5. SOIL ANALYSIS, DESCRIPTION AND CLASSIFICATION

5.1 Laboratory and Field Soil Classifications

5.1.1 Laboratory Classification Tests

Representative disturbed samples of soil were selected from bore cores and soil outcrops from a wide range of landslide types and also from undisturbed ground adjacent to, and beneath the landslides, for the following classification tests:

* determination of particle size distribution by sieving and hydrometer analysis
* determination of liquid limit (wL), plastic limit (wP) and thence the plasticity index (IP).

The in-situ winter moisture content was also determined when suitable samples existed. The above terms are defined in the Australian Soil Testing Standard As 1289 – 1977, and the tests were carried out by Soilmech Pty Ltd in accordance with this standard. The results are summarized in Table 5.1, and the individual test result sheets are held in the Geological Survey files as Appendix 5.1 of this report. Each sample has been classified according to the Unified Soil Classification.

5.1.2 Correlation between Field and Laboratory Soil Characteristics

Table 5.1 summarises the main field and laboratory characteristics of representative soil strata and samples from each strata. It must be emphasized that the field descriptions are based on visual and manual examination without the aid of the equipment used for laboratory classifications. In addition, the field classification refers to the entire strata, whereas the laboratory classification applies only to a representative sample from the strata. There is in fact a very close correlation between field and laboratory classifications, which serves to illustrate that the samples were representative of the strata and that the field descriptions are accurate.

Table 5.1 – Sheets 1 of 4 – Correlation between Field and Laboratory Soil Classification

Field Classification of Tests Soil Strata					Laboratory Classification of Samples from the Strata							
Bore No/ Depth of Strata (metres)	**Geological Formation**	**Consistency or Relative Density**	**Lithology**	**Group Symbol**	**Depth of sample (metres)**	**Lithology & % of major components**	**W_L %**	**W_P %**	**I_P %**	**m.c. %**	**Group Symbol**	**Comments**
1/0.20-1.25	Tec	Firm	Sandy silty clay	CH	0.20-1.25	Silty sandy clay (21/27/52)	70	30	40	35.6	CH	Fine sand
1/1.25-4.60	Kls	Stiff	Silty clay & clayey silt	CL, CH, ML, MH	2.30-2.70	Silty clay (37/56)	58	28	30	31.3	CH	Wth'd rock fragments present
1/4.60-6.05	Kls	Hard	Clayey silt	MH	5.30-5.70	Sandy clayey silt (29/32/38)	51	23	38	21.9	MH	
2/0.30-5.35	Tec	Firm-stiff	Sandy silty clay	CH	2.50-3.05	Sandy silty clay (23/24/52)	59	32	27	33.8	CH	Fine sand
3/0-1.60	Tec	Firm-stiff/ Compact	Silty clay/ clayey silty sand	CL, SM SC	1.20-1.60	Clayey silty sand (24/38/38)	24	15	9	19.5	SC	F-M sand
3/2.35-2.88	Tec	Compact	Clayey silty sand	SC	2.43-3.00	Clayey silty sand (17/36/41)	32	18	14	18.8	SC	F-M sand
3/2.88-3.72	Tec	Very stiff	Silty clay	CH	2.90-3.35	Sandy silty clay (12/33/55)	62	27	35	30.4	CH	F sand
3/3.72-5.10	Tec	Stiff	Clayey silty sand	SM	4.00-4.50	Clayey silty sand (27/33/34)	68	28	36	41	M	Minor gravel
3/5.64-6.20	Kls	Hard	Clayey silt	MH	5.70-6.20	Clayey sandy silt (18/18/60)	50	24	26	18.5	MH	
4/4.90-7.10	Tec	Firm-stiff	Clay	CH	5.25-5.85	Sandy clayey silt (15/30/47)	85	4	42	54.5	MH	F sand
5/1.50-2.66	Tvo	Stiff	Silty clay	CH	2.16-2.66	Sandy silty clay (17/20/59)	70	31	39	42.8	CH	Sand content consists of wth'd felspar
5/2.66-8.67	Tvo	Firm-stiff	Silty clay	CH	6.80-7.40	Clayey silty sand (26/28/43)	54	34	20	54.1	SC	

Table 5.1 – Sheets 2 of 4 – Correlation between Field and Laboratory Soil Classification

