9610	4.2306	43.3480	9.0148
IBH3-99	18.8980	4.8414	33.7750	5.8780

Note: I92-13 still has strong sewage smell
I92-14 casing is slightly tight @ 8.0 metres



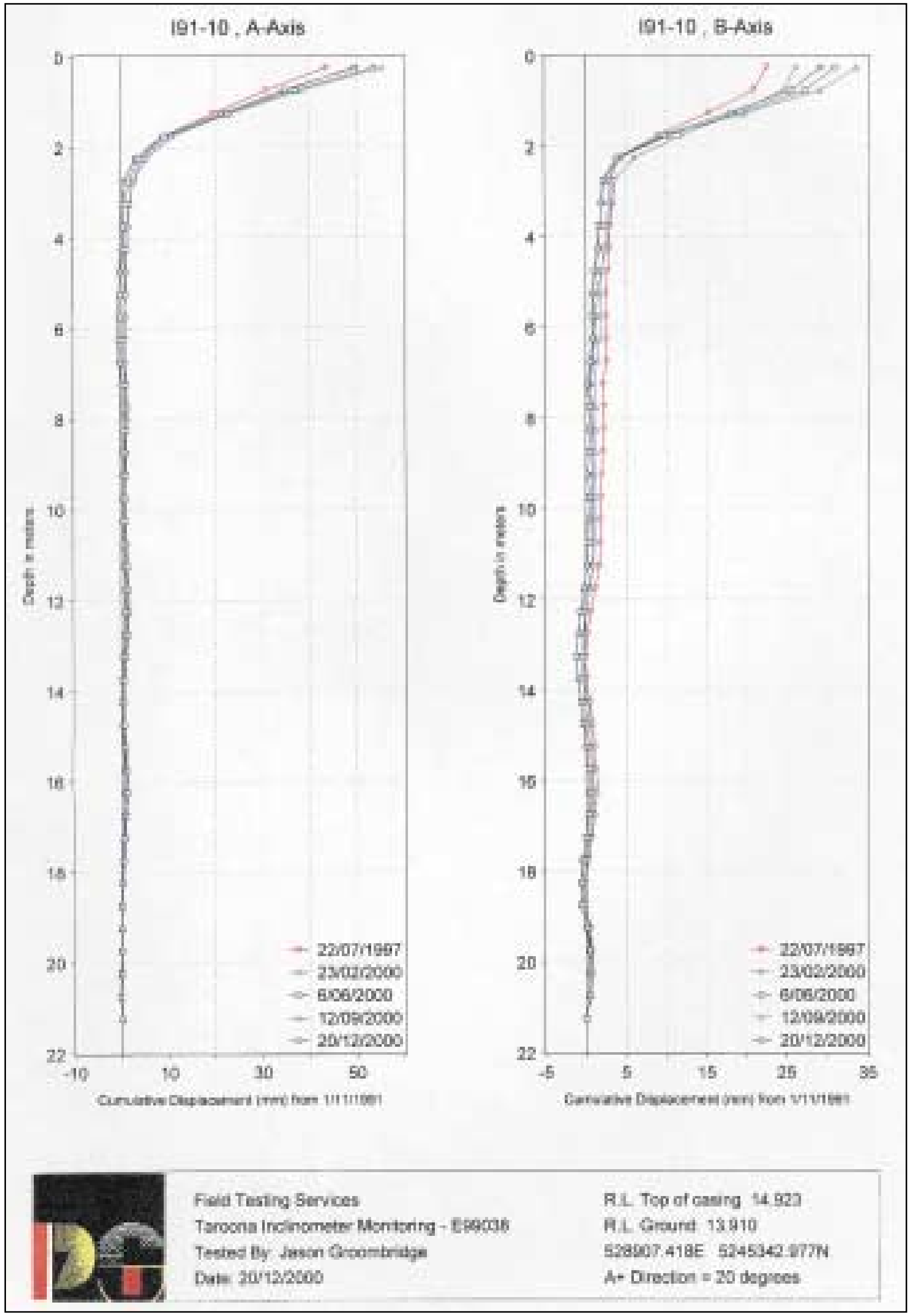
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 11.022
R.L. Ground 9.980
528950.093E 5245180.097N
A+ Direction = 100 degrees



