2. LANDSLIDE HAZARDS IN FIJI

2.1 Regional tectonics and geological setting

2.1.1 Geology

The islands of the Fiji archipelago form part of the Fiji Platform which lies within a complex transform zone delimited by the New Hebrides Arc-Trench to the west and the Tonga arc to the east. The arc systems are driven by convergence of the Indo-Australian and Pacific Plates. The region has undergone a complex history of plate convergence, subduction and arc-volcanism from the Middle Eocene to the Early Pliocene (Figure 2.1). Recent summaries of the geology are provided by Hathway (1993) and Rodda (1994). The following is taken from these accounts.

The oldest known rocks, named the *Yavuna Group*, occur in south west Viti Levu and consist of basaltic lavas and intrusive rocks with minor epiclastic conglomerates and limestones. These are intruded by a trondhjemite stock of Lower Oligocene age. An unconformity separates this unit from the overlying Lower Oligocene to Middle Miocene *Wainimala Group* of volcaniclastic conglomerates and lavas with sedimentary units which crop out in south Viti Levu. The Wainimala Group is disconformably overlain by turbidites and conglomerates of the Upper Miocene *Tuva Group*.

A period of folding and faulting separates the Tuva Group from the overlying Upper Miocene sedimentary rocks of the *Nadi Sedimentary Group* and *Navosa Sedimentary Group* exposed in west Viti Levu. A phase of calc-alkaline volcanicity in south and west Viti Levu was contemporaneous with these sediments. In the Late Miocene to Early Pliocene, high-potash lavas of the *Koroimavua Volcanic Group* were erupted in north west Viti Levu and followed by shoshonitic and calc-alkaline volcanism of the *Ba Volcanic Group* across the northern half of the island.

Table 2.1 Stratigraphy of south east Viti Levu

Pliocene-Miocene	Mendrausucu Group	Suva Marl Veisari Sandstone Waindina Sandstone/Navua Mudstone Quartz Diorite Namosi Andesite Serua Conglomerate
Lower Miocene	Savura Volcanic Suite	Vago Volcanics
Lower Miocene-Lower Oligocene	Colo Plutonic Suite	Diorite/tonalite Gabbro
	Wainimala Group	Tawavatu Tuff Nubuonaboto Volcanics

