UR1976_61

1118

1976/61. Investigation of a landslip at Deviot.

C.J. Knights

A landslip at Deviot [DQ944348] has destroyed one house, two houses are currently under tension, and two more are endangered.

The landslip is situated between Deviot Road and the Tamar River foreshore (fig. 1), on a slope with an overall angle of 11°. River erosion is active and has cut a one metre high scarp at the toe of the slip. The slip covers an area of about 4000 m^2 and is extending southwards.

The slip first caused concern in 1968 (Stevenson, 1971). At that stage of its development it stretched from the shore back towards a house, which was destroyed in the following two years.

Auger drilling was undertaken during winter 1974, when five holes were drilled to depths of up to 12 m. A further four holes were drilled in winter 1976. Clay samples were tested for Atterberg limits (appendix 2), X-ray diffraction and cation exchange percentage while groundwater has been chemically analysed and piezometric levels monitored. This work shows that the slip is generally less than 4 m thick. The results from the deeper drilling are included as part of the general study of Tamar sediments and groundwater.

GEOLOGY

The slope is composed of Tertiary sediments which crop out on the foreshore as grey plastic clays with orange oxidised fissures. A discontinuous mantle of basalt talus up to 1.5 m thick, weathered to brown clay and boulders, overlie these sediments. Solid basalt crops out above the road.

Drilling results (appendix 1) show a sequence of silty plastic clays to a depth of 6-10 m. These clays are blue-grey, brown or red, with thin sandy partings and ironstone gravels. The top 1-3 m is soft and wet, while deeper clays are stiff and fissured. Six to 10 m below surface (1.5-2.5 m below sea level) a stiff, dark grey or brown clay was encountered, while below this (4.5-5 m below sea level) is a water-bearing horizon of fine, clayey sand about one metre thick, which overlies a hard material which the drill did not penetrate (fig. 2).

DIP OF SEDIMENTS

The upper clays do not have a readily recognisable marker band, and the deeper, dark grey clay was not located with sufficient accuracy to allow stratigraphic dips to be calculated. Plotting plasticity indices against depth shows a distinctive pattern which can be used to indicate clay property horizons. At the plot for each hole, low plasticity indices coincide with a visual observation of grey plastic clay (fig. 3). Joining the comparable points on each plot indicates that the sediments have a downslope dip of 7°.

MATERIAL PROPERTIES

The sediments are mainly high plasticity inorganic clays, with occasional sandy laminae and gravel sized ironstone pellets. The top few metres are in a wet condition during winter, but are well below their liquid limit. Below this depth, the clays are a little moister than their plastic limit. Fissures are commonly present in these stiff overconsolidated clays.