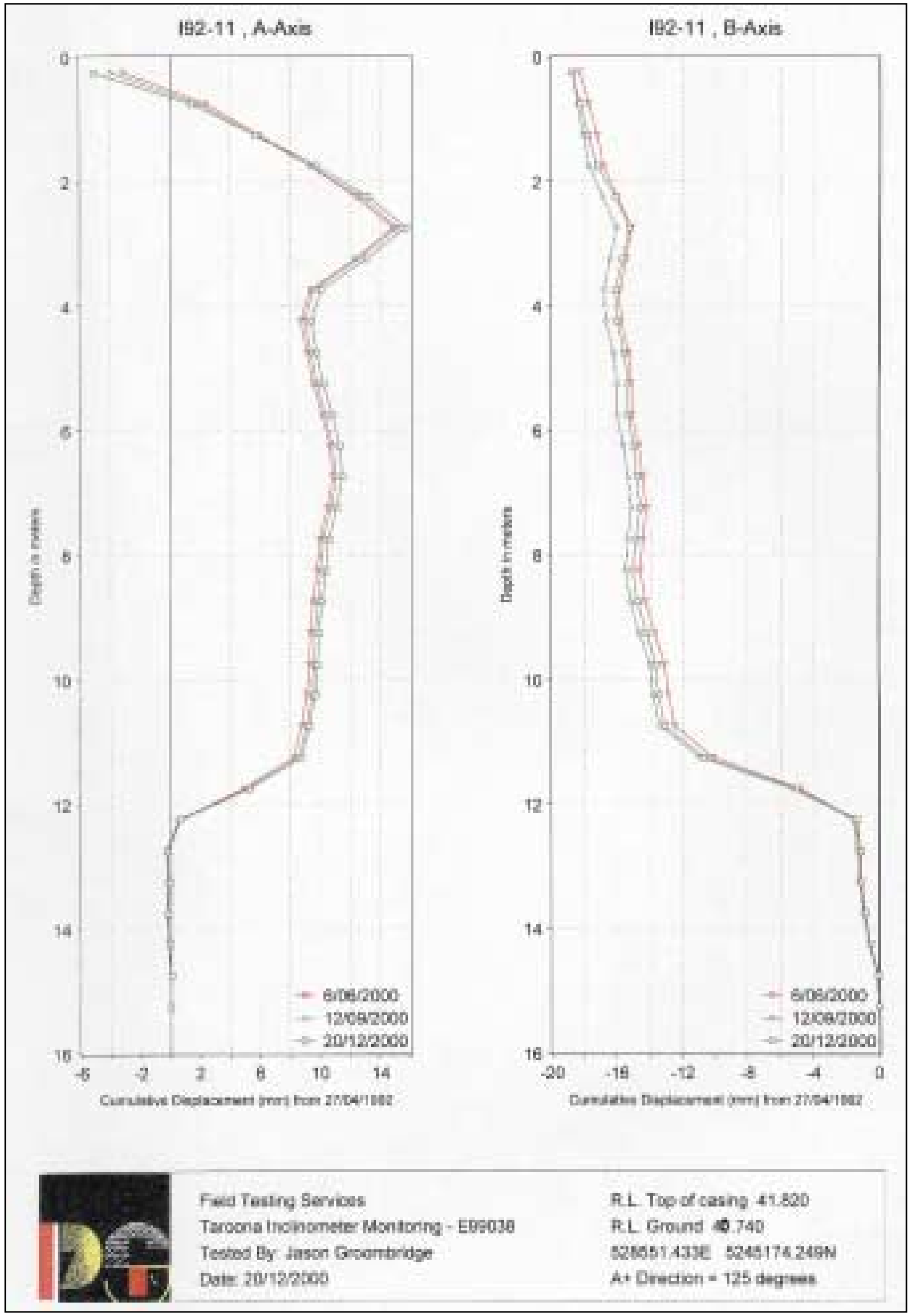
Field Testing Services
Taroona Inclinonemeter Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 9.004
R.L. Ground 8.110
528979.614E 5245306.604N
A+ Direction = 105 degrees