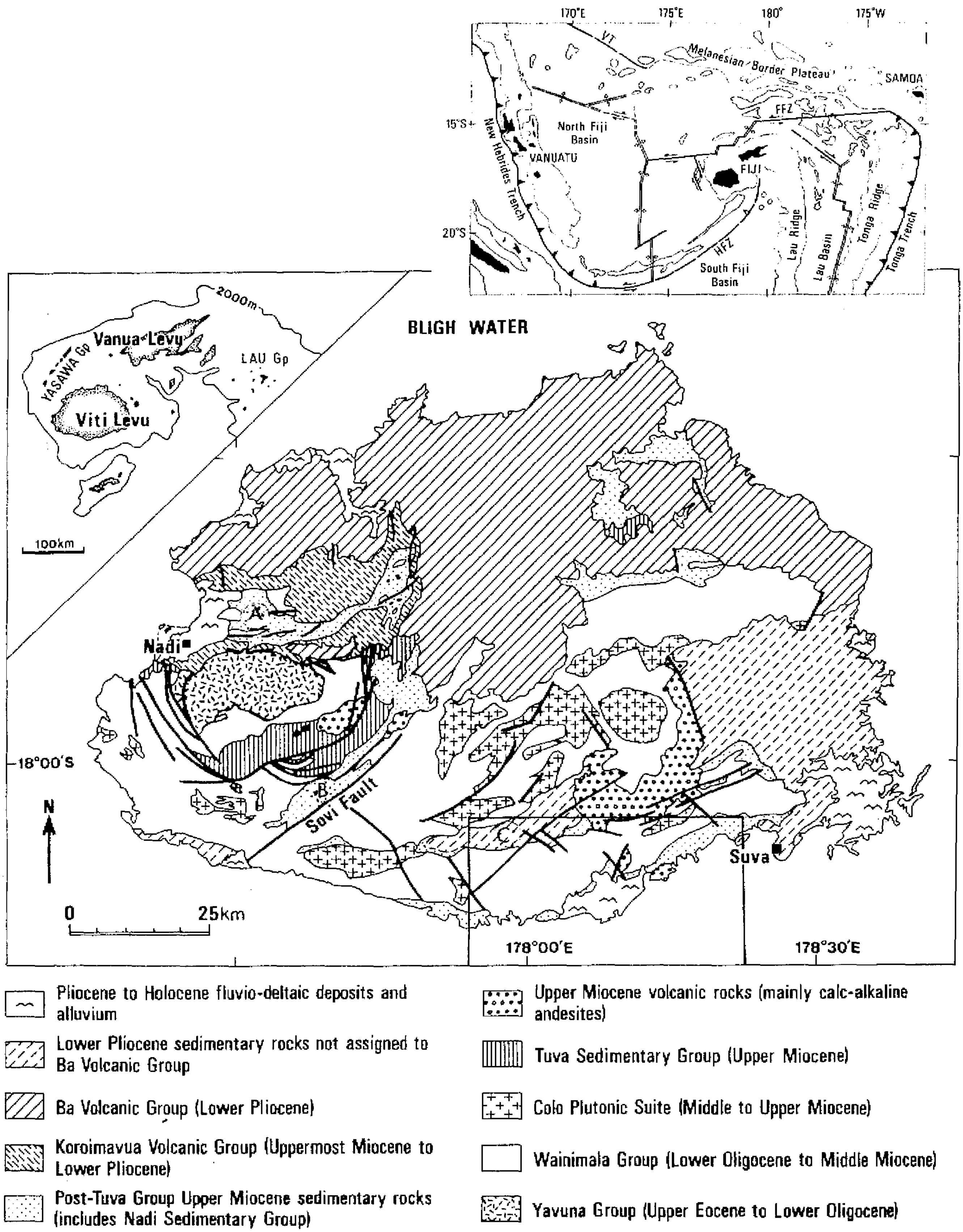


Figure 2.1 Generalised geology of Viti Levu with major faults. Late Miocene to Early Pliocene sedimentary basins shown in A, Nadi Basin; B, Sovi Basin : C, Navua Basin. Inset map of tectonic plate boundaries of the west Pacific region (reproduced after Hathway, 1993).

The stratigraphy of south east Viti Levu is summarised in Table 2.1 from published geological sheets 18 and 19 (Band, 1964; 1965). On the eastern margin of Sheet 19 (Mau area), olivine basalt flows of the *Nakobalevu Basalt Group* of Miocene/Pliocene age occur. These are correlated by Band (1968) with the *Ba Volcanic Group*.

2.1.2 Regional seismicity

The Fiji Platform lies within a triangular zone of active extension fault lines around which most of the shallow earthquakes have been centred (Louat and Pelletier, 1989). These are the Fiji Fracture zone (FFZ) to the north, the 176° Extension Zone (176°E EZ) to the west and the Eastern Seismic Line (ESL) to the east, equivalent to Hunter Fracture Zone (HFZ) of Hathway, 1993) (Figure 2.1). Lawson (1993) divided the seismicity of Fiji into seven zones most of which lie along, or near to, the tectonic lines described above. Earthquake activity is pronounced along the FFZ line with magnitudes of 6.5 to 7.0. The Suva earthquake of 1953 with a magnitude of 6.8 is known to have triggered landslides in the Navua area (Houtz, 1961 cited by Lawson, 1993). Seismicity recorded in south Viti Levu since 1979 is minor and shows no regular pattern.

2.1.3 Neotectonics

The neotectonism of Viti Levu is characterised by progressive uplift from the Late Pliocene onwards with a rate increasiMw toward the centre of the island. One manifestation of this is the uplift and dissection of the Pliocene Navua Plateau to form young narrow gorges. On Viti Levu and the other main islands, there are examples of active delta formation and coral reef building, whilst drowned coastal features are rare. Mesa-like features present on some coastal plains are thought to represent former coastal platform or alluvial deposits which now stand some 6 to 12 m above the present coastal plain (Twyford and Wright, 1965).

2.2 Landscape of southern Viti Levu

The highland area of southern Viti Levu may be divided into three topographic units:

Rama Range

Navua Plateau

Lokalevu Hills

The Rama Range in the eastern sector is formed of rugged volcanic terrain with some volcanic necks (Rama Peak 442 m) rising prominently above the landscape. Part of the Rama Range is underlain by gabbro of the Colo Plutonic Suite. The Navua Plateau is a peneplain whose base-level now stands at 150 m above sea-level. Much of this plateau is underlain by tuffs and volcaniclastics of the Wainimala Group. Changes in sea-level have rejuvenated the area resulting in the dissection and deepening of young narrow gorges (e.g. Navua Gorge). The Lokalevu Hills extend west from, and are bounded against the Navua Plateau by, the Yarawa Fault scarp.

Much of the upland relief of south east Viti Levu is carved from the Wainimala Group volcaniclastic rocks in the south sector, the Navua Basin sediments in the north, and Suva Marls in the east. The landscape shows a high density of deeply-incised small streams and many grey cliffs of 'soapstone', numerous waterfalls and occasional caves. Remnants of older plateaux surfaces rising above 1000 m and 600 m respectively are common. In the south east of the region near Suva, steep mudstone landscapes gradually give way to hilly and rolling land in Suva Marl near the coast.

2.3 Soils

2.3.1 Soil classification

The soil resources of the Fiji islands were documented in a comprehensive manner by Twyford and Wright (1965) who provided maps and a report covering Fiji. Their scheme has been modified in recent years by the Land Use Planning Section of the Ministry of Primary Industries (MPI) based on work done at the Koronivia Research Station near Nausori. The major soil groupings in the revised scheme are sub-divided into a series of range numbers corresponding to geographical and geological domains. These range numbers are further qualified by slope class symbols varying from flat to very steep.

According to Twyford and Wright (*op. cit.*), the two major groups of soil-forming materials on Viti Levu are tuffaceous sedimentary rocks and basic to intermediate volcanics. They occur predominantly in the hilly country with moderate to steep slopes. Soils derived from the intermediate volcanic rocks and their associated sediments are generally reddish-brown to red, although black soils occur where the sediments are calcareous or where the volcanics are enriched in pyroxene phenocrysts. Basaltic rocks give rise to reddish-brown, brown and black soils which vary in appearance according to age, stability and depth of weathering. The thickness of the soil profile correlates generally with the age of the parent rock i.e. younger rocks produce shallow soils, although there are several exceptions to this pattern. The colluvial, alluvial and aeolian soils prevalent on the foothills and floodplain areas are derived from a mixture of rock types but mineral grains from the intermediate andesitic types are dominant. Where siliceous rocks are prominent in the source area, the derived soils are usually rich in quartz grains.

