Slope Instability Hazards in the Auckland Region

A Preliminary Assessment

Auckland Regional Council
Technical Publication No. 71, June 1996.

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A Preliminary Assessment

A report prepared for the
Auckland Regional Council

A. L. Williams
Beca Carter Hollings and Ferner Ltd.
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FORWARD

This assessment was prepared to provide a general overview of slope instability in the Auckland region as part of the Auckland Regional Council's responsibilities under the Resource Management Act (1991). These include providing information on the risks and impacts of natural hazards, particularly those that are regionally significant, and investigating ways of avoiding or mitigating their effects.

The inherent conditions that affect slope stability are geology (interaction of the soil and rock mass including defects), the degree of weathering of the soil or rock mass, slope angle and height, existing instability and groundwater.

This assessment of the Auckland region's slope instability hazard has been prepared at a broad scale of 1: 250 000. Only those conditions that could be readily mapped over broad areas (geology, slope angle and areas of existing instability) have been used as the basis for the assessment. Analysis of this group of conditions allows *general areas* of potential slope instability hazard within the Auckland Region to be identified. It is important to note that detailed evaluations of all of the conditions need to be completed for a particular locality before an accurate hazard assessment of that locality can be made.

The Slope Instability Hazard Map indicates that much of the Auckland region is prone to instability. It must be appreciated that a high hazard classification does not necessarily preclude a particular activity from that area. Depending on the level of risk, the hazard in these areas can be mitigated by a number of measures including appropriate engineering design and/or ensuring appropriate land use practices.

For further information about instability hazards in the Auckland region, please contact the Land Resources section of the Auckland Regional Council.

Ian Mayhew
Manager, Land Resources
AUCKLAND REGIONAL COUNCIL

Slope Instability Hazard Assessment Map

Prepared for

AUCKLAND REGIONAL COUNCIL ENVIRONMENT

By

BECA CARTER HOLLINGS & FERNER LTD

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Report Prepared by
A L Williams *Signed* AL Williams

With Input from
W M Prebble, University of Auckland
and
G Mansergh, Graham Mansergh & Associates Ltd

Report Reviewed By
D V Toan *Signed* DV Toan

1 INTRODUCTION

The Resource Management Act, 1991 (Sections 30 and 31) designates responsibility for integrated management of the land, natural and physical resources and avoidance or mitigation of natural hazards to Central, Regional and Territorial Government.

For each potential hazard, the Auckland Regional Council (ARC) are working to:

- define the hazard;
- assess community vulnerability;
- define the risk and level of "acceptable" risk; and
- define and implement risk reduction policies.

This report and accompanying maps presents a preliminary assessment of the slope instability hazard for the Auckland Region as part of this ongoing work.

The objectives of this assessment are to:

- identify areas of known instability in the Auckland Region; and

- identify areas of potential land instability hazard.

This report is the property of our client, the Auckland Regional Council and Beca Carter Hollings & Ferner Ltd. This document discusses land instability at a regional scale. It is not suitable for a site investigation database and should not be used as such.

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2 SLOPE INSTABILITY IN THE AUCKLAND REGION

2.1 Introduction

The underlying causes of slope instability in the Auckland Region are fairly well known from case studies of specific failures. The causes can often be directly related to the rock and soil composition and defects (eg the inclination of bedding, fractures and clay seams in relation to slopes) which are relatively constant, or may be transient (eg seismic vibration) or imposed by new events (eg construction activity).

In a given area, the more constant factors can be recognised and their effects rated. Some can be mapped and correlated with each other and with past failures. An understanding of the mechanisms of slope failure and why failures occur when and where they do, allows prediction of susceptibility by extension of local information to larger areas.

A general description of the soil and rock masses that make up the Auckland Region is given in Section 2.2. A simple classification of types of slope instability is given in Section 2.3. The main conditions that promote instability are identified in Section 2.4 and their relative contribution estimated in Section 3. In this way a summary of the degree of potential hazard has been built up which depends on the number of failure inducing factors present, their severity and their interaction.

2.2 Soils and Rocks in the Auckland Region

Much of the Auckland urban area is built on Miocene, Pliocene and Quaternary sedimentary rocks and soils. Younger basaltic volcanoes (the youngest, Rangitoto erupted some 600 years ago) have erupted through these rocks, producing scoria cones, lava fields, explosion craters and tuff rings. To the west, the hills of the Waitakere Ranges are underlain by volcanic sedimentary rocks derived from eroded Miocene-aged volcanoes and to the east, the hills of the Whitford-Brookby district and the islands of Motutapu, Motuihe, and in part, Waiheke, Kawau, Little Barrier and Great Barrier are underlain by weathered Mesozoic greywacke. To the north, soft sedimentary rocks and much harder volcanics support gentle to moderately sloping lowlands and upstanding ranges respectively.