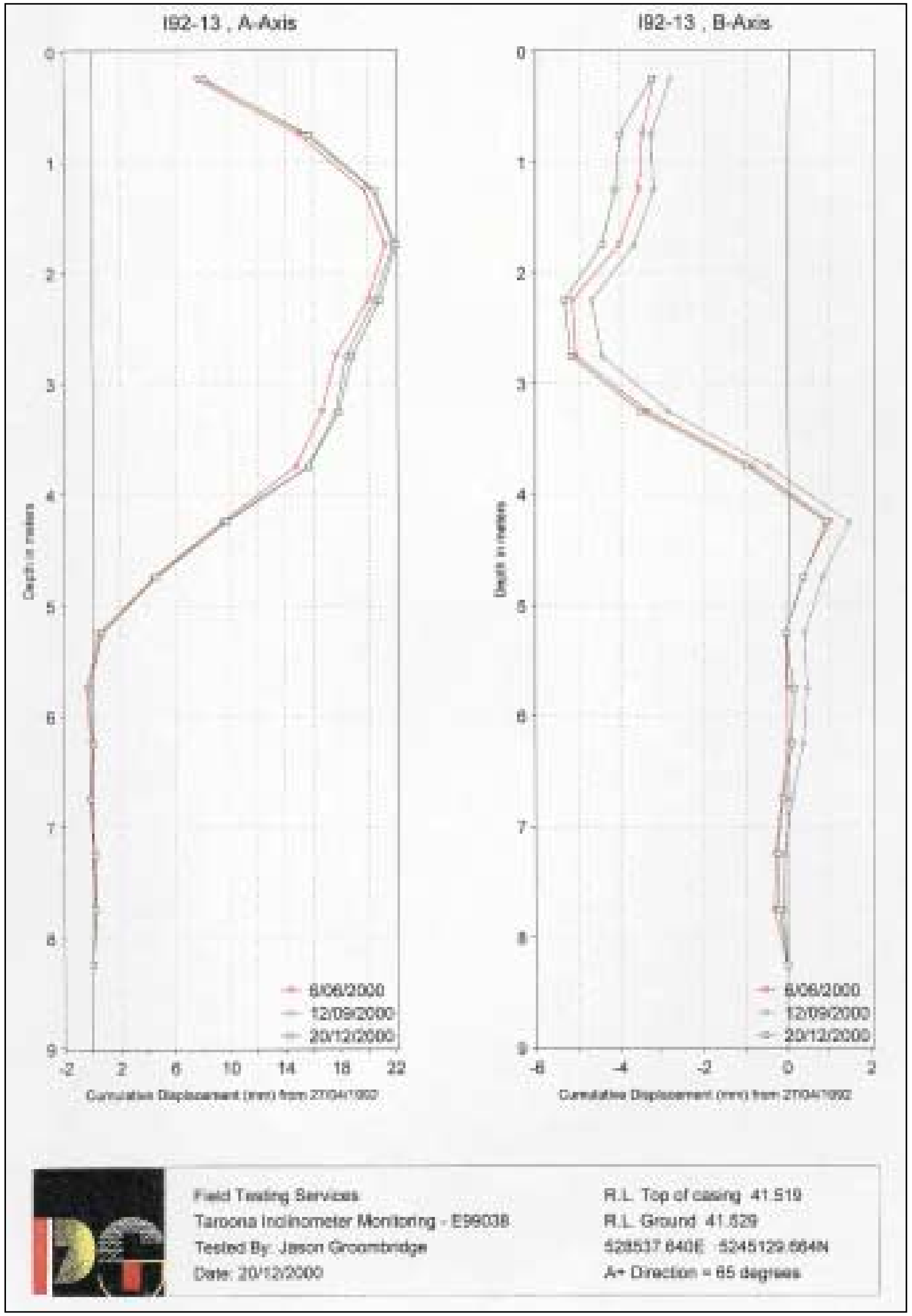
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 14.923
R.L. Ground 13.910
528907.418E 5245342.977N
A+ Direction = 20 degrees