In the Twyford and Wright scheme, the dominant soils of south east Viti Levu are classified as humic latosols derived mainly from rocks of basic to intermediate composition. In general terms, the latosols are the product of leaching in a very strong tropical weathering environment. They are ubiquitously clays in composition but behave like clay loams or loams in the field.

The following is a description of three major soil classes of the upland zones within the study area based on Twyford and Wright (1965)

The soils derived from rocks of andesitic and basaltic composition are predominant in the hilly country of the Navua and Serua Hills. These are probably synonymous with the *Serua and Lobau steepland clay and boulder clay unit* of Twyford and Wright (1965). The soil profile on moderate slopes typically shows a sequence as follows:

Reddish brown friable clay with a fine to very fine nutty structure	7 cm
Red friable clay with a fine angular fragmental structure	108 cm
Bedrock	

On very steep slopes, the soil profile is little more than 40 cm in thickness. These soils support the natural rain-forest and are locally used for subsistence cropping. A local variant on this soil type is *Batiwai clay* (Twyford and Wright, 1965, p 286) which is texturally very similar to the steepland clays above. They are invariably thicker soils, extending to 6 m, and are located on more gentle slopes to rolling hills.

A proportionally smaller area north of the Navua river within the study region is underlain by the *Naraiyawa steepland soil*. This is similar to the soil grouping derived from rocks of acidic composition and shows a typical profile as follows:

Dark brown friable stony silty clay loam with a weak blocky structure	10 cm
Light brown, friable, very stony, sandy clay with a coarse blocky structure to a fine, blocky and coarse granular structured sandy soil containing abundant weathered rock	24 cm

From the foregoing pedological descriptions there would appear to be few marked textural or compositional differences in the steepland latosolic clay soils of south east Viti Levu. However, geotechnical tests carried out on these soils indicated that, whilst there were no significant pedological differences due to parental bedrock, there were pronounced differences in engineering properties (Lawson, 1993). This highlights the difficulty of attempting to relate pedological classifications shown on regional soil maps to engineering behaviour and landslide distribution.

Differences in soil properties result from the gradational effects of weathering, both vertically and laterally within the soil profiles. For example, typical weathering profiles comprise 'mature' intensely weathered residual soil grading to successively less altered rock at depth. This gives rise to variations in material properties vertically within the profile. The intensity of the tropical (essentially chemical) weathering process is such that the physical and mechanical properties of the most highly altered surficial residual soils may bear no relation to the parent rocks from which they are deived (see above). Since weathering is increased around fissures in the parent rocks, there may also be marked lateral as well as vertical variations in the composition and physical properties of the weathering profiles. Lateral variations in properties on steep residual soil slopes may also result from surface material, which has attained near-equilibrium with the physico-chemical environment, being continuously removed by landsliding and erosion. This activity exposes less weathered, more 'immature', parts of weathering profile and thus leads to rejuvenation of the weathering process. Therfore, soils with markedly different material and engineering properties may occur in juxtaposition on the steepland slopes in south east Viti Levu. Such variations may not be indicated by the soil groupings shown on small to medium scale pedological maps.

Within the study area, the soil classification scheme of the MPI may be simplified for the purposes of description. The former soil classes have been reduced to two major groups as follows:

1.	Soils of the coastal marshes. Soils of the beach strands, dunes and estuaries. Soils of the major and secondary floodplains including terraces, fans and outwash surfaces.	Range 2-76
2.	Soils of the hill country	Range 116-243

The latter grouping is the more significant in the context of landslide phenomena and has been further divided into four sub-units based on broad compositional differences of the parental rocks, as follows:

2A	Soils from calcareous tuffs, sandstones, marls and volcaniclastic sedimentary rocks of intermediate to basic composition	Range 116-136
2B	Soils from quartz porpyhry, quartzite	Range 158-159
2C	Dacite, acidic andesite, silicified tuffs, sandstones	Range 163-182
2D	Soils from andesite and basalt and related tuffs	Range 204-243

For the purposes of GIS analysis, the MPI soil classes were modified to exclude their slope sub-category. This resulted in 43 soil types which formed the basis of the digital data. Although the use of the 5 groupings outlined above was considered for the GIS analysis, it was eventually decided to use all 43 classes so that any patterns of significance could be independently derived from the correlations with landsliding themselves.

2.3.2 Land use and soil erosion

Early accounts of soil erosion on Viti Levu focused on areas used for commercial agriculture and subsistence cropping. It was reported (Twyford and Wright, 1965, p 216) that agriculture was taking place on soils with moderate slopes which rendered the soil unstable. The degree of slope affects the amount of soil erosion, and even a slope of a few degrees is sufficient to induce severe soil loss in the wet season. Two types of soil erosion were noted: sheet and gully erosion. The former is much more subtle and is thought to be more prevalent on tuff-derived soils because these are naturally thinner in development than lava- or sedimentary-derived types. Gully-type erosion is common in the steep banks of river valleys and is expressed as large gullies or run-outs.