Weathering of these rocks has produced a mantle of residual soils (generally clayey) up to 10m to 30m thick. The Quaternary (Pleistocene and Holocene) deposits comprise soils which have been transported into place.

Soil and rock mass categories have been developed to group the soils and rocks according to their known or expected geotechnical characteristics[1] as follows (new

[1] *Terms used to describe soil and rock mass characteristics are defined in the Appendix.*

classes are named in italics):

Class A	Very soft to stiff and loose to medium dense deposits, usually less than 10,000 years old and generally water saturated. These include sand, silt, mud, shell, peat, stream alluvium, pumiceous clay, swamp deposits and man-made fill.
Class B1	Loose to dense and soft to very stiff alluvium less than 3 million years old. The alluvium comprises sand, silt, clay, peat, sensitive pumiceous silt and breccia. Weathers to very soft clay and silt to depths of 10m.
Class B2	Very soft to soft, sensitive pumiceous silts up to several metres thick at Te Atatu North, Hobsonville, and in the East Tamaki - Manurewa area; commonly very unstable if saturated and unconfined; readily dispersed by wind and water.
Class B3	Basalt lava and scoria overlying class B1 deposits. The basalt and scoria are generally closely associated and therefore difficult to dissociate on the soil/rock types map. These rocks are not generally prone to instability and failure tends to be defect-controlled rock fall. However, layers of loose scoriaceous material do occur and these would fail more readily than welded layers. For this reason, a score of 2-3 is given in Table 1.
Class B4	Ash, tuff and basalt fragments overlying class B1 deposits. These materials may be unstable where they overlie a weathered surface oriented unfavourably for stability (but less so than other weathering profiles).
Class C	Defined to distinguish the Onerahi Chaos-Breccia from other sandstones, siltstones and limestones. The soft to moderately soft blocks of undifferentiated deposits in a matrix of closely sheared, fractured and crushed mudstone and some sandstone weather to a soft to very soft clay to depths of 10m. The residual slopes are characteristically unstable even at quite low angles.
Class D1	Very weak to moderately strong sandstone, siltstone, mudstone, limestone, conglomerate and associated andesitic and basaltic lava flows, 3 to 75 million years old. Fractures are typically moderately widely to extremely widely spaced, but can be very closely spaced. Bedding-parallel clay seams occur within the Waitemata Group sandstones and mudstones. The parent rock weathers to soft to stiff residual soil to depths of 20m.
Class D2	Basalt lava and scoria overlying Class D1 deposits. (Refer Class B3).
Class D3	Ash, tuff and basalt fragments overlying Class D1 deposits. (Refer Class B4).

Class E Moderately strong to very strong greywacke sandstone, conglomerate, siltstone, mudstone, minor volcanics and chert more than 110 million years old. Closely to moderately closely fractured, these rocks weather to soft to stiff residual soil to depths of 30m. Younger hard to very hard basalt and andesite (and minor conglomerate) of the central Waitakere Ranges have been included in this class.

2.3 General Classification of Slope Instability

Classification of slope instability (slope movements) is based on:

(i) the type of slope movement (ie. falls, slides, flows and movements which include two or more types of slope movement); and

(ii) the type of material in which the slope movement occurs (ie. soil or rock mass).

Examples from within the Auckland Region are shown in Figures 1-9.

2.3.1 Falls

A slope movement is described as a fall when a rock or soil mass of any size becomes separated from a steep slope or cliff along a weakened surface and moves downslope, mostly through the air, by free fall, toppling, bouncing, jumping or rolling. (Figures 1 and 2).

2.3.2 Slides

Slides comprise movement along one or more surfaces that may be curved or planar. Slide movements are commonly controlled by planes or zones of weakness in the rock or soil mass such as faults, fractures, bedding planes and variations in strength between successive layers or the contact between bedrock and overlying soils. (Figures 3 to 5).

Where the slide mass comprises a single unit or a few closely related units that have largely remained intact during movement the slope movement may be termed a block slide. (Figures 6 and 7).

2.3.3 Flows

The failure surfaces within a flowing mass are generally transient and distributed among many fractures without concentration along any through-going fracture. Flows generally incorporate the fluidising effect of water (and/or air). Slower flows in plastic soils (creep) are common where clay or weathered clay-rich rocks occur in steep slopes subject to saturation. (Figures 8 and 9).