Particle size analysis of samples from Holes 1 and 2 (fig. 4) show

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LOCATION PLAN - DEVIOT SLIP

C.J.KNIGHTS

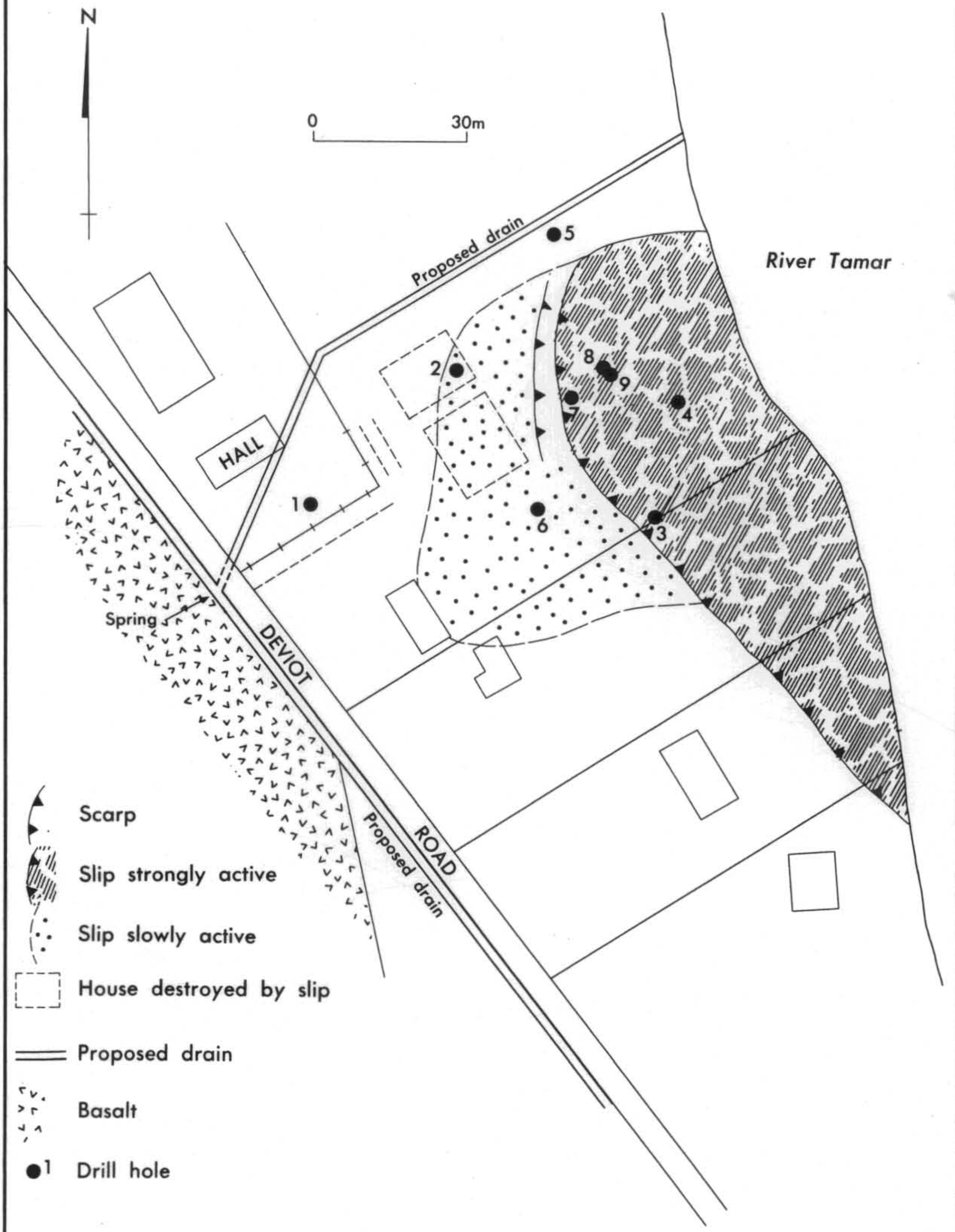

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Figure 1

5 cm

that the particle size gradings are very similar throughout the depths of the bore holes. Each sample has over 85% at less than 20 μm and 55% to 65% at clay size (less than 2 μm).

Plasticity indices and liquid limits are high for these materials, but plastic limits are low (fig. 3; fig. 5, appendix 2). This indicates that the clay is subject to plastic yield whilst at relatively low moisture content, but that it needs an almost fourfold increase in moisture content before liquid flow would occur. All of the samples have plastic limits near their average of 24%, but there is a large range of values for liquid limits.

Soil testing by Golder Associates (1975) on clay taken from the shore line gave residual cohesion (c_r') = 10 kPa and residual friction angle (ϕ_r') = 11°. Stability analysis using the simplified method of Bishop (1955), and considering the base of the slip to be along the line marked in Figure 1, gave the factor of safety = 1 when c' = 6 kPa and ϕ' = 11°.

CLAY MINERALOGY

The mineralogy of the clays has been investigated using X-ray diffraction. The following minerals have been recognised. (W.L. Matthews, pers.comm.).

Hole 1

Depth (m)	
0-1.8	Montmorillonite and quartz show strongly, kaolinite moderate to weak, gibbsite absent.
1.8-10.0	Montmorillonite weak or absent, quartz strong to very strong, gibbsite moderate to strong. At 2.7-3.6 m and 7.2-8.1 m, weak peaks at 2θ = 19.8° to 20° might represent illite.

Hole 4 Montmorillonite moderate to strong between 0 and 1.8 m, but is weak or absent below this depth. Kaolinite and quartz are strong to very strong throughout. Gibbsite variable from weak to strong. The primary illite peak of 2θ = 9° is moderate from 8 to 9 m and weak between 10 and 10.9 m. A persistent weak peak at 2θ = 19.8-19.9° may represent illite.

GROUNDWATER

Water becomes ponded in an unlined gutter at the base of the cutting on the top side of the road. Several days after rain, the water was still quite saline (about 1300 ppm), indicating that it is spring water from the base of the basalt, which is partially intersected by the road cut.

Groundwater was encountered at two levels during drilling. Shallow water is present within the top 3 m in all holes except BH5, which is the only hole drilled north of the active slip. A deep sand aquifer containing pressure water was intersected by Holes 3, 4, 5, 7, 8 and 9.

Water levels in the holes are controlled by the pressure of water from both levels, and only in BH5 can the piezometric pressures of the deep aquifer be studied in isolation. Water level changes with time are shown in Figure 6.

In BH5 the sand was intersected at 11-11.9 m and water rose to 6.3 m, having a pore pressure of 5.5 m. The recorded annual pressure range is only