Since the 1960s, the woodlogging industry has grown substantially, and the clearing of trees is very evident in the south western sector of the study area. Such clearing has exposed large areas of clay soil and rendered them susceptible to sheet and gully erosion. However, the risk of soil erosion has apparently been recognised, and evidence from the 1990 aerial photography shows that most of the logged zones have been systematically replanted in an attempt to stop further soil removal.

2.4 Climate and rainfall in south Viti Levu

2.4.1 Introduction

The Fijian archipelago lies within the zone of the South East Trades and consequently there is a marked difference in climate between the lowland areas of the south and east, and those of the north and west. In the higher ground of the interior, there is a clear distinction between wet windward and dry leeward zones with substantial differences in rainfall, humidity and range of mean temperature. The mean annual rainfall on south east Viti Levu ranges from 3750 to 5000 mm per year whilst the leeward zones to the north receive only 1750 mm (Figure 2.2).

The period between mid-November and mid-April is recognised as the *hurricane* or *cyclone* season when tropical revolving storms may sweep across parts of the archipelago. These cyclone events are accompanied by violent wind-speeds in the range of 165 to 212 km per hour and cause considerable damage to property and agriculture. They also induce landsliding.

2.4.2 Tropical cyclone and storm events in the Fiji region

During the last 15 years, at least six major cyclones have either directly affected, or passed in close proximity to, Viti Levu. These are listed below and their tracks are plotted in Figure 2.3.

Cyclone	**Date**
Wally	1-6 April 1980
Arthur	12-15 January 1981
Oscar	28 Feb - 2 March 1981
Eric and Nigel	17-20 January 1985
Kina	26 Dec 1992 - 5 Jan 1993

In addition to these catastrophic wind/rainfall events, there were a number of other severe storms which affected Viti Levu in the 1980s and which had significant landsliding associated with them (Lawson, 1993).

A good correlation exists, as might be expected, between these cyclone/storm events and the average monthly rainfall data. The figures which follow were recorded by the Fiji Meteorological Service from five rain-gauge stations located within the study area. The figures cited below in Table 2.2 will, therefore, be somewhat representative of extreme rainfall events.

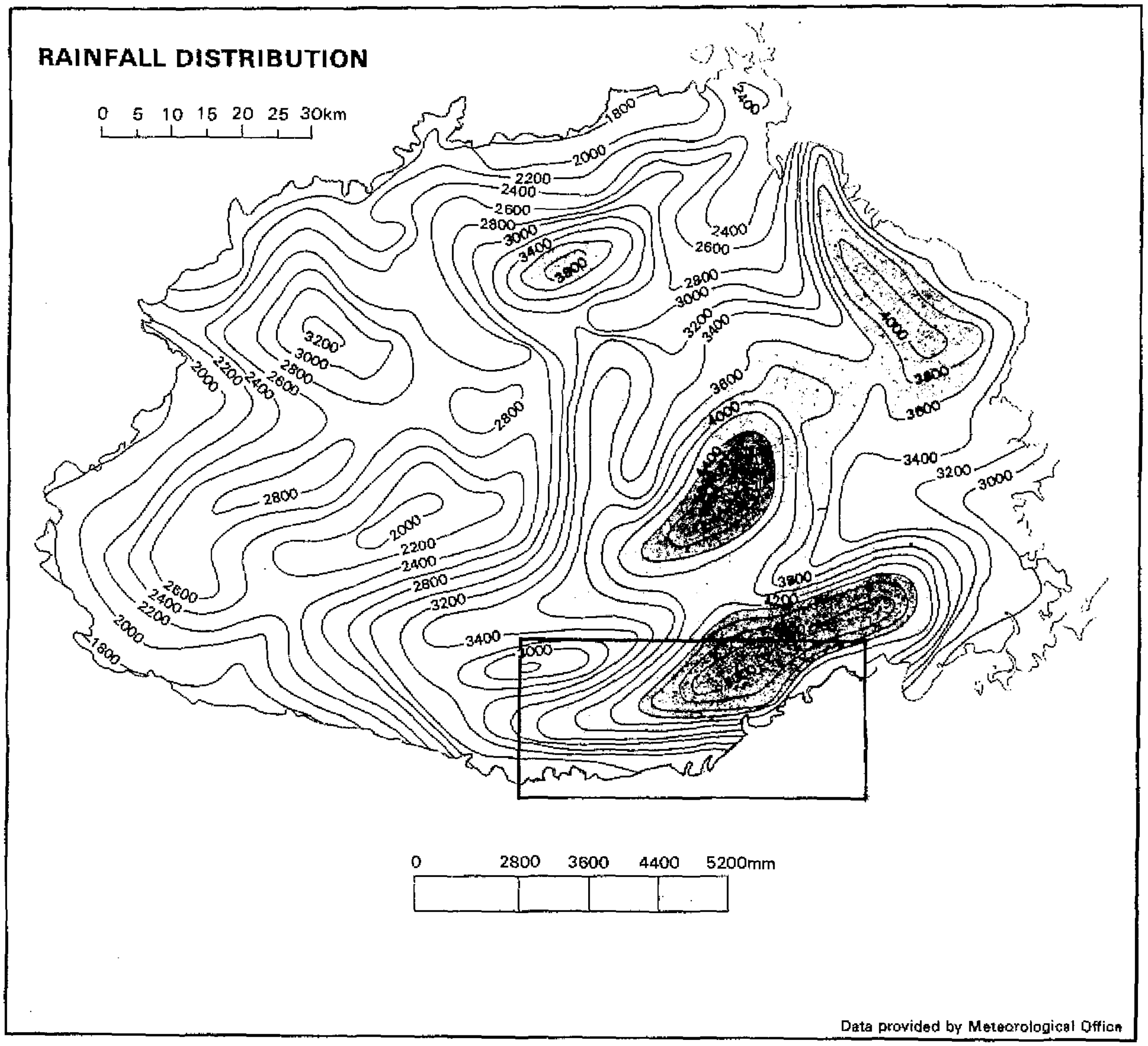


Figure 2.2 Rainfall distribution in Viti Levu. Data provided by Fiji Meteorological Service. (Reproduced after Gale and Booth, 1991).