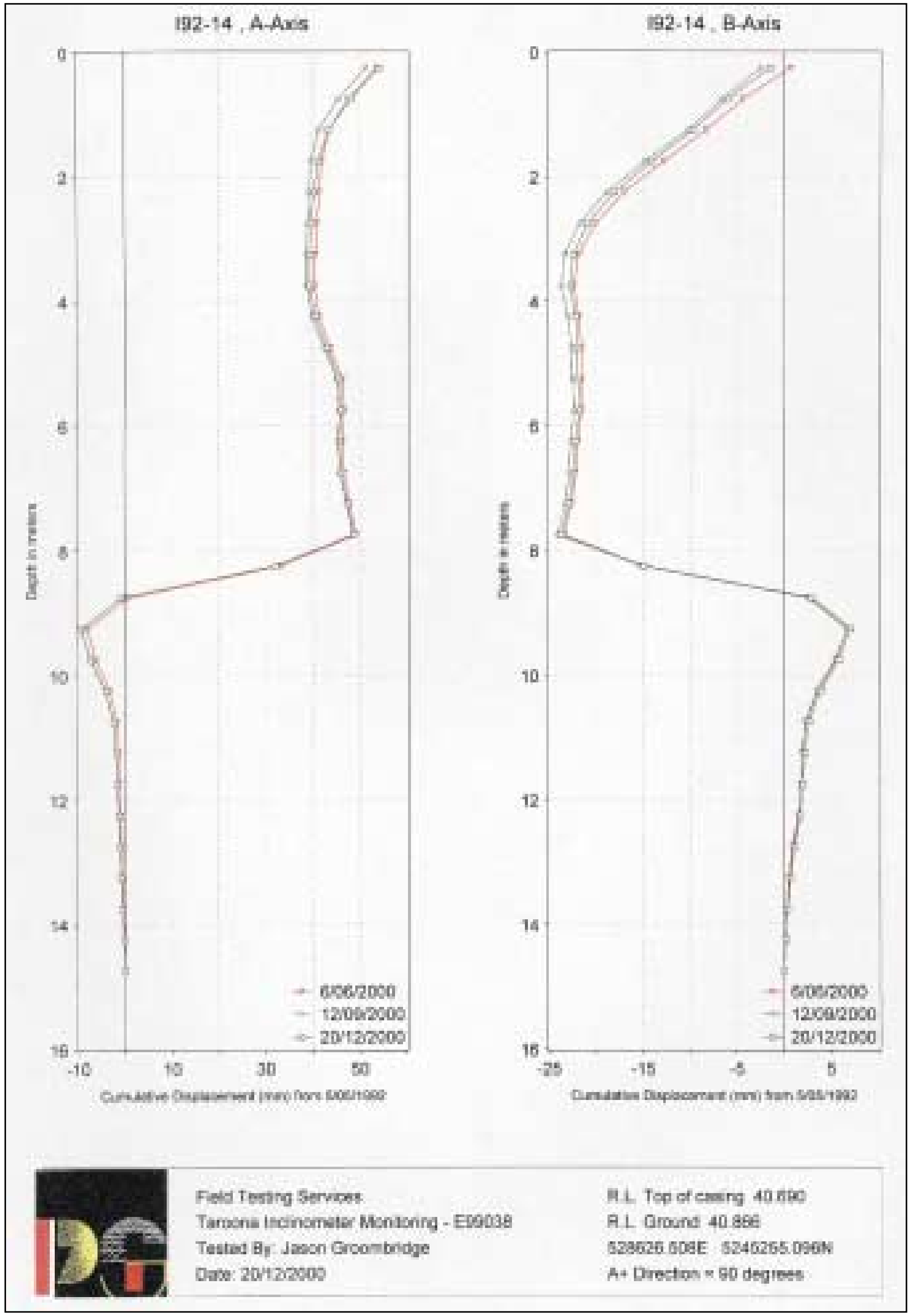
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 41.820
R.L. Ground 4[illegible].740
528651.433E 5245174.249N
A+ Direction = 125 degrees