Field Classification of Tests Soil Strata					**Laboratory Classification of Samples from the Strata**							
Bore No/ Depth of Strata (metres)	**Geological Formation**	**Consistency or Relative Density**	**Lithology**	**Group Symbol**	**Depth of sample (metres)**	**Lithology & % of major components**	**W_L %**	**W_P %**	**I_P %**	**m.c. %**	**Group Symbol**	**Comments**
6/1.80-5.72	Tvo	Stiff	Clay	CH	4.30-4.90	Silty clayey sand (27/28/38)	63	38	25	42.1	SC	Silty & sand is wth'd felspar
7/0.30-4.85	Tvo	Stiff	Clay	CH	4.30-4.85	Sandy silty clay (11/27/62)	73	35	38	54.9	CH	
7/5.05-7.92	Tec	Compact	Silty sand	SM	5.45-6.30	Silty sand (16/80)	Non-plastic			24.2	SM	F-M sand
	Tec	Compact	Clayey silt	MH	7.00-7.50	Clayey silt (35-56)	49	23	26	19.2	MH	
9/0.30-6.70	Tvo	Firm	Clay	CH	3.35-3.60	Gravelly sandy silty clay (10/22/24/44)	60	30	30	-	CL	Gravel & sand are Fe_2O_3 nodules
10/0-1.85	Tec	Firm-stiff	Sandy clay	CL	1.65-1.83	Sandy silty clay (11/24/63)	76	31	45	-	CH	
13/0-3.05	Tec	Firm	Sandy clay	CL	2.50-2.70	Gravelly silty clayey sand (12/18/32/38)	40	20	20	-	SC	M-C sand
14/0.30-4.00	Tvo	Firm	Clay	CH	3.20-3.35	Sandy clayey silt (10/39/49)	69	37	32	-	MH	Sand & silt is wth'd felspar
14/4.00-5.45	Tec	Stiff-very stiff	Silty clay to clayey sandy silt	CL, MH	4.80-5.00	Sandy clayey silt	59	19	31	-	MH	
15/0-3.95	Tvo	Soft-firm	Clay	CH	3.05-3.35	Gravelly clayey silty sand (15/17/27/41)	69	39	23	-	SC	Completely wth'd rock minerals
15/4.05-4.75	Tec	Soft	Clayey silt	MH	4.20-4.50	Sandy clayey silt (12/28/60)	44	20	24	-	MH	F sand

Table 5.1 – Sheets 3 of 4 – Correlation between Field and Laboratory Soil Classification

Field Classification of Tests Soil Strata					**Laboratory Classification of Samples from the Strata**							
Bore No/ Depth of Strata (metres)	**Geological Formation**	**Consistency or Relative Density**	**Lithology**	**Group Symbol**	**Depth of sample (metres)**	**Lithology & % of major components**	**W_L %**	**W_P %**	**I_P %**	**m.c. %**	**Group Symbol**	**Comments**
15/5.15-5.90	Kls	Firm-stiff	Silty clay	CL	5.60-5.90	Clayey silt (37/59)	62	30	32	-	MH	
18/0.30-2.40	Tec	Firm	Sandy clay	CL	1.68-1.90	Gravelly silty sandy clay (14/23/31/32)	47	23	24	-	CL	M-C sand
18/2.40-5.60	Tvo	Firm-stiff	Clay	CH	3.20-3.35	Sandy silty clay (15/19/63)	60	35	25	-	MH	Includes wth'd rock
21/1.05-6.25	Tec	Stiff	Clay	CH	3.05-3.35	Silty clay (25/70)	78	27	51	-	CH	
22/5.90-7.70	Tec	Stiff	Clayey silt	ML	6.85-7.15	Sandy clayey silt (23/36/41)	41	17	24	-	MH	
23/8.67-9.80	Tec	Compact	Silty sand	SM	9.40-9.65	Silty clayey sand (12/21/65)	26	23	3	-	SC	F-M sand
24/1.05-1.97	Tec	Compact	Clayey silt	SC	1.20-1.45	Sandy clayey silt (22/26/48)	37	17	20	-	SC	
24/1.97-9.11	Tec	Stiff	Silty clay	CL	6.25-6.55	Sandy silty clay (10/42/48)	60	25	35	-	CH	M sand
25/1.05-1.82	Kls	Firm	Silty clay	CL	1.65-1.82	Sandy silty clay (24/32/43)	54	27	27	-	CH	F-M sand
27/4.10-6.40	Kls	Hard	Clayey silt	ML	4.87-5.12	Sandy clayey silt (10/32/56)	50	27	23	-	MH	