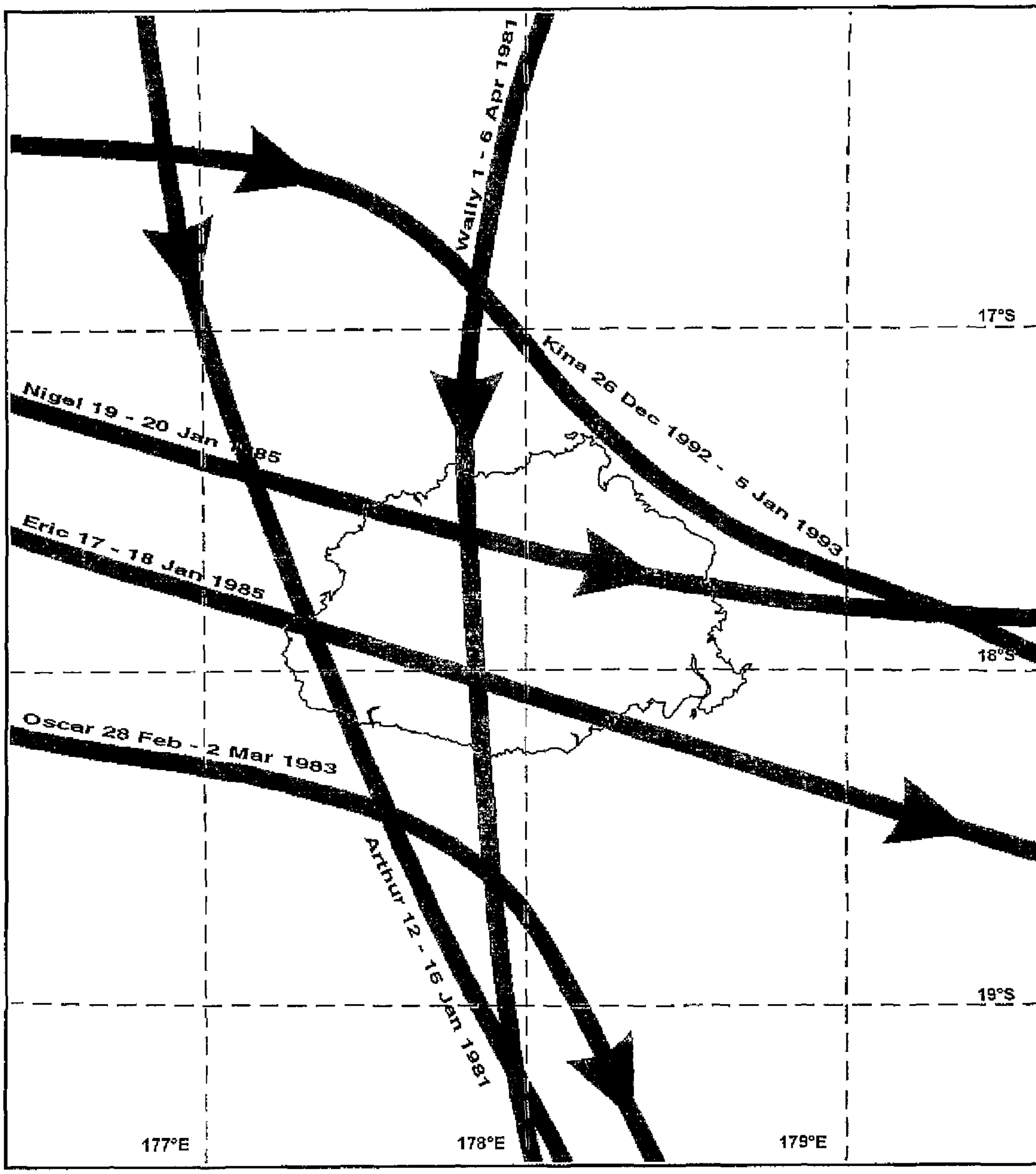


Figure 2.3 Plot of cyclone tracks in the Viti Levu area, April 1980 - January 1993. Data from the Fiji Meteorological Service.

Table 2.2 Monthly rainfall data plotted for cyclone and major storm events

Cyclone/storm	Month/year	Range in monthly rainfall (mm)	Monthly maximum (mm)
Wally	April 1980	501 - 924	1035
Storm	November 1980	310 - 576	1136
Storm	June 1984	260 - 288	790
Arthur	January 1981	273 - 452	527
Oscar	February 1983	384 - 785	1033
Storm	April 1986	966 - 1177	1422
Kina	December 1992 January 1993	280 - 538 175 - 376	597 399

For cyclone Wally, the monthly rainfall figures for April 1980 recorded from the five stations are moderaately high with an extreme of 1035 mm. However, the storm of 24 November of the same year produced a similar volume of rain ranging from 310 mm to a record high for any single month of 1136 mm. In some years, as for example in 1984, the rainfall in autumn/winter was average. This culminated in a storm on 16 June 1984 which produced landslides observed on road cuttings (Lawson, 1993). The range in monthly rainfall figures from 273 to 452 mm for cyclone Arthur in January 1981 is atypical but not wholly exceptional.