PLASTICITY INDICES, VARIATION WITH DEPTH

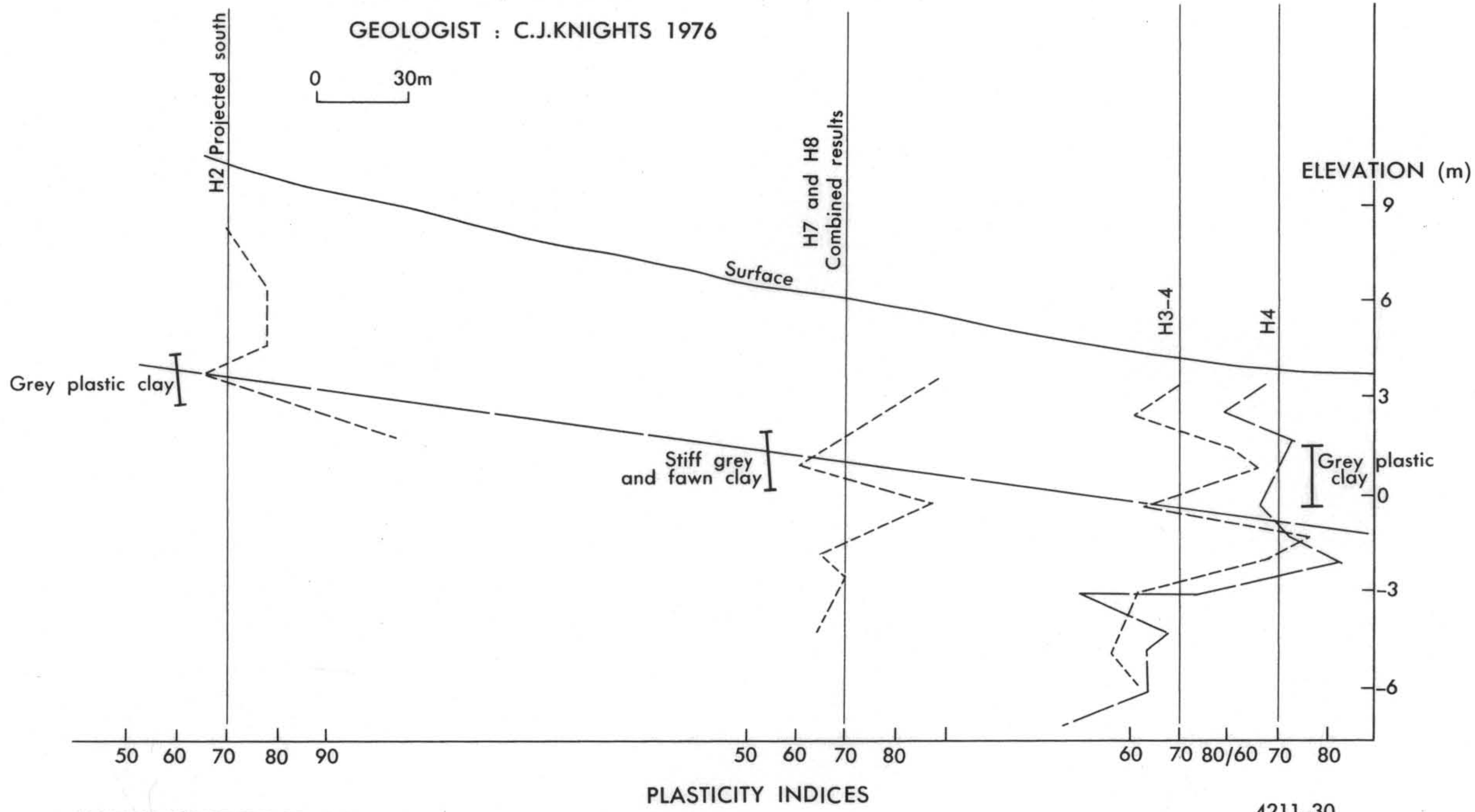

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Figure 3

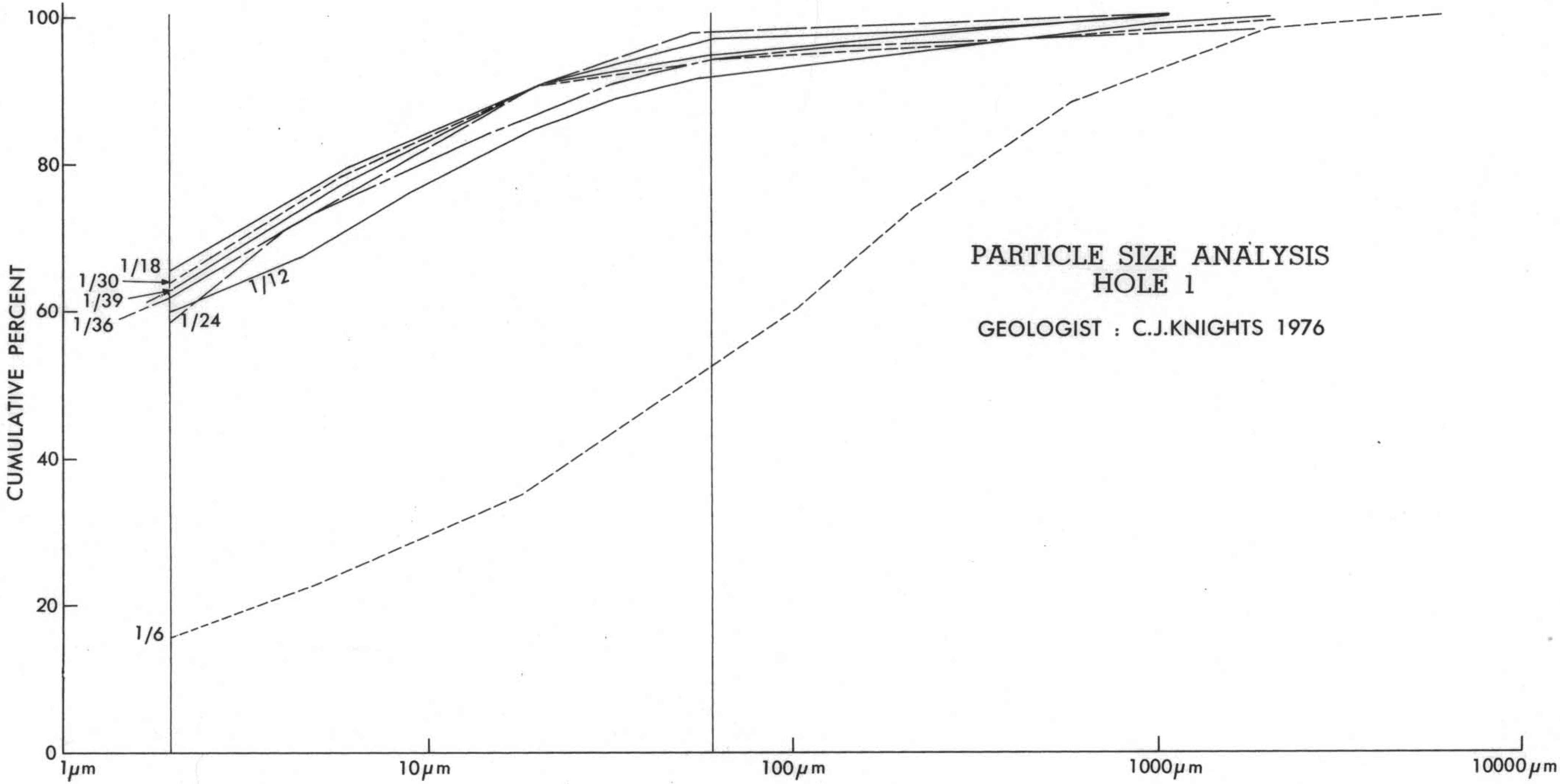