Table 5.1 – Sheets 41 of 4 – Correlation between Field and Laboratory Soil Classification

Field Classification of Tests Soil Strata					Laboratory Classification of Samples from the Strata							
Bore No/ Depth of Strata (metres)	**Geological Formation**	**Consistency or Relative Density**	**Lithology**	**Group Symbol**	**Depth of sample (metres)**	**Lithology & % of major components**	**W_L %**	**W_P %**	**I_P %**	**m.c. %**	**Group Symbol**	**Comments**
Dingley Dell (1)	Tec	Stiff	Sandy silty clay	CL	Outcrop	Sandy silty clay (10/27/60)	59	29	30	-	CH	
Dingley Dell (2)	Kls	Loose	Silty sand	SC	Outcrop	Clayey silty sand□(20/22/58)	34	17	17	-	SC	F-M sand
Dingley Dell (3)	Tvo	Stiff	Clay	CH/CL	Outcrop	Silty clay (23/67)	87	41	46	-	CH	
Dingley Dell (4)	Tec	Very soft	Sandy silty clay	CL	Outcrop	Gravelly silty sandy clay (14/17/30/39)	38	28	18	35.4	CL	Sloppy
Dingley Dell (5)	Tec	Compact	Silty sand	SM	Outcrop	Clayey sand (18/80)	29	17	12	-	SC	M-C sand
Klevans (1)	Kls	Very stiff	Silty clay	CL	Outcrop	Sandy gravelly silty clay (18/19/31/32)	48	24	24	-	CL	
Klevans (2)	Kls	Very stiff	Clayey silt	ML	Outcrop	Gravelly clayey sandy silt (10/13/37/40)	47	28	19	-	SM	
Landslide No. 16	Tec	Compact	Gravelly sand	SC	Outcrop	Clayey gravelly sand (11/40/46)	50	25	25	-	SC	C sand
Landslide No. 10 Sample A	Tec	Stiff	Silty clay	CL/CH	Outcrop	Sandy silty clay (21/24/51)	65	37	28	-	CH	
Landslide No. 10 Sample B	Tec	Compact	Clay/silty, sandy gravel	SW	Outcrop	Gravelly sand (43/54)	47	26	21	-	SW	M-C sand
Landslide No. 10 Sample C & D	Tec	Compact	Silty/clayey, sandy gravel	GM	Outcrop	Silty clayey gravelly sand (13/20/25/42)	36	19	17	-	SC	M-C sand
Landslide No. 7	Kls	Stiff	Silty clay	CL	Outcrop	Silty sandy clay (29/31/37)	48	27	21	-	CL	F sand

5.2 *Soil Descriptions for each Geological Formation*

5.2.1 Tertiary Older Volcanics

Stace et al (1968) classifies the soils derived from the Older Volcanics in the Krasnozem pedological group and describes them as acid friable porous soils in which the texture generally increases with depth. They are usually deep soils with a dark red A1 horizon of friable clay with a strong crumb structure. "The A1 horizon grades through a redder and more clayey A-B into a red or dark red medium or heavy clay B horizon. These are moderately plastic clays and often rather compact in place, but highly structured, very permeable and friable when moist. Very fine, reddish, ochreous and sometimes black, ferromanganiferous nodules are common. The B horizon continues with little change for many feet, finally grading through a B-C horizon of yellow-red; or reddish brown more plastic clay into a C horizon of weathering rock. In wetter environments the B-C is somewhat mottled red, light grey and yellow-grey clay grading into a thick C horizon of weathering rock which may be partially saturated with water. The soils are associated with well-drained sites on hilly uplands and plateaux. They are formed by strong weathering and leaching of the basalt." This general description by Stace et al, is essentially true for the basaltic clays in the study area. However, the clays usually have high plasticity and they are not always as friable or permeable as suggested.

