

UNDERSTANDING FIJI'S SOILS



**Vilitati Seru¹,
Timoci Qeisene¹
Dave Leslie²,
Gerard Faber³**



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¹ Research Division, Koronivia Research Station; PO Box 77, Nausori, Fiji

² Landcare Research New Zealand Ltd; PO Box 40, Lincoln, New Zealand

³ Soil and Crop Evaluation Project; PO Box 77, Nausori, Fiji

Why a small booklet on a big subject? This commentary on the soils of Fiji is aimed at those who have to work in the landscape of Fiji and with its soils. Its aim is to provide the uninitiated with their first exposure to the many soil types that occur within the variable landscape of Fiji. Even those who regularly walk across the landscape do not always appreciate the degree of soil variability, often over short distances.

These notes are designed to provide information and establish guidelines so that those who work with the land can better understand the landscape and the soils that develop within it. The intent of this booklet is to enable you to comment with certainty on the possible soil types occurring in a landscape.

The purpose of this commentary is to provide:

- a basis for understanding the complexities of soil development, their properties and why they occur where they do;
- the tools that can advise those who till, build on, exploit and generally utilize soils and their special characteristics;
- guidance for sustainable soil utilization and practice; and,
- a foundation for using the soil identification key included in the Soils of Fiji (Leslie, 1997).

This booklet explains soils in a non-technical way. When you have completed the booklet and if you wish to know more about the soils of Fiji, extra information can be found in the reports and soil maps listed on pages 26 and 27.

To help you acquire the skills for identifying and understanding the place of soils in the landscape a series of exercises are included throughout the body of the text. These exercises are designed to make you *feel* soil and so *understand* soil. Or to paraphrase a current advertisement

SOILS AIN'T SOILS

What is then a soil? A useful early definition of soil was developed and introduced by the Russian school led by Dokuchaev in about 1870. They conceived soils to be

“independent natural bodies with properties that result from the effects of climate, and living organisms acting on parent materials over time as conditioned by relief”

Expanding this definition further, soil scientists in the U.S.A. (Marbut, 1921) developed a soil classification system using the following eight criteria to differentiate soils:

- The number of horizons present in the profile
- Colour of the various horizons with special emphasis on the first two
- Texture of the first two horizons
- Structure of the first two horizons
- Relative arrangements of the horizons
- Thickness of the horizons
- Chemical composition of the horizons
- Geology of the soil material as indicated by the parent material

Exercise 1.

List any information relevant to the above eight criteria for the soil that your house is built on.

It is from similar information lists that soil scientists came to understand the characteristics of soils and advanced theories as to their genesis and development.

Jenny (1961) re-examined the soil-forming factors and reduced them to three factors:

- the initial state of the soil system;
- the climatic and organic factors which control the supply and loss of energy to and from the system;
- the third factor, which was time.

Simonson's (1959) generalised theory of soil genesis put forth the concept that soil development involved additions, removals, transfers and changes of soil materials. Thus, in contrast to Jenny's concept, it provides a useful framework within which to consider the processes of soil formation and change. In addition it allows for these processes to be considered alone or in combination. It allows users and managers of soil resources to understand how these processes act.

Simonson recognised that the same processes take place in all soils and that the soil formed is the result of the interaction and effect of many processes acting over time. These concepts are

“consistent with the sharing of some properties by all soils”

and show

“the common lack of sharp boundaries between one soil and the next”

So can we be present at the birth of a soil? - the time zero after which the processes which shape the soil act.

Exercise 2.

In the steps of soil formation what events (processes) would you see operating at time zero?

So there are events (processes) which mark the conception and subsequently the birth of a new soil. The new soil will, as Dokuchaev noted, be an

independent natural body with properties that result from the effects of climate, and living organisms acting on the parent material over time as conditioned by relief; with the processes which Simonson recognised all interacting over time to form the new soil.

So while Dokuchaev noted its independence, Simonson recognised the multiplicity of processes for change and Marbut developed a classification system, others (Jenny, 1941) endeavoured to formalise the process of soil formation.

Exercise 3.

At the stage of soil birth, list one item for each of independence, multiplicity and classification.

The model popularised by Jenny (1941) recognised the complexity of the system and allowed the soil scientist to consider one, some or all of the soil forming influences. The model identifies five soil forming factors. These are:

- climate (C_i);
- organisms (O);
- topography (R);
- parent material (P); and
- time (t)

This model is commonly expressed as the factorial equation

$$S = f(C_i, O, R, P, t, \dots) \quad (\text{equation 1})$$

where the dots (.....) indicate additional but unspecified factors. These factors define the soil system in terms of the variables that influence the characteristics that identify the soil within a classification system. However, it does not address the processes, causes, or forces continuously active in the soil system. For this Jenny (1961) reduced his model to a three factorial equation and thus broadened its applicability. These were:

- initial status of the system (L₀)
- potential change to the system (P_x) and
- age of the system (t)

giving the equation

$$S = f(L_0, P_x, t) \quad (\text{equation 2})$$

Exercise 4.

What are some characteristics of the soil in exercise 1 that you can relate to any of the three factors above?

Were we there for soil when it all began? There are current events which allow us to be present at time zero for soil. However for most soils this is not possible and equations 1 and 2 above allows the soil scientist to evaluate any soil in terms of its past, its present and its future. This is important when, for example, the effect of a given land use is being studied over a period of time.

Exercise 5.

Give an example of a land use where the past, present and the future could be determined using the above concepts.

Thus, L₀ includes all five soil forming factors as described above at the time 'now'; P_x includes all five soil forming factors at some past or future time, and represents those factors not defined for a specific soil or time; and t is the time between the two observations.