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Figure 4

5 cm

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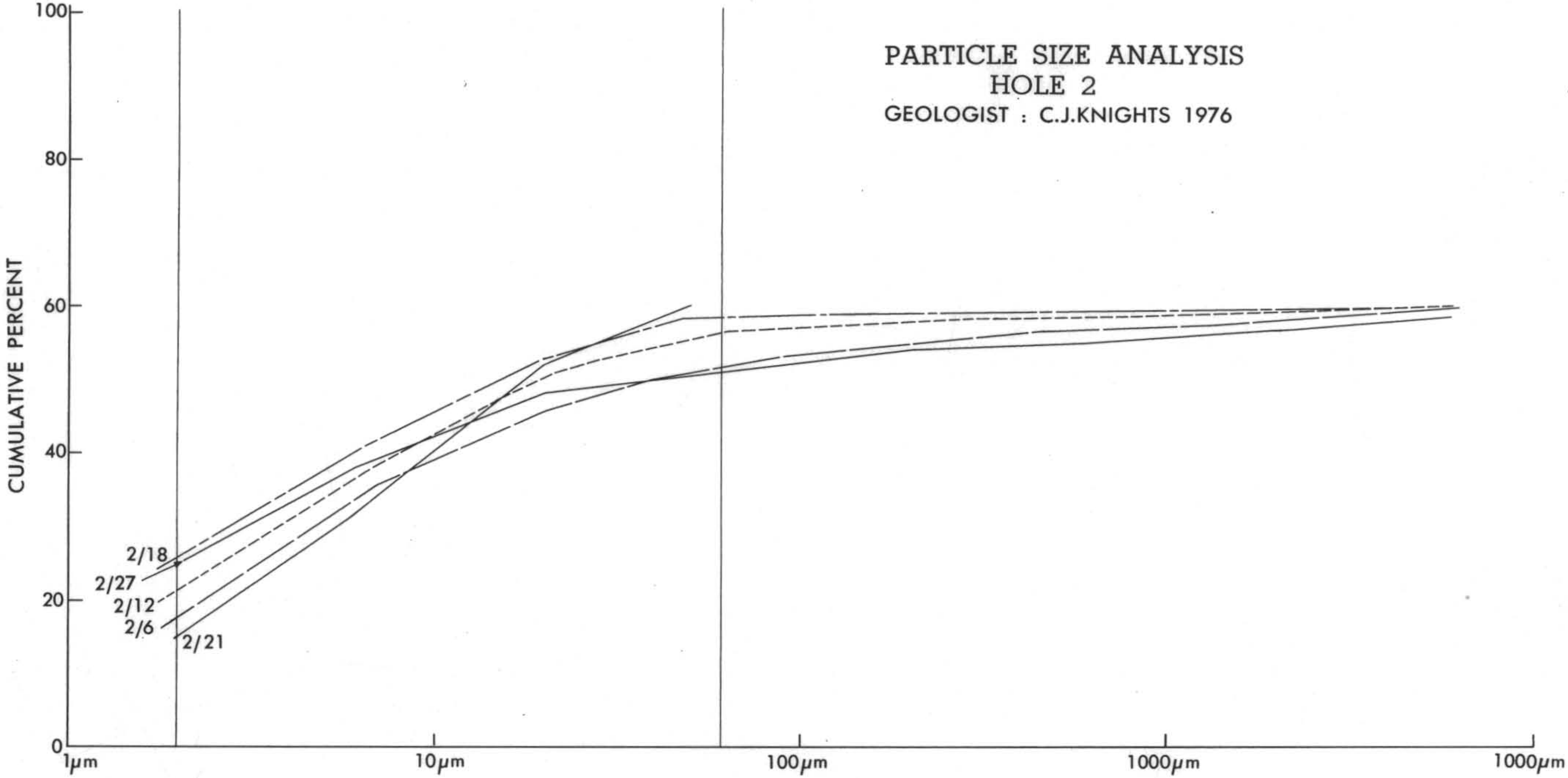

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Figure 4a.