In engineering terms, the soils are clays with silty, sandy and/or gravelly components consisting of partly weathered rock and mineral particles and occasional iron oxide nodules and ferruginized concretions. The clays are mainly classified as high plasticity CH type soils, but the weathered rock content of some samples gives the soil a silty or sandy texture and an MH or SC classification. In these cases the clays have lower plasticity and are usually friable. Low plasticity CL type soils also occur. The overall high plasticity is illustrated by a medium plasticity index of 32% with a range of 20% to 46%. The liquid limit has a medium valley of 69% and a range of 54% to 87%. The in-situ winter moisture content was estimated in the field to be generally grater than the plastic limit and this was confirmed by laboratory tests. In some cases the in-situ moisture content approaches the liquid limits.

Most of the soils are of a firm, firm-stiff or stiff consistency, but a range from soft to stiff-hard occurs. Consistency generally increases with depth. The soils are commonly friable at shallow to moderate depth. The predominant colours are red, brown, yellow and grey, commonly with mottled or speckled combination thereof. All samples were taken from within landslide areas.

The following figures show the texture and colour of selected example of the basaltic clay:

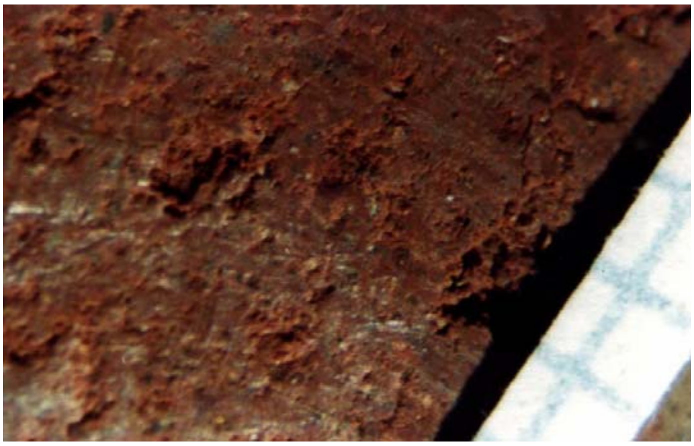

Figure 5.1 - Red-brown, stiff silty clay of the Tertiary Older Volcanics (Bore 7, Landslide 16, depth 4.2 magn. 19x)

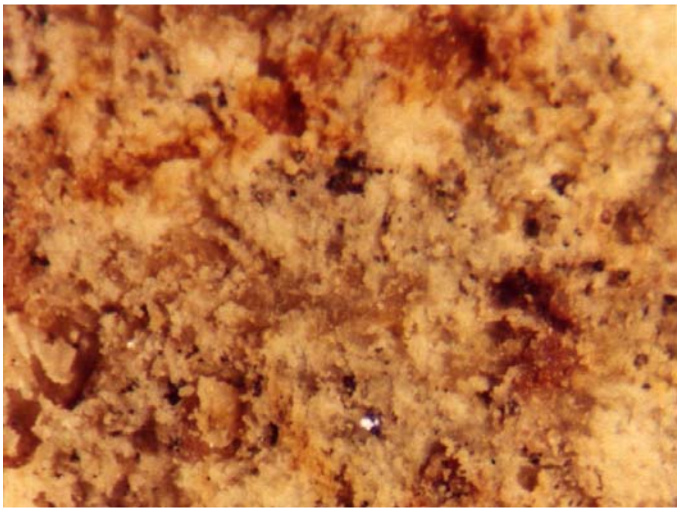

Figure 5.2 – Friable, brown, speckled, stiff, clay of the Tertiary Older Volcanics (Bore 16, Landslide 10, depth 5.0 m, magn. 19x)

Figure 5.3 – Recent earth flow in friable, red-brown, silty clay of the Tertiary Older Volcanics. Dingley Dell landslide complex July 1978.

Grant and Ferguson (1978), distinguish two terrain patterns within the Tertiary Older Volcanics of the area. In the Thorpdale area the topography is undulating with broad smooth crests and smooth convex slopes to 10o. In contrast, areas such as around Narracan and elsewhere are mainly strongly undulating with steep dissected slopes up to 40o. The division of the Older Volcanics into these two terrain patterns is shown in Figure 2.4. All the landslides selected for this study lie within the areas of strongly undulating terrain. Relatively few landslides occur in the undulating terrain. Grant and Ferguson describe the soils as gradational red silty clay to 0.5 m over red medium to heavy-textured clay to greater than 1.0 m (CL-CH), some minor areas of rock outcrop, and occasional basalt floaters occur. This general description is consistent with the more detailed analysis of the soils carried out in the present investigation.