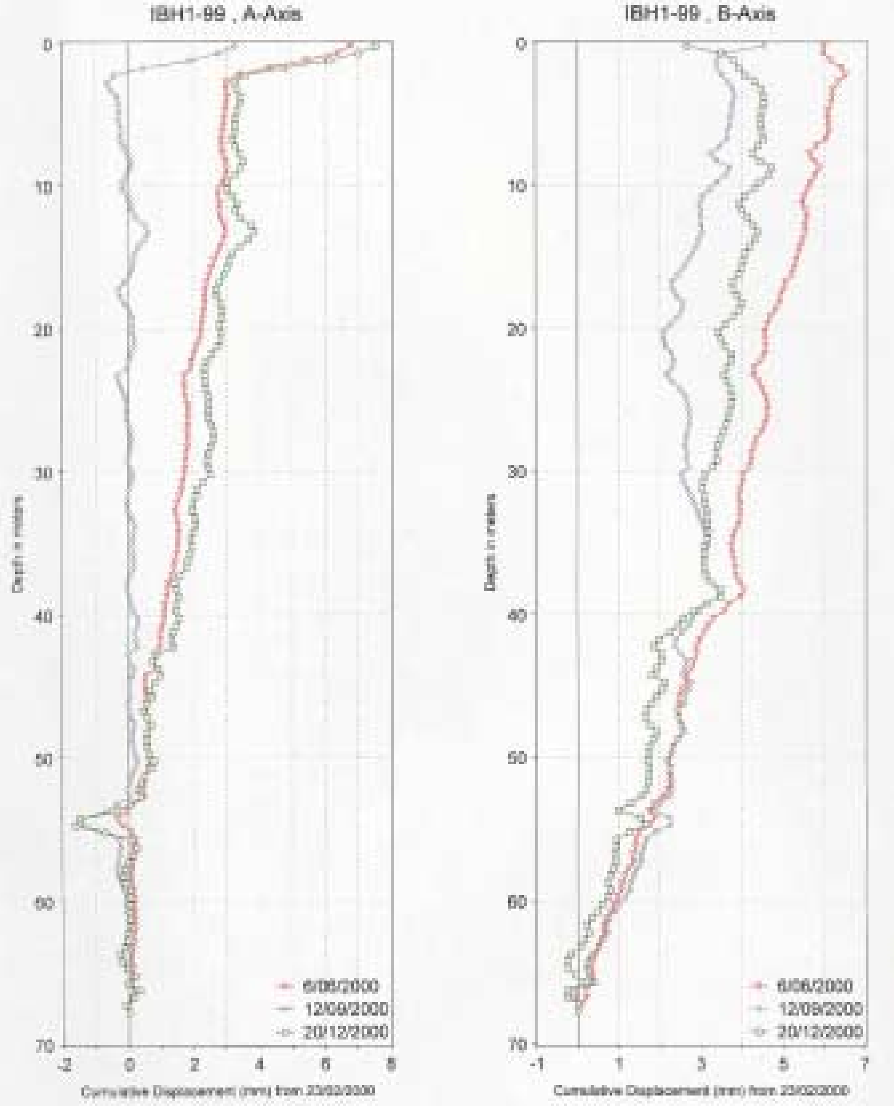
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 41.519
R.L. Ground 41.529
528537.640E 5245129.664N
A+ Direction = 65 degrees