2.4 Conditions that Affect Instability

The inherent conditions that affect slope stability are geology (interaction of the soil and rock mass including defects), the degree of weathering of the soil or rock mass, slope angle and height, existing instability and groundwater.

At a scale of 1:250,000, it is appropriate to address conditions that can be readily mapped over broad areas. For this reason, geology, slope angle and existing instability form the basis of this assessment. Analysis of this group of conditions allows general areas of potential slope instability hazard within the Auckland Region to be identified.

2.4.1 Geology

In this context, geology includes composition, texture and fabric and the influence of these factors on the physical or chemical behaviour of the soil and rock mass. These characteristics influence properties such as shear strength, permeability and susceptibility to weathering, which in turn affect slope instability. Many slope failures occur within the residual soils or along the interface between rock and soil.

Rock mass structure is also considered in the geological groupings. Structure includes features that cause weakness and inhomogeneity in the rock mass such as bedding planes, fractures, clay seams, faults and folds. Many failures occur along or within weak zones or on surfaces that are oriented unfavourably for stability.

2.4.2 Slope

The steepness of slope in relation to the slope-forming soils and rock may be critical to the slope stability. While most natural slopes are irregular, comprising sections of different steepness, average slope angles have been grouped into ranges of degrees for the purposes of this assessment.

2.4.3 Past Instability

Evidence of past instability indicates a potential for failure of geologically similar slopes of similar slope grade in the same area, thereby providing an important guide to the likely future behaviour of slopes in the locality.

2.5 Known Instability in the Auckland Area

2.5.1 Areas Unstable on Gentle Slopes

Class B1, B2 and C soils are prone to creep, flow and sliding even in gentle slopes, and particularly when saturated. This behaviour reflects the high swelling characteristics of soils derived from Class C rocks (Onerahi Chaos Breccia) in particular.

2.5.2 Moderate to Steep Inland Slopes

The near surface (up to several metres) Class D1 and E rocks are often weathered. When highly to completely weathered these rocks behave essentially as soils, and fail typically as slides and flows on or above the soil/rock interface. In the same way, instability commonly occurs where ash, lapilli and/or tuff (Classes B4 and D3) overlie a lower permeability weathered surface (eg the weathered surface of Class D1 and E rocks) oriented unfavourably for stability.

Surfaces of weakness commonly control slope movements in moderately weathered to unweathered Class B3, D1 and E rocks. Block slides are common in moderate to steep slopes of Class D1 rocks in the South Auckland area. In this area, semi-intact rock blocks are inferred to have moved on (often) gently inclined clay-lined bedding-parallel fractures or clay seams. Where these gently dipping defects daylight in moderate to steep slopes block slides may be initiated.

Rock falls may occur from oversteepened fractured faces of Class B3 and D2 rocks.

2.5.3 Coastal Cliffs, River Banks and Gullies

Rock falls and slides are common where less weathered Class D1 and E rocks are exposed in coastal cliffs or steep banks and cuts. The overlying weathered materials commonly fail initially by sliding on or above the soil/rock interface. The mobilised mass may then continue by flowing or falling from the face or cliff.

3 HAZARD ASSESSMENT

Preliminary assessment of the slope instability hazard in the Auckland Region was undertaken by preparation of a series of maps at a scale of 1:250,000 using the Geographic Information System (GIS) based ArcInfo technology.

3.1 Soil/Rock Mass Map (Map 1)

The "Preliminary Ground Shaking Hazard" plan developed as part of the preliminary Earthquake Hazard Study for the Auckland Region (ARC Environment Technical Report No.57) was used as a base plan for the Auckland Region Soil/Rock Type Distribution data base, presented as Map 1.

Soil/rock mass categories developed are described in 2.2 above.

Scores were allocated to each soil/rock class (Table 1) according to the known or expected geotechnical characteristics of that class.