5.2.2 Childers Formation

The soils of the Childers Formation consist mainly of poorly sorted, sandy, silty clays (CH) and clayey silts (MH).

The following soil types also commonly occur:

* silty and gravelly, sandy clays (CL) and clayey sands (SC)
* clayey or silty gravelly sands (SC, SM, SW)
* clayey silty sands (SC, SC), and
* sandy clayey silts (MH)

The sand content consists predominantly of angular or sub-rounded translucent quartz, and the gravel fraction is usually rounded opaque quartz. Sand seams occur which are occasionally ferruginized. Black carbonaceous seams, zones and concretions are common. The soil is often friable, sometimes fissured and occasionally contains joints which are commonly cemented with limonite.

The plasticity of the cohesive soils is generally high. The plasticity index ranges from zero (non-plastic) to 51% with a median value of 24%. The liquid limit ranges of 24% to 78% and has a median value of 47%. The in-situ winter moisture content was estimated in the field to be slightly greater than the plastic limit in most cases. Laboratory determination of moisture content for selected samples confirmed this observation. In no cases was the in-situ moisture content either determined or estimated to be near the liquid limit.

When cohesive, the soils are mainly firm-stiff and stiff, but all grades of consistency from soft to very stiff occurs. For the soils which are essentially non-cohesive, the relative density varies from loose to very dense, but is usually compact. The colour is usually pale brown/grey or mottled red/brown/grey/yellow. Yellow-brown, dark brown and red-brown colours also occur.

The following figures show the texture and colour range of soils from the Childers Formation:

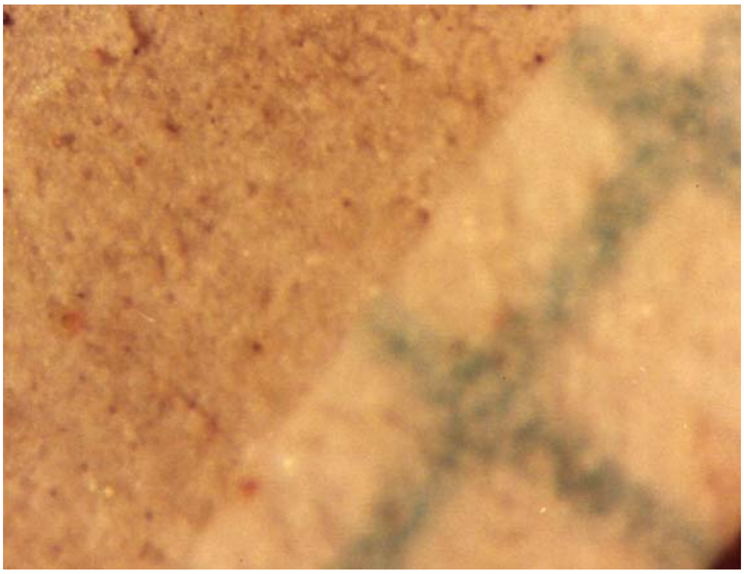

Figure 5.4 – Pale brown, friable, fine sandy, silty clay (CH), of the Childers Formation. (Bore 24, Landslide 13, depth 6.25 m, magn. 40x)

Figure 5.5 - Stiff, pale grey, clay (Ch) (1.80-2.35 m) with carbonaceous seams, plus compact, clayey silty sand (SC) from 2.35 to 2.45 m. Childers Formation, core from bore 3.

The pedological classification of Australian soils by Stace et al, (1968), is at too small a scale to portray the soils of the Childers Formation. They would however be grouped with the Krasnozems. Grant and Ferguson (1978), have delineated the Childers Formation as a distinct terrain pattern consisting of dissected slopes which are mostly capped by the overlying Tertiary Older Volcanics. The soils are described as variable, consisting of "gradational light to dark grey-brown sandy silt or silty clay to 0.3 m over gravelly silty clay to 0.6 m over yellow-brown mottled gravelly or sandy medium-textured clay commonly to 1.0 m (SM – CL/GC/GC-SC-CL) over decomposed rock". The more detailed nature of the present study has found that CH and MH type soils are also dominant members of the Childers Formation.