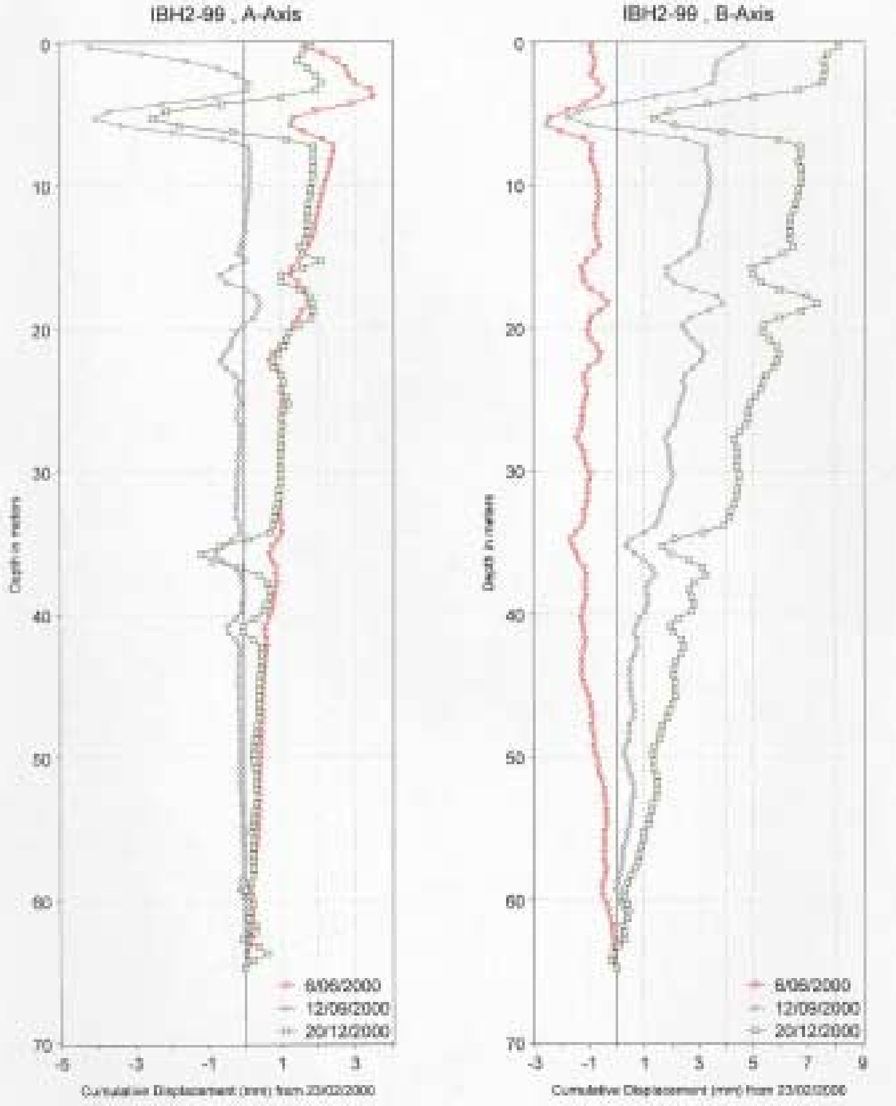
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 40.690
R.L. Ground 40.866
528626.508E 5240265.096N
A+ Direction = 90 degrees