5 cm

PLASTICITY CHART OF DEVIOT CLAYS

GEOLOGIST : C.J.KNIGHTS 1976

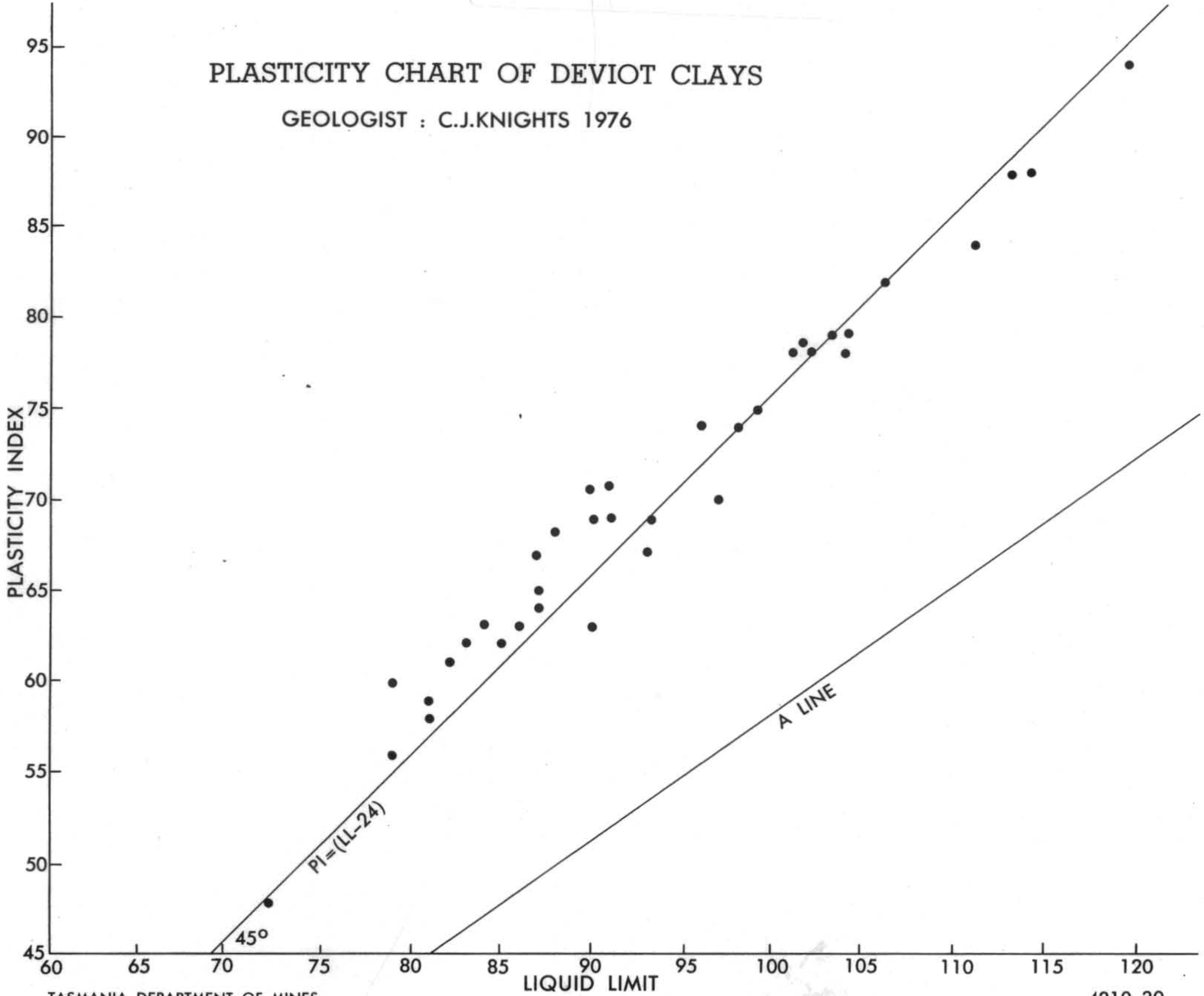

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FIGURE. 5

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0.3 m, which indicates that the water is isolated from its surface source.

Water levels in Holes 3, 4 and 8 show far more variability, and may be the result of small variations of pressure in the deep aquifer, combined with the effect of near surface water pouring into the hole at a rate too great for the lower aquifer to dispose of. Holes 8 and 9 are adjacent, but Hole 9 is only 4 m deep. By 25 February 1976, after a lengthy dry period, the water level in BH9 had stabilised at a depth of 2.74 m, indicating that the shallow water source had dried up, and that the base of the permeable layer is at this depth. At this time, water levels in Hole 8 began to drop more rapidly, but still slowly enough to take three months to reach the pore pressures of the lower aquifer, as known from BH5. As the drop in levels within BH8 was so slow, it indicates that the permeability of the deeper aquifer is low; alternatively the slots in the lower part of stand pipe may be blocked.

DEPTH OF LANDSLIP

Auger drilling showed that the top 2-3 m of material were soft and disturbed. Detailed sampling allowed moisture content to be measured in Holes 6, 3 and 2 (fig. 7). These show that moisture is higher above depths of 2 m and 3.2 m respectively, and confirm observations of near surface disturbed conditions.

The depth of crushing of the plastic stand pipes has been observed in several holes. A minimum depth can be found by measuring from the top of the pipe closure to the surface. To observe the maximum depth of pipe crushing, a string with a metal nut tied to the end is left hanging in the pipe. After the pipe is crushed, the string is withdrawn until the nut wedges at the base of the closure. The depth to this point can then be calculated, giving the maximum depth of crushing.

The maximum depth of crushing in BH8 is 3.9 m. An early minimum depth in BH4 is 4.2 m and 2.4 m in BH6. It appears that the slip is moving above a level 4 m or so below surface, and that this level is one metre deeper than the evident wetness and disturbances.

CONCLUSIONS

The landslip affects the top 3-4 m of sediments and is located in an area where there is a local concentration of shallow groundwater. Upslope of the slip, at the top side of the road, saline spring water from the basalt is partially intersected by the road cut. North of the slip, at BH5, shallow surface water is absent and the ground appears to be undisturbed.

The southern perimeter of the slip is not distinct. Beyond the obvious deep fissures, the ground is deforming slowly as is indicated by closure of BH6 and by tension cracks in the two nearest houses. Atterberg limits indicate that the clay materials behave plastically at a relatively low moisture content, but are unlikely to turn into an earth flow.

RECOMMENDATIONS FOR CONTAINING THE LANDSLIP

The most important recommendation is for the spring water, behind the road to be drained. A lined drain, at least one metre deep, and preferably to the depth of the wet zone, should be constructed behind the road, and the water then collected taken by a lined surface drain to the river. The surface drain may be constructed on stable ground by running it down the northernmost edge of the Crown land (fig. 1).