5.2.3 Lower Cretaceous, Strzelecki Group

The soils which have formed on the mudstones and sandstones of the Lower Cretaceous Strzelecki Group consist predominantly of poorly sorted silty clays (CH and CL) and clayey silts (MH) which are usually sandy and commonly include angular fragments of highly weathered rock. Clayey silty sands (SC, SM), silty sandy clays (CL) and clays sandy silts (MH) also occur.

With increasing depth, the soils grade into friable and fissile hard soil or highly weathered rock, in which the original rock fabric is discernible. Lamellar, sub-horizontal bedding is present along which the material readily cleaves, often to show the impression of fossil plant fragments as shown in Figure 5.6. The fossil plants belong to the D. speciosus Zone (Archer 1979) which forms the upper biostratigraphical unit (Aptian age) of the Strzelecki Group of Lower Cretaceous rocks. Thin carbonaceous seams occasionally occur and joints are sometimes stained with limonite.

Figure 5.6 – Hard, pale brown, clayey silt, cleaved along original bedding to show fossil plant fragments (Bore 1, Landslide 15, depth 5.0m, magn. 12x). Lower Cretaceous Strzelecki Group.

The soils are moderately cohesive. The plasticity index ranges from 17% to 38% with a mean value of 26%. The liquid limit ranges from 34% to 62% with a medium value of 50%.

Field estimates of in-situ winter moisture content indicated values close to the plastic limit, an observation confirmed by laboratory tests. The moisture content decreases with depth.

Most of the soils are cohesive and are mainly of a stiff consistency, becoming harder with increasing depth. The colour is predominantly pale brown and grey grading to yellow-brown/grey with depth.

Grant and Ferguson (1978), distinguish three terrain patterns within the soils and weathered rocks of the Lower Cretaceous Strzelecki Group of the study area. The area covered by each pattern is shown in Figure 2.4, and the topography of each pattern is described by Grant and Ferguson as follows:

1 The fragmented area to the north-west and south-west of Childers consists mainly of steep dissected slopes to 40^o. The only landslide studied within the area was a portion of the western Dingley Dell landslide complex. (Dingley Dell sample No. 2).

2. A north-south elongated segment along the valley of the Elizabeth Creek between Allambee and Childers. The area is characterised by a strongly undulating surface with slopes to 20o. No landslides were studied within this area.

3. Along the western and northern boundary of the study area, the topography consists of strongly undulating dissected terrain with slopes to 40o. Most of the landslides studies occur within this terrain. Grant and Ferguson describe the soils on the slopes of this terrain as “gradational light grey-brown silty clay to 0.3 m over yellow-grey mottled medium to heavy-textured clay to 0.6 m (MC-CL/CL-CH); over decomposed rock.” The present study also found MH type soils to be common. Landslides are normally confined to the well developed soil profiles and are most common in the sandy silty clays (CL and CH), but are known to occur in all soil types.

   Table 5.2 Summarises the dominant characteristics of the soils involved in landsliding from each geological formation.

Table 5.2 – Dominant Characteristics of Soils involved in Landslide Movements

STRATIGRAPHY	DOMINANT CHARACTERISTICS OF SOIL					
	Lithology	**Group Symbol**	**Consistency**	**Colour**	**Clay mineralogy**	**Winter Moisture Content**
Tertiary Older Volcanics	Clay	CH	Firm-stiff	Red-brown, yellow, grey	Kaolinite, Halloysite	$> W_P$
Childers Formation	Sandy, silty clay Sandy, clayey silt	CH MH	Firm-stiff	Brown, grey Red-brown, yellow	Kaolinite, Halloysite	$\geq W_P$
Lower Cretaceous	Sandy, silty clay Sandy, clayey, silt	CH, CL MH	Stiff	Brown, grey, yellow-brown	Montmorillonite	$\approx W_P$

5.3 Clay Mineralogy and Groundwater Chemistry

In addition to many other factors slope stability naturally depends on the shear strength of the soil. In turn, the cohesion component of shear strength is influenced by the types of clay present in the soil and the ways in which water behaves with the clays. Clay mineralogy also controls the compressibility and permeability of the soils and is therefore an important factor in determining the stability of slopes in clay soils and clay shales. Tests were therefore carried out to determine the mineralogy of the clays in the study area.