TABLE 1: SOIL/ROCK MASS CATEGORIES		
Soil/Rock Mass	**Class**	**Score**
Very soft to stiff mud, silt, peat, pumiceous clay, stream alluvium and swamp deposits; loose to medium dense fine sand and shell; generally water saturated and less than 10,000 years old (Holocene); man-made fills also included	A	4
Soft to very stiff alluvium, sensitive pumiceous silt, silt, peat and clay and loose to dense sand and breccia less than 3 million years old (Pleistocene)	B1	5
Very soft to soft pumiceous deposits up to several metres thick; commonly very unstable if saturated and unconfined; can be dispersed easily by wind or water (Pleistocene)	B2	6
Basalt, basanite lava and scoria overlying Class B1 deposits	B3	2-3
Ash, tuff and basalt fragments overlying Class B1 deposits	B4	4
Soft to moderately soft, variously sized blocks of undifferentiated deposits in a matrix of very closely fractured, sheared and crushed mudstone and some sandstone; 40-65 million years old (Eocene-Palaeocene) Weathers to soft to very soft clay to depths of about 10m	C	6
Very weak to moderately strong sandstone, siltstone, mudstone, limestone and conglomerate with associated basaltic and andesitic lavas and volcanigenic alternating sandstone and siltstone, generally 3-25 million years old; fractures generally moderately widely to extremely widely spaced; bedding-parallel clay-seams occur in the sandstones and mudstones Weathers to soft to stiff residual soil to depths of 20m	D1	3
Basalt, basanite lava and scoria overlying Class D1 deposits	D2	2-3
Ash, tuff and basalt fragments overlying Class D1 deposits	D3	3
Moderately strong to very strong basement and old sedimentary rocks >110 million years old (Mesozoic); greywacke sandstone, conglomerate, siltstone, mudstone and minor volcanics and chert; closely to moderately closely fractured; in the northern region, some volcanic rocks of 5-24 million years (Tertiary) Weathers to soft to stiff residual soil to depths of 30m	E	2

The scores allocated are relative numbers calculated by back-analysis[2] of the stability of each soil/rock Class in slopes of different steepness. The highest score was given to Class B2 and C soils/rocks which tend to have low effective strength parameters when disturbed. The lowest score was given to Class E rocks which, when unweathered to slightly weathered, typically stand readily in slopes of 0.5H:1V (64°) to 2H:1V (26°).

3.2 Slope Grade Map (Map 2)

Slope information was sourced from the New Zealand Land Resource Inventory data licensed to ARC Environment by Landcare (NZ) Ltd. Existing categories were grouped into the four classes defined in Table 2 and illustrated in Map 2. Relative scores were assigned to each slope category based on known behaviour of each rock type class (refer 2.2, 2.3 and 2.4 above) within each slope angle range through back-analysis of the stability of each rock-type in the slope range given.

TABLE 2: SLOPE CATEGORIES

Slope Grade	Class	Score
gentle (0 - 7°)	A	0
moderately steep (8 - 15°)	B	2
steep (16 - 20°)	C	4
very steep (> 20°)	D	5

3.3 Areas of Known Instability (Map 3)

Categories of known slope instability on a regional scale were identified from knowledge of type areas prone to instability and specific areas that have been investigated by the authors and/or reviewers of this document. The approximate location of these areas is shown on Map 3 and described in Table 3 below. As Map 3 was compiled at a scale of 1:250,000, it is important to be aware of the limitations of the very broad scale used. This map should **not** be used to determine whether a specific site has been subject to past instability. The map gives an indication only of general areas of known instability for the purposes of adjusting hazard assessment scores considered by the GIS program in production of Map 4, Slope Instability Hazard Map for the Auckland Region.

[2] *Back-analysis means that we start with a known instability situation, and work back to assess the relative stability of the same soil or rock mass type in slopes of different steepness.*

Although three classes of known instability are distinguished, each class is allocated the same score. This is because the type of potential slope movement is not distinguished on the hazard map. Assessment of the likelihood of the occurrence of slope instability is incorporated in the soil/rock type scores (Table 1) and the slope scores (Table 2).

TABLE 3: AREAS OF KNOWN INSTABILITY

Instability Category	Class	Score
Unstable even on gentle slopes	A	6
Coastal cliffs, river banks and gullies	B	6
Moderate to Steep inland slopes	C	6

3.4 Hazard Scores (Map 4)

The combined scores from Table 1, Soil/Rock Type Categories and Table 2, Slope Categories are presented in Table 4 as Hazard Assessment Scores. Where a locality has been subject to past instability, a score of 6 is added to the tabulated score. The total score is interpreted in terms of slope instability hazard in Table 5.

For example, using Table 4, a Class A slope (0 - 7°) of Class A soil/rock (very soft to stiff Holocene deposits) gives a total score of 4. From Table 5, it is seen that a score of 0 - 5 equates with a low slope instability hazard. If the area is known to have been subject to past instability (refer Map 3) an additional score of 6 would be added. A total score of ≥8 indicates that the slope instability hazard is high (Table 5).

For the same soil/rock class in a Class B slope (8 - 15°) and assuming no known past instability, a score of 6 from Table 4 indicates a moderate slope instability hazard, with potential for instability dependent on local factors such as depth of weathering and degree of saturation. Where Class A soil/rock exists in slopes of 16° or steeper (Class C or D slopes), the hazard is rated high and the slopes may be considered unstable.