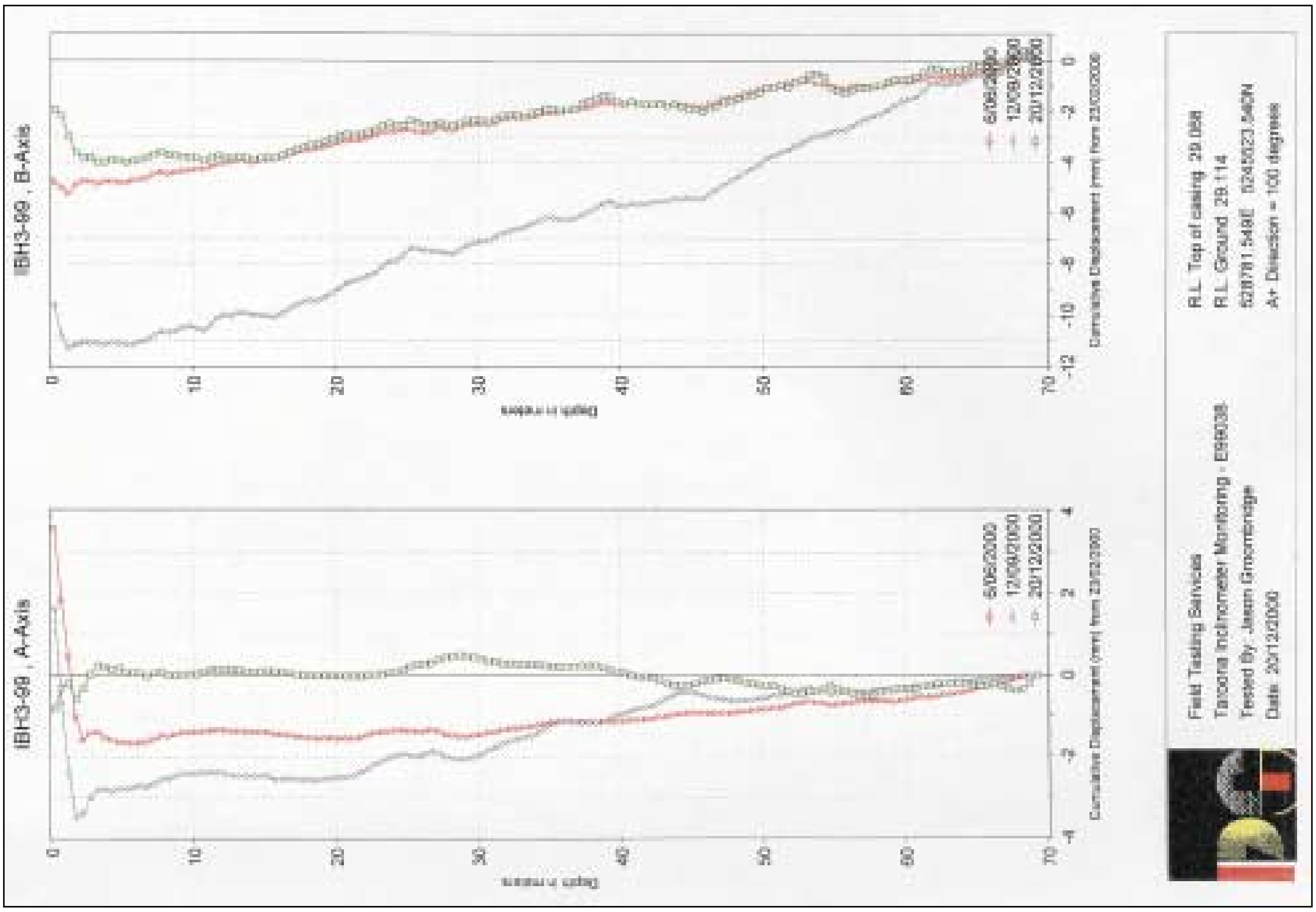
Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 30.723
R.L. Ground 30.780
528785.509E 5245198.898N
A+ Direction = 70 degrees