A total of 15 samples were selected from 8 landslides with the aim of obtaining a representative spread of samples from different landslides in each geological formation. The samples were analysed by the Australian Mineral Development Laboratories in South Australia, using x-ray diffraction methods. The procedure used, the results obtained and remarks on the results, are attached as Appendix 5.2. Table 5.3 is a summary of the results, tabulated to show the clay mineralogy of each geological formation.

The Tertiary Older Volcanics formation consists of residual basaltic clays. The dominant mineral is kaolinite which has almost certainly been admixed with halloysite. The following clay minerals were also present as sub-dominant components:

* Hydrated halloysite
* Dehydrated halloysite (metahalloysite)
* Montmorillonite, and
* Randomly layered mixed clay

The silty and sandy clays of the Tertiary Childers formation are composed mainly of kaolinite which is sometimes admixed with halloysite. The known sub-dominant clay minerals include:

* Mica/illite
* Illite-montmorillonite as regularly and randomly mixed layers
* Other randomly layered mixed clays

Accessory or trace amounts of mica/illite, illite-montmorillonite (as randomly mixed layers), and montmorillonite, also occur.

The clay fraction in the clayey silts and silty clays of the <u>Lower Cretaceous formation</u>, consists almost entirely of montmorillonite. Only accessory of trace quantities of mica/illite, kaolinite and chlorite were identified in addition to montmorillonite.

A general knowledge of the structure of clay minerals is needed to appreciate the significance of clay mineralogy to slope stability. Deere et al (1966), provides a comprehensive description of the structure, chemistry and physical properties of the clay minerals. The structure of most clay minerals is based on composite layers consisting of silicon-oxygen tetrahedral and magnesium or aluminium oxygen-hydroxyl octohedra. The three main clay groups which occur in the study area are:

1. The kandite group which consists of various stackings of unit layers, each layer consisting of a tetrahedral sheet and an octahedral sheet with A1 as the octahedral ion. The result is a number of polymorphs; comprising caolinite (the most common), dickite, macrite and halloysite which is completely irregular and randomly stacked. Kaolinite has no ionic charge deficiency, and layers have strong hydrogen boding thus accounts for kaolinite having the strongest cohesiveness of all the clay minerals. The strong hydrogen bonding also makes it difficult for water molecules to penetrate the layers, hence kaolinite is not prone to volume changes during the seasonal cycles of wetting and drying.

If kaolinite was the only dominant clay mineral in the Older Volcanics and the Childers Formation, the high frequency of landslides in these formations would be more difficult to explain. However, the polymorphyl halloysite, is also a dominant constituent. Halloysite sheets tend to curl into rods because of low bond energy, and it is therefore possible to introduce materials into the structure. For example, molecular layers of water can penetrate between each sheet. As a result, halloysite rich clays have a much lower cohesiveness than kaolinite clays.

Table 5.3 - Summary of Clay Mineralogy Results

STRATIGRAPHY	**CLAY MINERALOGY**		
	Dominant Minerals	**Known Sub-Dominant Minerals (>20%)**	**Known Accessory or Trace Minerals (≤ 20%)**
Tertiary Older Volcanics	Kaolinite with halloysite probably admixed in some samples and definitely admixed in other samples.	• hydrated halloysite • dehydrated halloysite (metahalloysite) • montmorillonite • randomly layered mixed clays	None
Childers Formation	Kaolinite, sometimes with halloysite admixed	• mica/illite • illite-montmorillonite (regularly and randomly mixed layers) • other randomly layered mixed clays	• mica/illite • illite-montmorillonite (randomly mixed layers) • montmorillonite • mica/illite • kaolinite • chlorite

2. Illite and other hydrous micas. The structure of illite is essentially that of a mica in that it contains layers with a plane of octahedrally co-ordinated cations sandwiched between two inward pointing sheets of linked (Si, AL)O4 tetrahedra. The mica structure consists of composite sheets of this type alternating with layers of potassium ions. Very weak oxygen-oxygen bonds exist between illite sheets, allowing good basal cleavage and therefore a lower cohesiveness than in kaolinite. A relatively high charge deficiency exists between layers, though this is usually neutralized by potassium ions. Thus interlayer bonding is strong and expansion of the lattice cannot occur by water molecules being adsorbed between layers.