TABLE 4: HAZARD ASSESSMENT SCORES				
Soil/Rock Class	Slope Class A	Slope Class B	Slope Class C	Slope Class D
A	4	6	8	9
B1	5	7	9	10
B2	6	8	10	11
B3	2-3	4-5	6-7	7-8
B4	4	6	8	9
C	6	8	10	11
D1	3-4	5-6	7-8	8-9
D2	2	4	6	7
D3	3	5	7	8
E	2	4	6	7

The Arcinfo system avoids the need for hundreds of manual calculations such as these by overlaying Maps 1, 2 and 3 and totalling the input scores for each attribute (soil/rock type, slope and areas of known slope instability) for every part of the Auckland Region. The resultant map, Map 4, shows areas of low, medium and high hazard as described in Table 5.

TABLE 5: HAZARD ASSESSMENT		
Class	Total Score	Hazard
A	0 - 5	Low slope instability hazard
B	6 - 7	Moderate Hazard: Slope instability will be dependent on local factors such as depth of weathering and degree of saturation
C	≥8	High Hazard: Slopes unstable

4 CONCLUSIONS & RECOMMENDATIONS

This report presents details of the methods used to produce the accompanying preliminary slope instability hazard map.

The preliminary slope instability hazard map has been compiled as a desk study at a broad scale (1:250,000) to identify areas of high, moderate and low slope instability hazard based on available information on existing slope failures, slope angle and soil/rock type.

The preliminary slope instability hazard map identifies the following major areas of high instability hazard:

- slopes comprised of Onerahi Chaos-Breccia (eg Silverdale area)
- coastal areas (eg Whangaparaoa Peninsula; Leigh - Pakiri coast)
- sensitive pumiceous deposits (eg Te-Atatu North, Hobsonville, East Tamaki-Manurewa)
- steep inland slopes of 20°+ (eg the Whitford - Brookby area).

Areas of high and moderate hazard coincident with high population density and/or lifeline services should be addressed at a scale of 1:10,000 to 1:25,000 as part of a second, more detailed stage of slope instability hazard assessment. Groundwater should be considered as part of the hazard assessment at this scale.

ARC's current objectives are to:

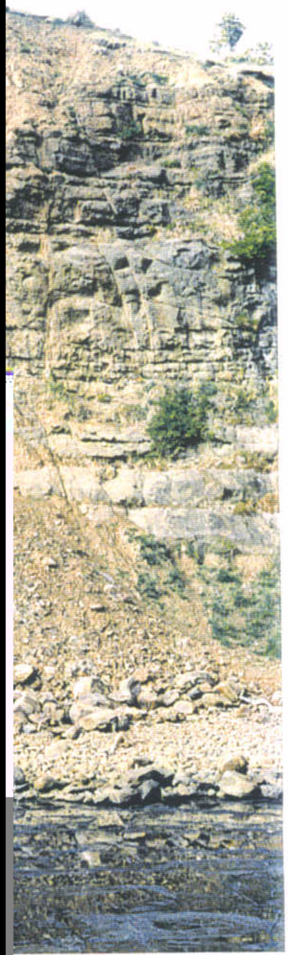
- assess community vulnerability;
- define the risk and level of "acceptable" risk; and
- define and implement risk reduction policies.

In order to achieve these objectives, it will also be necessary to address the relationship between:

- design factor of safety against slope failure, and
- risk of failure in a given period of time.

This will allow assessment of "acceptable" factors of safety (which correspond to a frequency of failure) to be adopted by the greater Auckland community.

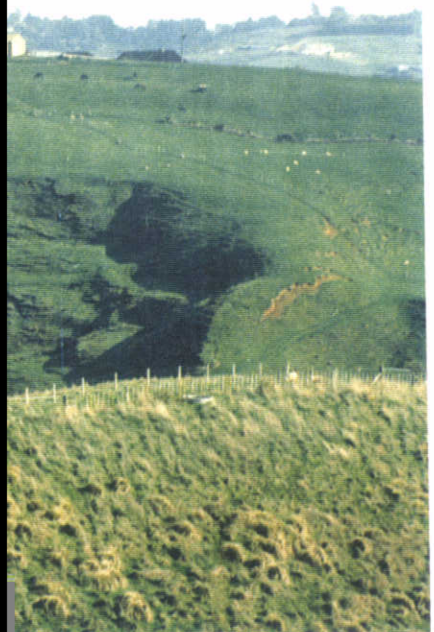
FIGURES



[redacted] stone/mudstone, soil/rock mass Class

[redacted] ıtion in ash of soil/rock mass Class B4

[redacted]ted over ash



[redacted]e/mudstone of soil/rock mass Class D1

Figure 5 Multiple scarps indicating ongoing slide movement of the ash slope

Figure 6 Block slide in weathered sandstone/mudstone of soil/rock mass Class D1. A group of cows are drinking from water ponded between two semi-intact slide blocks.