Even though its track lay to the south west of the island, cyclone Oscar in February-March 1983 was associated with prodigious rainfall, in the 384 to 785 mm range with an extreme of 1033 mm for February recorded at the Wainikavika station. The storm of 16-21 April 1986 produced the highest average rainfall record for a single month (1422 mm) with an exceptionally higher than average range for any month in this area.

The average range of rainfall recorded at the stations for January 1993, with an above average figure of 597 mm for December 1992, is not exceptional in comparison with the above extreme rainfall events. This time-span corresponds to the passage of cyclone Kina and it illustrates that the localised effects of cyclones passing north of the island (Figure 2.3). The destructive effects of this cyclone in east and north east Viti Levu are documented by Howorth *et al.* (1993). The main impact on the south east Viti Levu area was flooding of the Rewa and Navua river valleys with associated landsliding.

An important parameter of rainfall data is the intensity of the actual rainfall over a twenty-four hour duration of a particular storm or cyclone event. According to Lawson (1993), rainfall intensity and duration data is the simplest approach to understanding the relationship between rainfall and landslide occurrence. Figure 4.1 in Lawson *(op. cit.)* illustrates this concept but data of this type was not available to the present study.

2.5 Landslides in south east Viti Levu

2.5.1 Landslide classification

Landslides are influenced by, and occur in response to, a combination of many factors (e.g. lithology, geological structure, hydrogeology, topography, climate, vegetation, seismicity and erosion). Numerous classification schemes exist, many of which were designed for a specific local purpose and are not applicable elsewhere. Of the more general classification schemes, that of Varnes (1978) is the most widely used and one of the easiest to apply. It is particularly amenable to the rapid classification of landslides assessed from appropriately-scaled aerial photography or rapid field reconnaissance.

Based on Varnes' scheme, a relatively simple classification of landslides in south east Viti Levu was devised by Lawson (1993) and is used here, with qualification, for consistency. Classification is based primarily on type of movement, qualified by descriptive terms relating to type of material involved and rate of movement (Figure 2.4).

Varnes divides material involved in landslide movements into two main types - bedrock and engineering soil. *Bedrock* is defined as hard or firm rock that was intact and in its natural place before initiation of movement. *Engineering soil* includes any loose, unconsolidated or poorly cemented aggregate of solid particles, either transported or residual in origin. It may be further sub-divided into *debris* and *earth* depending on the dominance of coarse or fine material. In south east Viti Levu, the distinction between bedrock and engineering soil is not clear-cut due to the formation of deep residual weathering profiles formed by intense alteration of the parent rocks under tropical (hot and humid) climatic conditions. Thickness of the weathering profiles varies markedly in steep volcanic terrain but *regolith* (i.e. all materials above the solid bedrock in various stages of decomposition) often extends many metres below the ground surface. For example, borehole investigations for the Suva-Nadi highway traversing the southern edge of the study area, recorded highly altered rock to depths well in excess of 15 metres (Lovegrove & Fookes, 1972).

Based on appearance, texture, and physical and geotechnical properties, a six-fold weathering classification for residually weathered rock masses, based on the recommendations of the Geological Society Engineering Group Working Party Report on tropical residual soils (Anon, 1990), is shown in Figure 2.5.[1]. In some descriptions, weathering Zones IV and IV are collectively known as '*saprolite*' (a term generally used to describe undisturbed, though wholly altered material, showing original rock textures and structures), but in this classification, Zones IV, V and VI are generally considered as 'engineering soil' and Zones I-III as 'rock'. However, since the weathering profiles tend to be markedly gradational in their characteristics, this distinction is somewhat arbitrary and may vary from locality to

[1]*This classification is similar to that developed during investigations for the Suva-Nadi highway (Lovegrove & Fookes, 1972) which also recognised six weathering zones (I, II, II, IVa, IVb, V). In this scheme, weathering zones IVa, IVb and V are equivalent to zones IV, V and VI of the currently accepted Engineering Group classification (Anon, 1990). The use of weathering zones IVa and IVb during the highway investigations, attests to the practical difficulty of distinguishing boundaries between 'highly' and 'completely weathered' zones in the field.*