The presence of mica/illite clays in the Childers Formation and in the Lower Cretaceous formation indicates soils of relatively low shear strength. As illite weathers, potassium soils of relatively low shear strength. As illite weathers, potassium ions are lost and montmorillonite type layers may form. The resulting illite-montmorillonite layered clays will readily adsorb water, thus lowering the shear strength of the soil even further. Illite-montmorillonite clays are common in the Childers Formation.

3. The structure of the montmorillonite group of clays is similar to illite with both dioctahedral types (montmorillonite, beideliite, montonite, and volkonskoite) and trioctahedral types (saponite, hectorite and suaconite). All are swelling clays in that they can adsorb water between their structural layers, and all show marked cation exchange properties. Montmorillonite is the sodium rich member of the group and is also the most common. It has weaker sheet bonding than illite which is shown by the decreased shear strength or cohesiveness of montmorillonite when compared with illite. The weak bonding allows water to be adsorbed between sheets causing the clay to expand. Bowman (1972), explains that "the water molecules are orientated. Initially orientated water does not decrease the cohesiveness of clay as it helps in tying the sheets together. However, additional water reduces the shear strength. The ability to adsorb water (and thus the cohesiveness) is influenced by the exchangeable cation. Evidence suggests that sodium ions are not hydrated although sodium ions strongly orient three molecular layers of water and weakly orient many addition water layers. Calcium ions on the other hand are hydrated. They strongly orient four molecular layers and only weakly orient a few additional water layers. Thus, sodium montmorillonite can adsorb more water than calcium montmorillonite and is more sensitive to water with a resulting greater loss in cohesiveness".

Montmorillonite is the dominant clay mineral in the soils derived from the Lower Cretaceous rocks. Only accessory or trace quantities of other clay minerals occur. Montmorillonite also occurs in the clays of the Tertiary Older Volcanics and in the Childers Formation in subdominant and accessory quantities respectively. In all cases, montmorillonite would be a significant factor contributing to slope instability.

Groundwater samples were collected from two boreholes and a chemical analysis was performed on each of these samples. The analyses are given in the following table.

Table 5.4 – Chemical Analyses of Groundwater Samples

Borehole No		**5**	**25**
Total solids in solution (by summation) mg/litre		**mg/litre** 156	**mg/litre** 135
Chloride	(Cl)	34	53
Carbonate	(CO_3)	Nil	Nil
Bicarbonate	(HCO_3)	51	8
Sulphate	(SO_4)	8	13
Nitrate	(NO_3)	5	4
Calcium	(Ca)	6	6
Magnesium	(Mg)	5	5
Sodium	(Na)	29	28
Potassium	(K)	1	2
Iron-Total	(Fe)	12	21
Iron-Soluble	(Fe)	0.1	0.1
Silicate	(SiO_3)	17	16
Total hardness	(as $CaCO_3$)	36	36
pH		7.21	6.30
Electrical Conductivity at 25^{o} C (micromhs/cm)		225	228

The sample from borehole 5 was taken from within the clays of the Older Volcanics and the sample from borehole 25 was from the Lower Cretaceous Formation. The results are very similar except for the bicarbonate values. The high bicarbonate content in water from borehole 5 is probably consistent with the relatively high bicarbonate values commonly associated with the weathering of basalts (Knights and Matthews, 1977). In both cases, chloride is a major anionic contaminant and sodium is the principal cationic contaminant.

The most likely source for sodium chloride is aquifer recharge by rain, which in the coastal region carries atmospherically-borne sea spray. The sodium to calcium ratios are relatively high, thus favouring the formation of sodium rather than calcium montmorillonites. Mesri and Olsen (1970) explain in detail how stronger bonding occurs in calcium montmorillonite. Therefore, an environment which favour the formation of the weaker sodium montmorillonite will accentuate the slope stability problems.

In the absence of detailed laboratory strength testing, it is difficult to assess the relative effective shearing strength of the various clay soils present on the basis of clay mineralogy alone. However, the significant fact is that all three geological formations are dominated by clays such as halloysite, montmorillonite and mica/illite, which are noted for their associated with landslide-prone soils and rocks.

Deep weathering and kaolinisation of the Tertiary Older Volcanics is probably associated with the period of Tertiary laterization in which small deposits of bauxite were also formed. Alteration is more marked where the basalt is associated with permeable clayey sands of the Childers Formation, suggesting that groundwater leaching occurred through the fractured basalts into the permeable sediments. Halloysite would than have been produced by secondary chemical changes.