Figure 7 Debris derived from a large rock block slide beyond the cliff top is now tree-covered. A composite debris flow/fall has occurred to the right of the block slide and the trails of individual rock falls from the higher part of the cliff are visible to the left of the block slide.

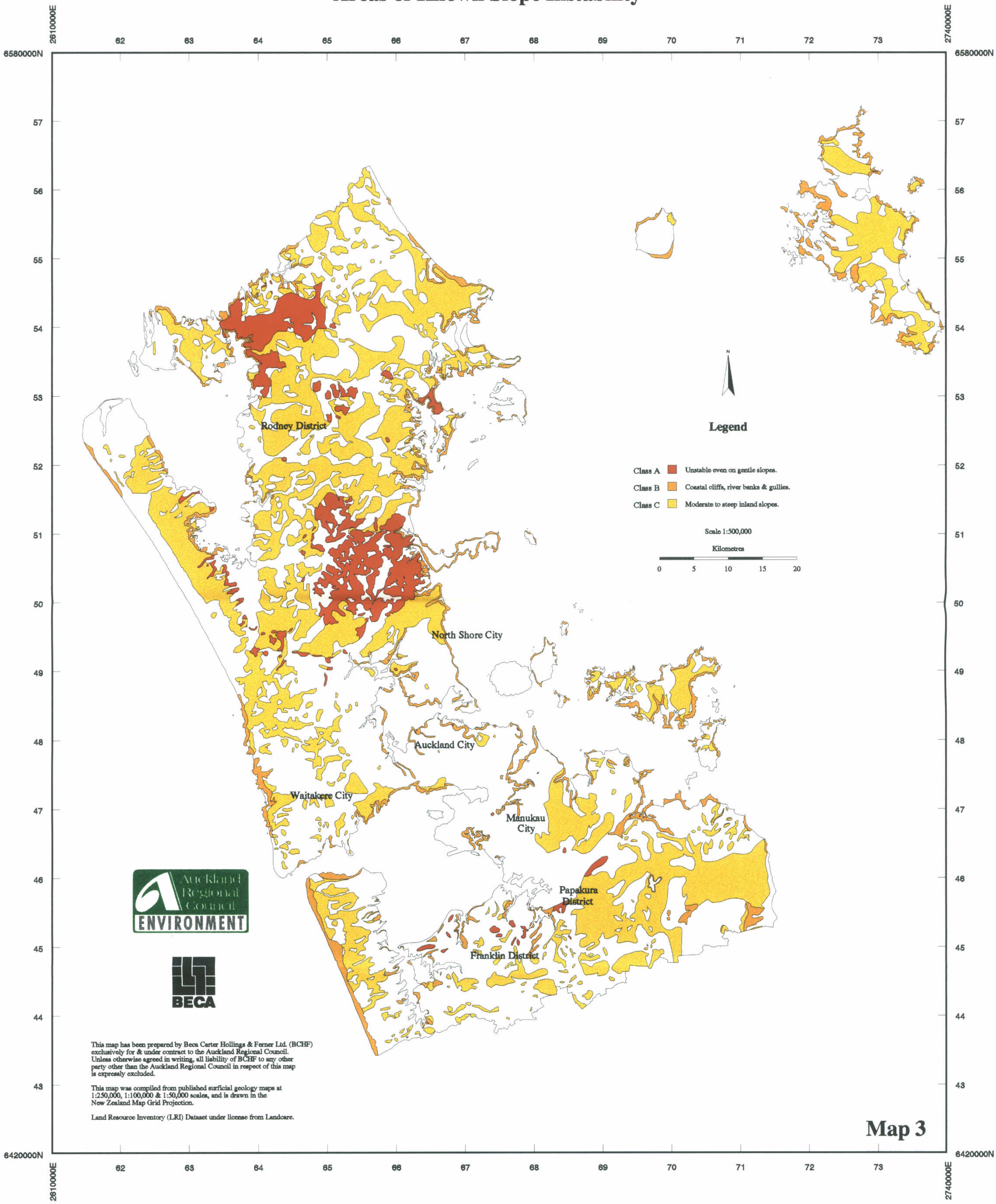
Figure 8 Composite slide/flow within soils derived from weathered sandstone and mudstone of soil/rock mass Class D1.