VARIATION OF MOISTURE CONTENT WITH DEPTH; HOLE 6 AND HOLE 3-4

GEOLOGIST : C.J. KNIGHTS 1976

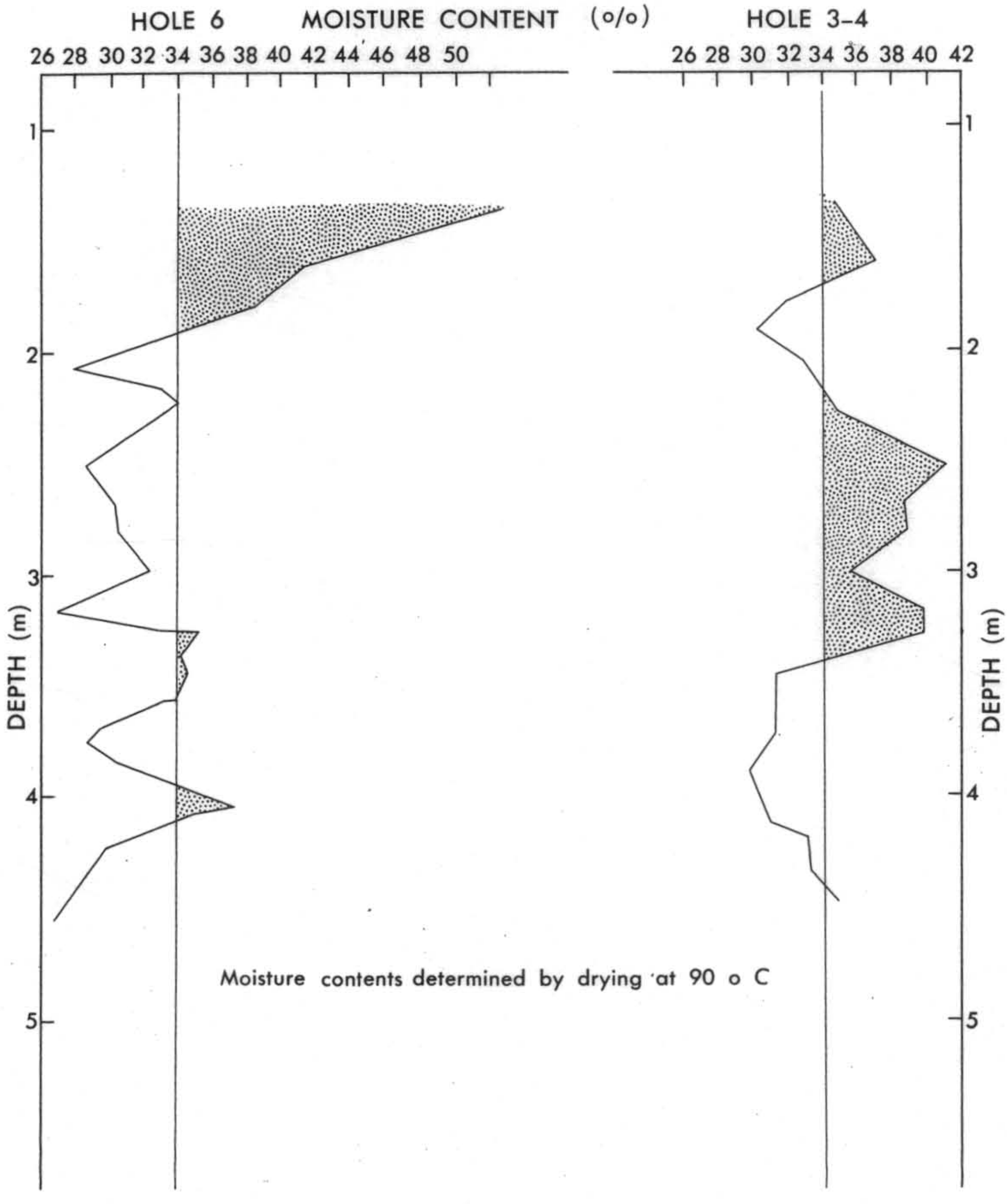

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Figure 7

5 cm

Trees should be planted and maintained wherever possible. Trees planted upslope of the slip will help to intercept surface runoff, will cause a soil moisture deficit which will retard infiltration into the groundwater zone and will add strength to the clays by the binding action of their roots.

REFERENCES

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[21 September 1976]

APPENDIX 1

Bore hole logs for Deviot landslip.

Hole 1

Depth (m)	*Description*	*PI*	*LL*
0-0.9	Wet, sandy, dirty grey clay.		
0.9-1.8	Dry silty, red-brown clay, crumbly texture.	32	63
1.8-2.7	Moist, plastic clay, crumbly texture. Brown, changing to orange and grey. Tough sandy band.	67	93
2.7-3.7	Stiff, plastic and fissured clay. Orange-brown and grey.		
3.7-4.6	Stiff, plastic and fissured clay. Orange-brown and grey.		
4.6-5.5	Stiff clay. Orange and grey.	75	98
5.5-6.4	Stiff clay. Orange and grey becoming more grey with shiny slip surfaces probably caused by drilling.		
6.4-7.3	Softish clay, grey and brown.	76	99
7.3-8.2	Softish clay, grey and brown, easily squashed in the fingers. Nodules of hematite surrounded by limonite about 2 cm in diameter.		
8.2-9.1	As above, orange colour. Small limonite gravel.	87	113
9.1-10.0	After a break in drilling, as above. Very soft.		
10.0-11.0	As above.	78	104
11.0-11.9	Dark chocolate-brown clay, stiff and shiny.	79	104
	Water enters hole near surface and possibly at 7.3 m.		

Hole 2

0-1.8	Crumbly clay, grey and yellow-brown in fine layers.	69	93
1.8-2.7	Stiff plastic clay with polished fissures, grey and yellow.		
2.7-3.7	As above, more yellow.	78	102
3.7-4.6	Stiff clay, flaky texture, yellow-brown and grey.		
4.6-5.5	As above.	78	104
5.5-6.4	Stiff plastic clay, flaky texture. Grey, sticks to the augers.	65	87
6.4-7.3	Stiff plastic clay, brown and grey. Does not adhere to the augers.		
7.3-8.2	As above.	94	119
8.2-9.1	As above. Softer and more plastic towards the end of the run.		
9.1-10.0	As above.		
	Water enters hole near surface.		

Hole 3

0-0.6	Wet brown clay.		
0.6-0.9	Damp, clayey sand.		
0.9-1.8	Damp clayey sand.		

Hole 3 (continued)

Depth (m)	*Description*	*PI*	*LL*
1.8-2.7	Silty plastic clay, light brown, fragmented.		
2.7-4.6	As above, light grey and brown.		
4.6-5.5	Dry, tough clay, fragmented brown and grey.		
5.5-6.4	As above, brown.		
6.4-7.3	As above, grey and brown.		
7.3-10.0	Clay with silty laminae, ironstone gravel throughout. Dark grey-brown colour.		
10.0-11.0	Silty clay passing into wet, fine-grained sand. Hard band below the sand which the drill could not penetrate. Pressure water.		
	Water (salinity approx. 4500 ppm) enters hole near surface and at 10.5 m.		

Hole 3-4

0-0.9	Brown pebbly clay.		
0.9-2.7	Light brown clay, occasional pebbles.		
2.7-4.5	Light grey-brown plastic clay.		
4.5-6.2	Brown plastic clay, fragmentary.		
6.2-7.2	Dark grey-brown clay.		
7.2-10.0	Darkish grey brown silty plastic clay.		