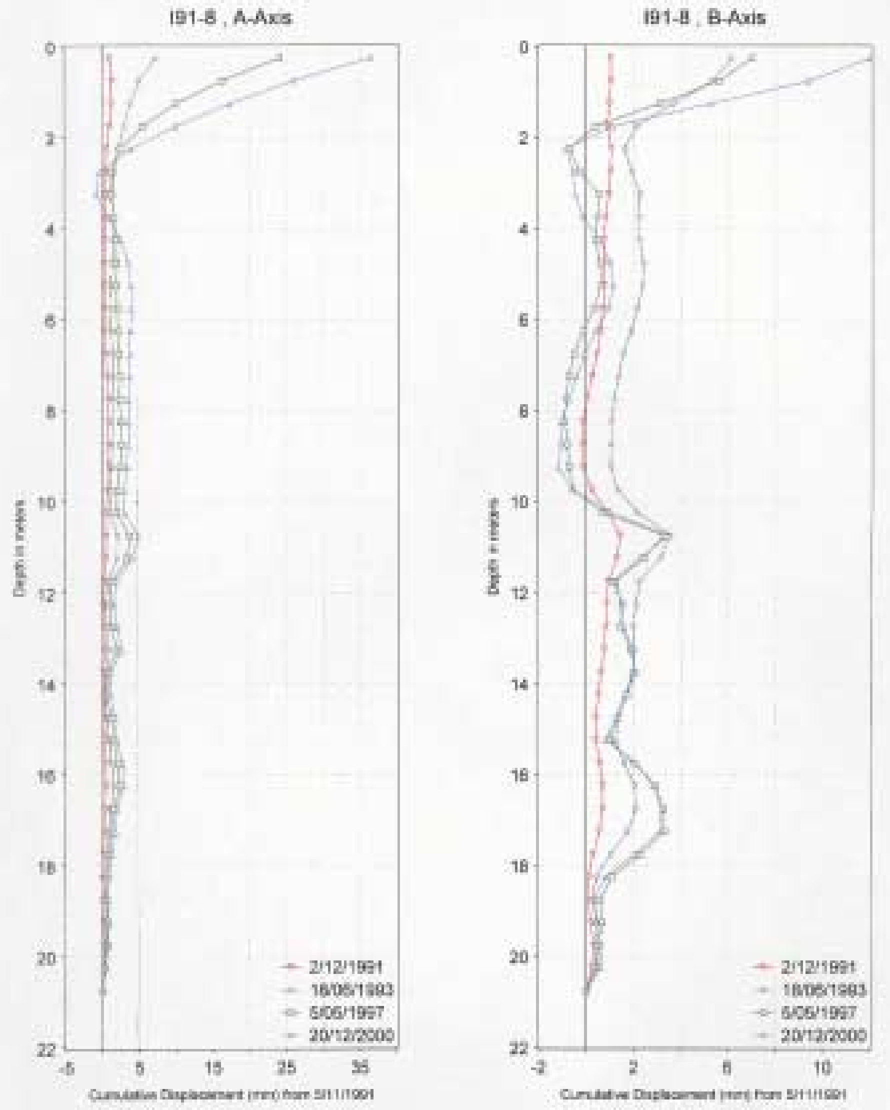


Field Testing Services
Taroona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 20/12/2000

R.L. Top of casing 23.875
R.L. Ground 23.902
528757.345E 5245024.675N
A+ Direction = 105 degrees

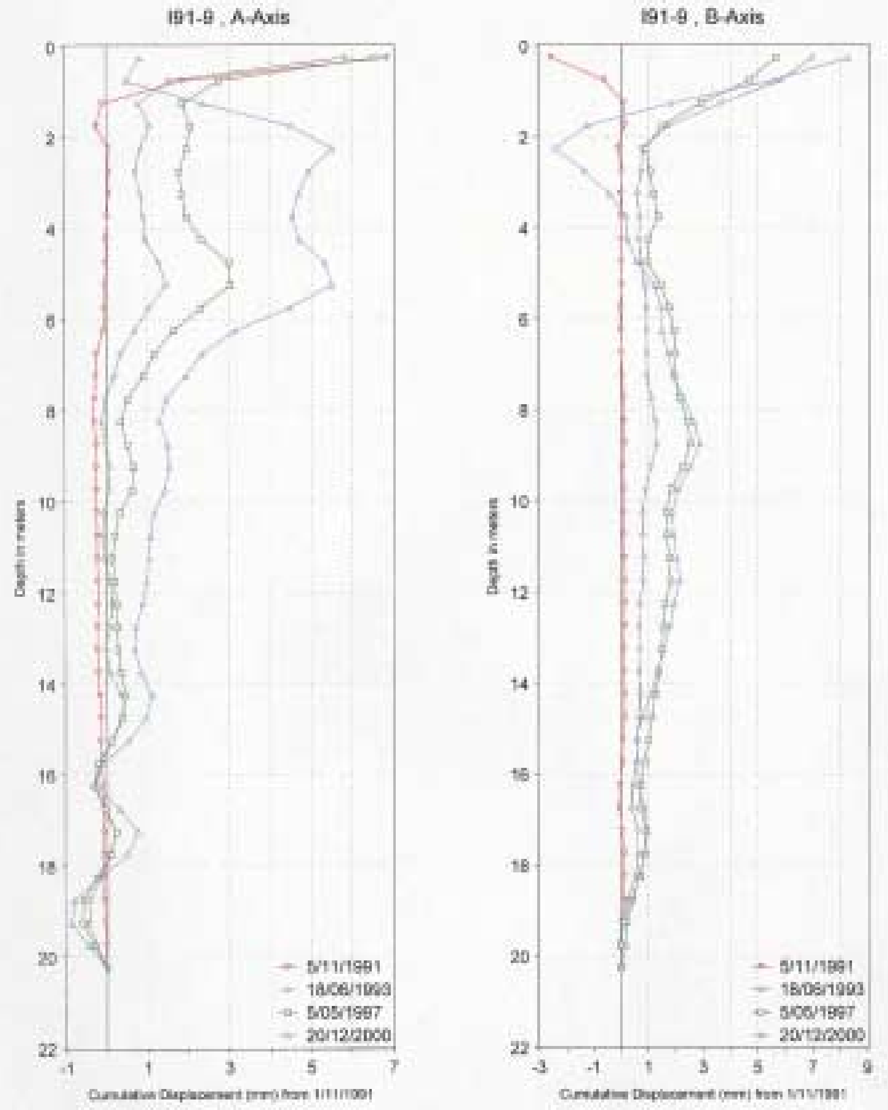


LONG TERM BEHAVIOUR OF I91–8 AND I91–9



Pitt & Sherry
Field Testing Services

Tarcona Inclinometer Monitoring - E99038
Tested By: Jason Groombridge
Date: 3/1/2001



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