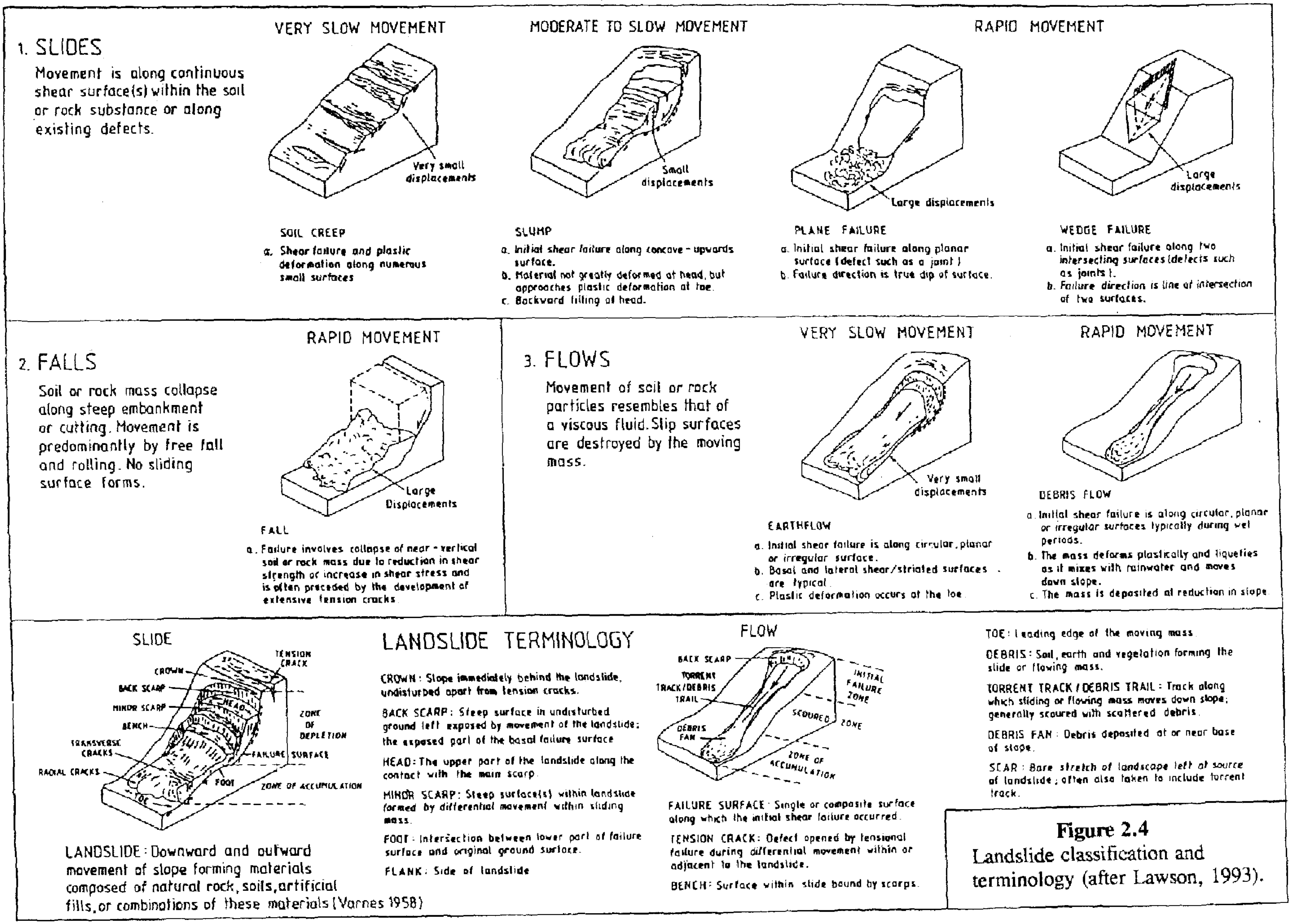
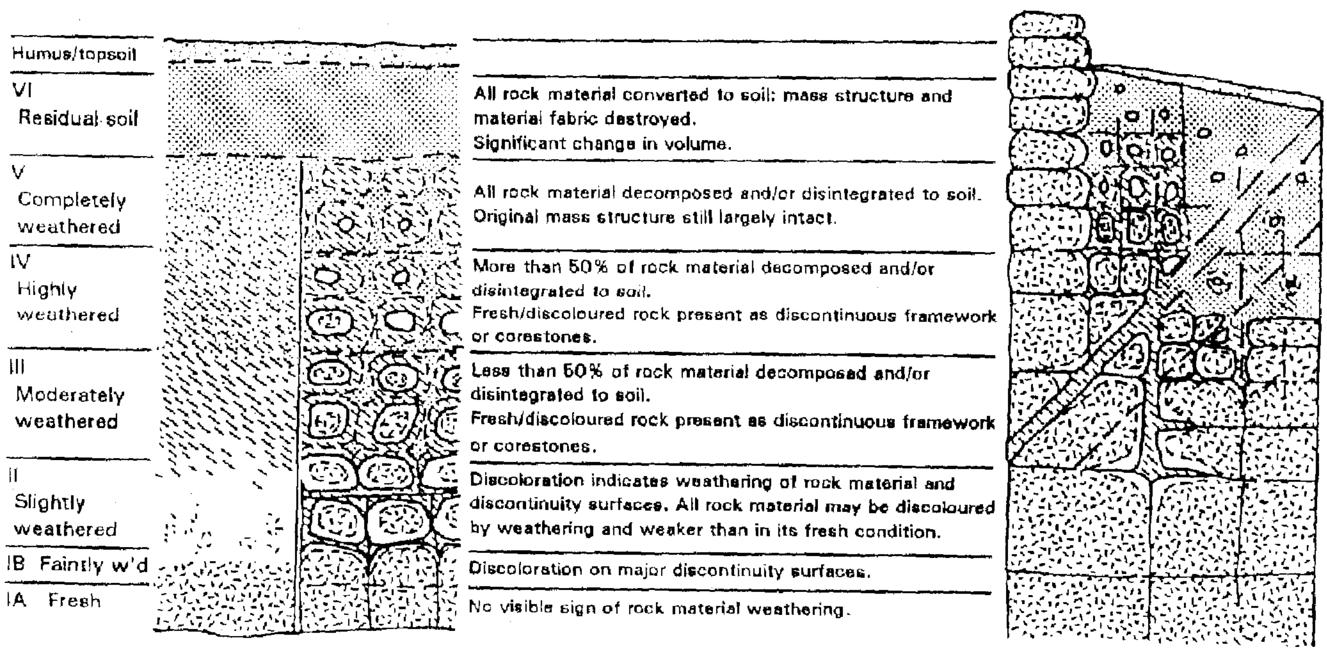