Hole 4

0-0.9	Grey clay in pellets. Some sandy areas.		
0.9-1.8	Iron-stained grey clay with pellets.		
1.8-2.7	Brown clay with pellets and silty grey clay, medium stiff. Some fissure surfaces.		
2.7-3.7	Flaky plastic clay with fissure surfaces, light grey with pink streaks.		
3.7-4.6	As above but more brown in colour.		
4.6-5.5	Brown, rather fragmented plastic clay and limonite. Possible fossil mussel horizon.		
5.5-6.4	As above, more plastic.		
6.4-9.4	Stiff silty clay, dark grey-brown colour. Fossils at 6.4-7.3 m.		
9.4-11.3	Fine sand, little return. Water rose to about 8.2 m.		
11.3-11.9	Fine sandy clay and angular fragments of carbonate.		
	Water salinity approx. 5000 ppm. Enters near surface and at 9.4 m.		

Hole 5

0-0.4	Basalt soil and boulders.		
0.4-0.9	Fairly stiff plastic silty clay, light brown and grey.		
0.9-1.8	Medium stiff, plastic, grey silty clay.		
1.8-2.7	Fragmented clay, light grey-brown.		
2.7-3.7	Plastic clay, brown-grey.		
3.7-4.6	As above. Also with some flaky pink clay.		
4.6-5.5	Plastic, brown-grey clay.		

Hole 5 (continued)

Depth (m)	*Description*	*PI*	*LL*
5.5-10.0	Stiff silty clay. Dark grey-brown colour.		
10.0-11.9	Fine, even-grained, clayey sand with pyrite nodules and limonite fragments. Pressure water.		
11.9-	Hard band.		
	Water salinity approx. 4600 ppm. Enters hole at 10 m.		

Hole 6

0-0.9	Soft brown clay and basalt boulders.		
0.9-1.8	Soft, crumbly greenish clay and sand. Water.		
1.8-2.7	Fairly stiff blue-grey and brown fissured clay.		
2.7-3.7	As above. Brown amd more crumbly.		
3.7-4.6	Stiff, brown, fragmented clay.		
4.6-5.5	Brown and purple clay. Very plastic and flaky.		
5.5-6.4	Grey plastic clay.		
6.4-8.2	Poor sample recovery. Very plastic shiny brown clay which sticks to the augers.		
	Water enters hole near surface.		

Hole 7

0-0.9	Very soft wet, brown sandy clay.		
0.9-1.8	As above. Water.		
1.8-2.7	Clay with fine limonite sand. Grey and orange soft patches.		
2.7-3.7	Stiff orange-brown fissured clay.		
3.7-4.6	No sample recovered.		
4.6-5.5	Very stiff plastic grey and fawn clay with ironstone sand and gravel.	60	79
5.5-6.4	No sample.		
6.4-7.3	As above. Fissured clay with ironstone fragments. Softer.		
7.3-8.2	No sample.		
8.2-9.1	Very plastic clay with sand-size ironstone. Grey and fawn, becoming more pink and softer.		
9.1-11.9	Poor recovery. A mixture of very stiff brown and dark grey clay, fawn clay, soft patches, ironstone.		
11.9-12.8	Very stiff dark grey clay and pyrite nodules. Fossil mussels. Sand. Pressure water.	63	90
	Water enters near surface and at 12.8 m.		

Hole 8

0-1.8	Very soft, wet, sandy clay.		
1.8-2.7	Soft orange and grey clay with hard orange pellets and ironstone fragments. Water.	79	103
2.7-3.7	As above. Firmer.		
3.7-4.6	As above. Firm.		

Hole 8 (continued)

Depth (m)	*Description*	*PI*	*LL*
4.6-5.5	Very tough orange clay and limonite with hematite band.	84	111
5.5-6.4	Orange and grey clay and ironstone. Sand.		
6.4-9.1	No recovery. Fragments on augers are dark grey, stiff, plastic clay. Sand.	64	87
8.2-9.1	Very soft drilling. Pressure water. Water enters hole near surface and at 8.2 m.		

Hole 9

0-1.8	Very soft, wet, sandy clay.		
1.8-2.7	Soft orange and grey clay with hard orange pellets and ironstone fragments. Water.	79	103
2.7-3.7	As above. Firmer.		
3.7-4.6	As above. Firm.		
4.6-5.5	Very tough orange clay and limonite with hematite band.	84	111
5.5-6.4	Orange and grey clay and ironstone. Sand.		
6.4-9.1	No recovery. Fragments on augers are dark grey, stiff, plastic clay. Sand.	64	87
8.2-9.1	Very soft drilling. Pressure water. Water enters hole near surface and at 8.2 m.		

APPENDIX 2

Atterberg limits and particle size analysis.

Bore hole 1

Depth (m)	2.8	3.6	6.5	7.3	9.0	10.1	11.9
Particle size				*% Finer*			
6 mm	100					100	
2 mm	98	100	100		100	99	100
600 μm	89	98	99	100	97	96	99
200 μm	73	95	98	99	96	95	97
60 μm	53	92	97	98	94	93	95
20 μm	37	85	91	91	91	87	90
6 μm	25	72	80	76	79	75	78
2 μm	16	60	66	59	64	62	63
Density	2.72	2.70	2.71	2.67	2.71	2.71	2.69
LL	63	93	98	99	113	104	104
PI	32	67	75	76	87	78	79
LS	13	19	21	21	23	21	21

Bore hole 2

Depth (m)	1.8	3.6	5.5	6.4	8.1
Particle size			*% Finer*		
6 mm	100				99
2 mm	98	100			97
600 μm	97	99	100		95
200 μm	95	98	99		94
60 μm	92	97	99	100	91
20 μm	86	91	93	92	88
6 μm	74	77	80	72	78
2 μm	58	61	66	55	65
Density	2.68	2.67	2.70	2.68	2.75
LL	93	102	104	87	119
PI	69	78	78	65	94
LS	19	19	22	21	23