Figure 9 Tunnel gully erosion within soil/rock mass Class A overlying soil/rock mass Class D1.

MAPS

Auckland Region

Areas of Known Slope Instability



This map has been prepared by Beca Carter Hollings & Ferner Ltd. (BCHF) exclusively for & under contract to the Auckland Regional Council. Unless otherwise agreed in writing, all liability of BCHF to any other party other than the Auckland Regional Council in respect of this map is expressly excluded.

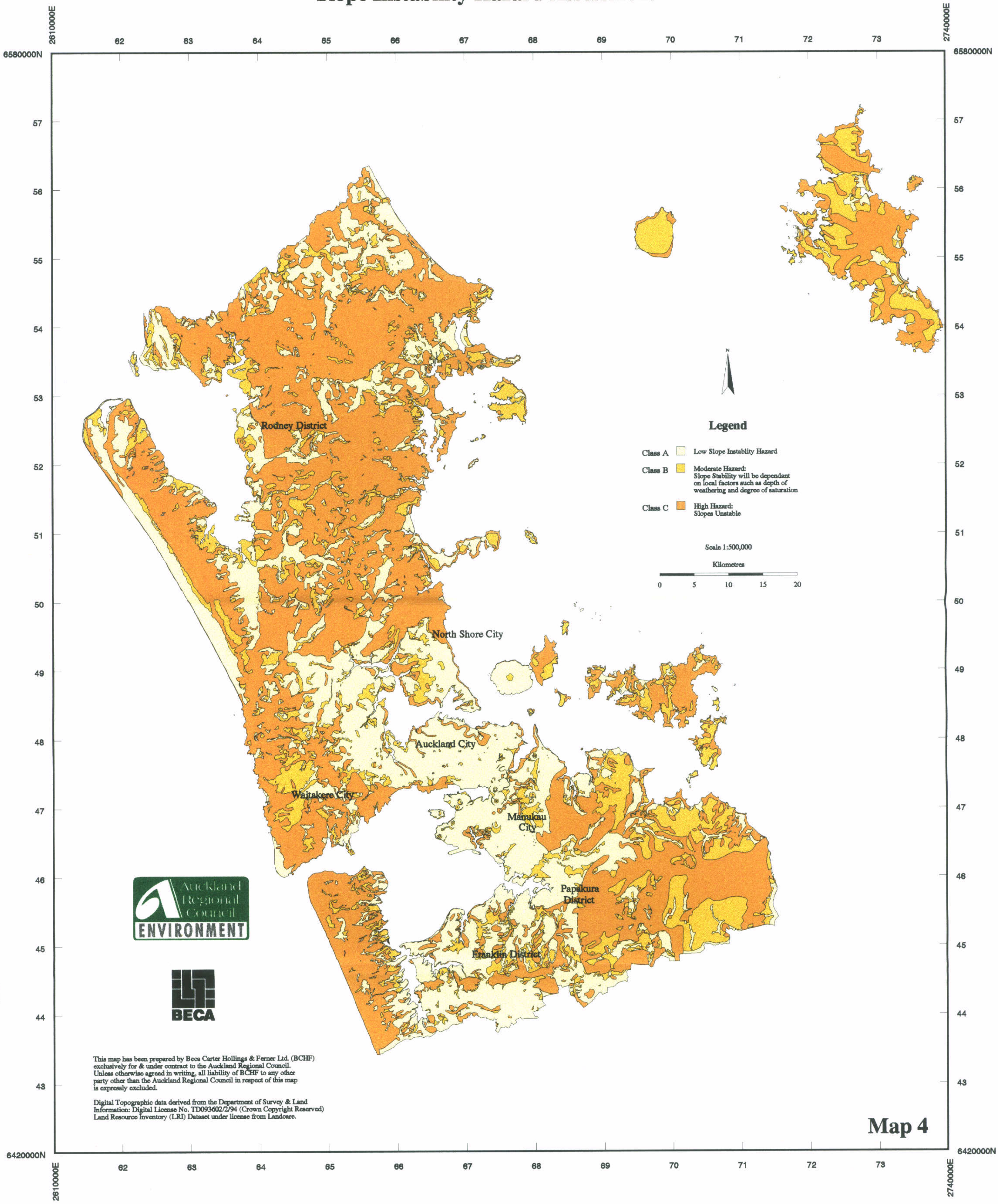
This map was compiled from published surficial geology maps at 1:250,000, 1:100,000 & 1:50,000 scales, and is drawn in the New Zealand Map Grid Projection.