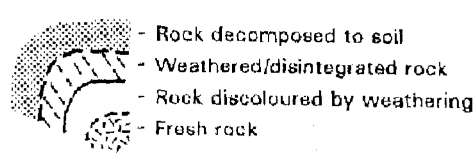
Figure 2.4
Landslide classification and terminology (after Lawson, 1993).

TERM	DESCRIPTION	GRADE
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.	II
Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.	III
Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI



A. Idealised weathering profiles - without corestones (left) and with corestones (right)

B. Example of a complex profile with corestones



locality. The specific term 'residual soil' is restricted here to describe material of weathering Zone VI, that is, near-surface material in which virtually all traces of the original rock mass structure are destroyed.

Rates of landslide movement are described as ranging from 'very slow' to 'extremely rapid'. Approximate quantitative movement rates pertaining to these terms are shown in Figure 2.6.

Based primarily on type of movement, Lawson (1993) recognised three main groups of landslides - slides, falls and flows - the identification of which is based largely on landslide morphology and arrangement of debris (Figure 2.4).

2.5.1.1 Slides

Slides involve the downslope movement of a rock, soil or debris mass occurring dominantly on surfaces of rupture or relatively thin zones of intense shear strain (slip, shear or failure surfaces) which may be curved or planar. Two main sub-divisions can be recognised: *rotational slides* and *translational slides*.

Rotational slides (slumps) are characterised by curved, concave-upward slip surfaces which impart a backward rotation or tilt to the slipping mass, which sinks at the rear and heaves at the toe. Movement typically ranges from slow to rapid. In relatively uniform materials (e.g. residual soil fills), the slip surface is generally circular. In natural slopes, the slip surface is usually controlled by lithological and strength boundaries or the presence of discontinuities such as bedding and joints, which may result in the slip surface being markedly non-circular. As a general rule, the slipped mass becomes more disrupted as the slip surface becomes more planar in character. In south east Viti Levu, relatively shallow slumps (generally less than 5 m in depth) occur mainly in thick, dominantly cohesive (clayey) sequences of residual soil or weathered regolith (weathering Zones IV-VI). Larger, deeper-seated slides may involve weathered rock (weathering Zone III). The backscarps of these slides following initial failure are usually steep, often sub-vertical, and multiple failure movements are common, resulting in a series of bench-like slip masses and scarps formed as rotational movement retrogresses upslope from the unsupported original backscarp.

Because of the concave-upward nature of the slip surface, slumps often reach a state of near-stability after only relatively small displacements. This usually results in most of the slumped mass remaining within the area of shear failure. Once stability is attained, slumps begin to rapidly degrade and acquire a vegetation cover (Figure 2.7). Shallow slumps, in particular, may rapidly degrade to innocent-looking grass or scrub-covered cross-slope hummocks or mounds which, if unrecognised, can be readily reactivated if the slope equilibrium is adversely altered by excavation or loading.

Translational slides involve movement along essentially planar shear surfaces, or zones, usually running sub-parallel to the ground surface and related to a layer of weakness or zone of contrasting strength within the slope. Rates of movement vary widely from very slow to rapid, depending mainly on the steepness of slope and type of material involved. In south east Viti Levu, translational slides are most frequent in the residual soils or granular weathered regolith overlying more competent rock, with the depth of failure largely controlled by the thickness of weathered debris (Figure 2.8). Howorth *et al.* (1980; 1993)

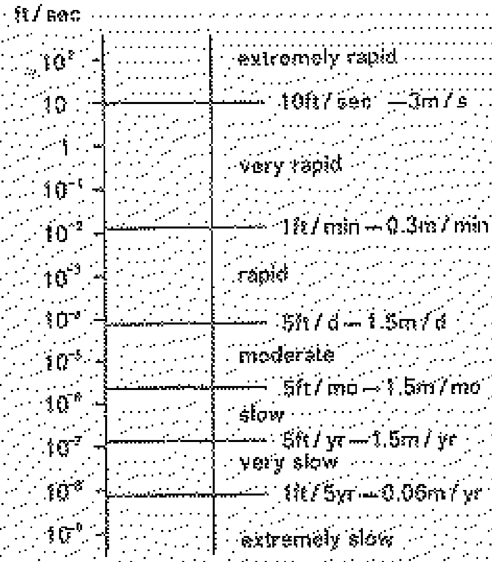


Figure 2.6 Rate of movement scale.
(after Varnes, 1978)

Figure 2.7 Multiple rotational slump in residual soil on unforested slope. The slump masses below the steep backscarp are rapidly degrading to rounded hummocks and attaining a vegetation cover. (Location: Serua Hills area)