Bore hole 3-4

		Parameter		
Depth (m)	*LL*	*PL*	*PI*	*LS*
0.9	90	19	71	24
1.8	84	24	60	24
2.7	90	21	69	20
3.65	101	23	78	21
4.6	85	23	62	17
5.5	114	26	88	23
6.4	106	29	77	26
7.3	82	21	61	18
8.2	81	23	58	18
9.1	79	23	56	18
10.0	83	21	62	20

Hole 4

Depth (m)	*LL*	*PL*	*PI*	*LS*
0.9	91	22	69	-
1.8	81	22	59	-
2.7	96	22	74	-
3.65	91	20	71	20
4.6	87	20	67	20
5.5	98	24	74	23
6.4	106	24	82	-
7.3	72	24	48	-
8.2	88	20	68	-
9.1	84	21	63	20
9.75	86	23	63	20
10.7-11.9	62	18	44	17

Parameter

Hole 7

Depth (m)	*LL*	*PI*	*LS*
5.5	79	60	18
9.0	97	70	21
11.9	90	63	20

Hole 8

2.8	103	79	26
5.5	111	84	23
7.3	87	64	19

SECTION THROUGH DEVIOT LANDSLIP
GEOLOGIST : C.J.KNIGHTS
LEGEND
Basalt boulders and clay
Plastic silty clays, ironstone present in places
Stiff dark grey clay
Sand
Approximate position of water entering hole
5 cm
0
2.5
5m
BH1
BH7
BH5
Projected
south
BH8
BH9
BH4
Sea level
Base of slip for stability analysis
ELEVATION (m)
15
10
5
0
5
10
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Figure 2

DEVIOT LANDSLIP
PIEZOMETRIC LEVELS COMPARED WITH RAINFALL JULY 1974 - JUNE 1976

GEOLOGIST : C.J.KNIGHTS

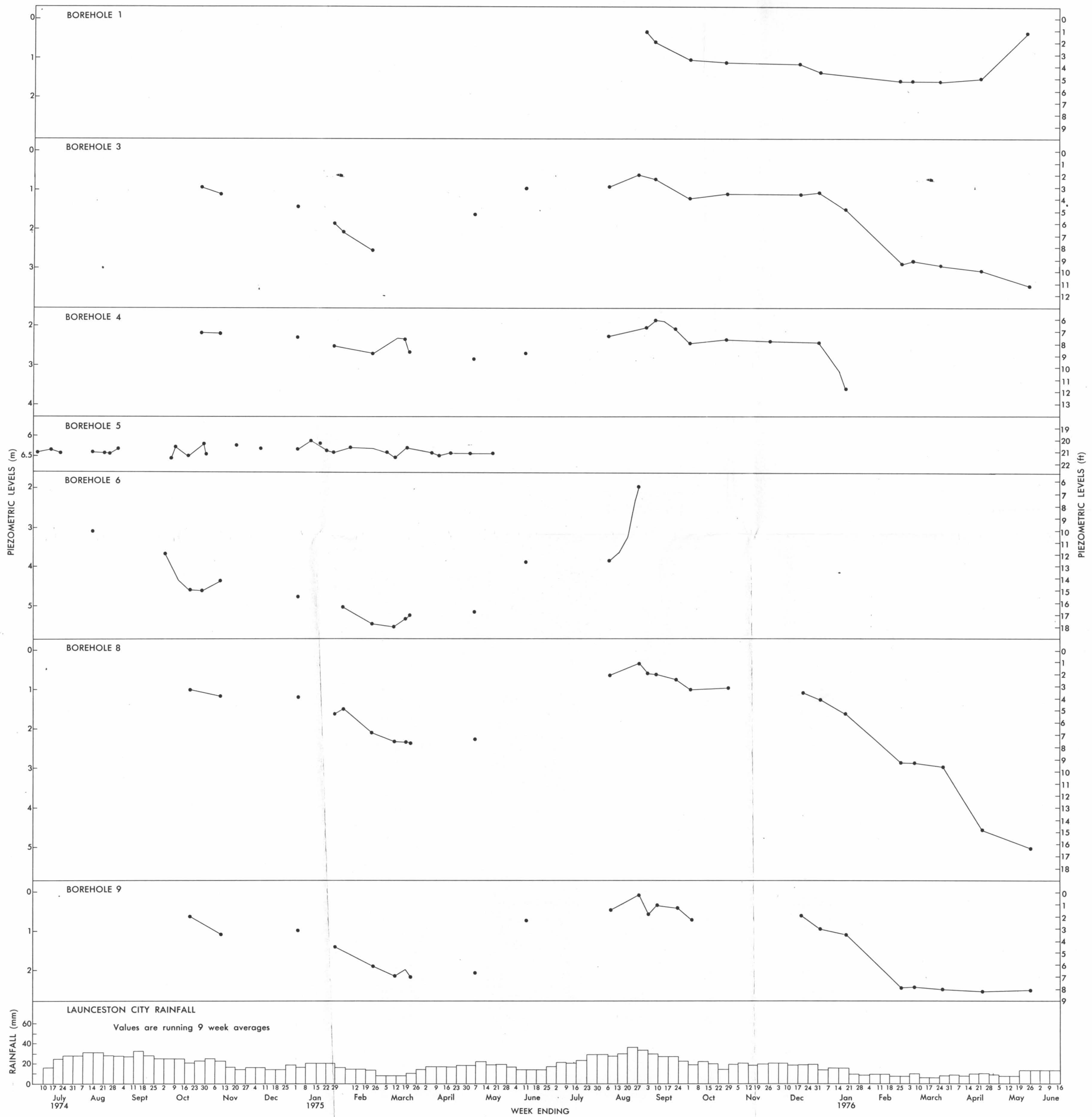

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Figure 6

5 cm