Land Resource Inventory (LRI) Dataset under license from Landcare.

This map accompanies and should be read in conjunction with ARC Technical Report No. 71, June 1996.

Auckland Region

Slope Instability Hazard Assessment



This map accompanies and should be read in conjunction with ARC Technical Report No. 71, June 1996.

APPENDIX

APPENDIX: TERMS USED TO DESCRIBE ROCK MASS CHARACTERISTICS

Reference: New Zealand Geomechanics Society 1988: Guidelines for the Field Description of Soils and Rocks in Engineering Use.

SCALE OF ROCK MASS WEATHERING

TERM	GRADE	ABBREVIATION	DESCRIPTION
Fresh (unweathered)	I	UW	Rock material shows no discolouration, loss of strength or any other effects due to weathering. There may be slight discolouration on major discontinuity surfaces.
Slightly weathered	II	SW	Rock material may be slightly discoloured. Discontinuities* have discoloured surfaces and may be open. The rock material is not significantly weaker than the fresh rock material.
Moderately weathered	III	MW	Rock material is discoloured and discontinuity* surfaces will have a greater discolouration which also penetrates slightly into the rock material. The rock material is significantly weaker than the fresh rock and part of the rock mass may have been changed to a soil.
Highly weathered	IV	HW	Rock material is discoloured and more than half the rock mass is changed to a soil. Weathering adjacent to discontinuities* penetrates deeply into the rock material but lithorelicts or core stones of fresh or slightly weathered rock may still be present.
Extremely (completely) weathered	V	CW	All the rock mass is decomposed and externally changed to a soil, but the original rock fabric is mainly preserved.
Residual weathered (residual soil)	VI	RW	Rock is completely changed to a soil with the original fabric completely destroyed but the resulting soil is not significantly transported.

* = defects

SPACING OF DEFECTS OR DISCONTINUITIES

TERM	SPACING
Very widely spaced	> 2 m
Widely spaced	600 mm - 2 m
Moderately widely spaced	200 mm - 600 mm
Closely spaced	60 mm - 200 mm
Very closely spaced	20 mm - 60 mm
Extremely closely spaced	< 20 mm

FIELD IDENTIFICATION OF ROCK STRENGTH

TERM	FIELD IDENTIFICATION OF SPECIMEN	UNCONFINED UNIAXIAL COMPRESSIVE STRENGTH q_u (MPa)	POINT LOAD STRENGTH $Is_{(50)}$ (MPa)
Extremely strong	Can only be chipped with geological hammer.	> 25	> 10
Very strong	Requires many blows of geological hammer to break.	100 - 250	5 - 10
Strong	Requires more than one blow of geological hammer to fracture.	50 - 100	2 - 5
Moderately strong	Cannot be scraped or peeled with a pocket knife. Can be fractured with single firm blow of geological hammer.	20 - 50	1 - 2
Weak	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with point of geological hammer.	5 - 20	< 1
Very weak	Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife.	1 - 5	
Extremely weak (also needs additional description in soil terminology)	Indented by thumb nail or other lesser strength terms used for soils.	< 1	

Note: No correlation is implied between q_u and $Is_{(50)}$.

TERMINOLOGY FOR DESCRIPTION OF SOIL STRENGTH

(i) Fine Grained (Cohesive) Soils

TERM	DIAGNOSTIC FEATURES	UNDRAINED COMPRESSIVE STRENGTH (kPa)
Very Soft	Exudes between fingers when squeezed	< 25
Soft	Easily indented by fingers	25 - 50
Firm	Indented only by strong finger pressure	50 -100
Stiff	Indented by thumb pressure	100 -200
Very Stiff	Indented by thumbnail	200 - 400
Hard	Difficult to indent by thumbnail	400 - 1000

(ii) Coarse-Grained Soils

Visual Assessment:

Loosely Packed   can be removed from exposure by hand or removed easily by shovel

Tightly Packed   requires pick for removal, either as lumps or as disaggregated material

Assessment from Standard Penetration Test (SPT) and Scala Penetrometer Test Results:

TERM	SPT (BLOWS/300mm)	SCALA PENETROMETER (BLOWS/100mm)
Very Dense	> 50	> 17
Dense	30 - 50	7 - 17
Medium Dense	10 - 30	3 - 7
Loose	4 - 10	1 - 3
Very Loose	0 - 4	0 - 2

Note: Although given in the same table, no correlation is implied between the SPT and the Scla Penetrometer values.