These additional unspecified factors may be either continuous, intermittent or one-off but are due to vegetation, animal and human inputs into the soil system. Furthermore, many of these factors can be reduced to smaller components. For example, in the case of climate (C_i) these are solar radiation, heat transfer, gaseous diffusion, water flow, colluviation and for

organisms (O) biotic migration. These factors are external to the information by which soils are classified.

Exercise 6.

List further unspecified soil-forming factors.

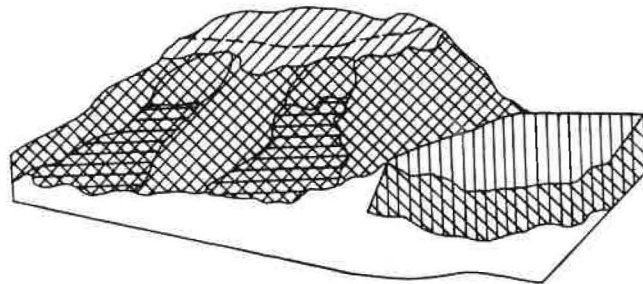
So how do budding soil scientists come to grips with the soils of the landscape in which they work? The landscape is what is seen when you step out of the door; when you take the bus to work; when you go on leave and when you fly across Fiji.

Exercise 7.

Draw a familiar landscape and the soils in it.

Where are the soils in the landscape? In the landscape shown in Figure 1 certain features are easily seen and understood. These landscape features are the tools used to develop the soil map.

Figure 1. Koronivia hill and plateau landscape

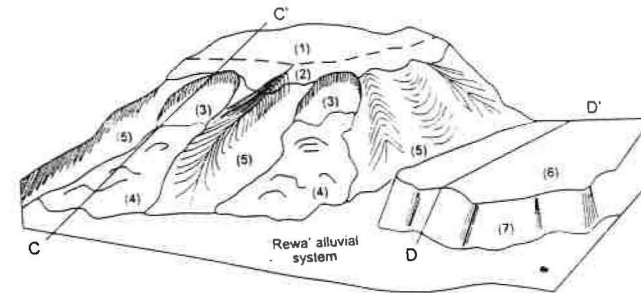







Landscape members

- | | | | |
|--|--------------------------------------|---|---------------------------------------|
|  | Alluvium |  | <i>In situ</i> weathered acidic tuffs |
|  | Erosional debris |  | Colluvium |
|  | <i>In situ</i> weathered basic tuffs | | |

The prominent landscape features in Figure 1. are the visual markers that a soil scientist uses for locating primary boundaries between soils. The landscapes in which Simonson worked lacked sharp boundaries between one soil and another implying that each soil grades into the next.

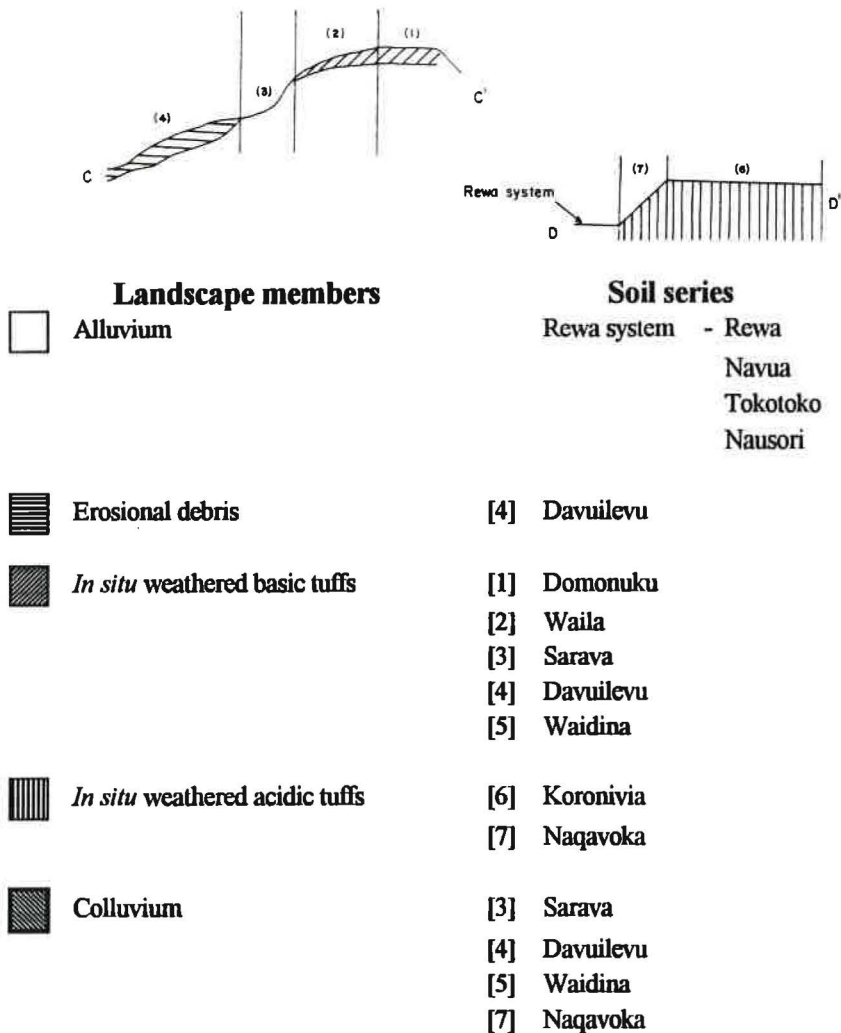
Figure 2. Koronivia hill and plateau landscape soil series sequence



- | Landscape members | | Soil series | |
|---|---------------------------------------|-------------|-----------|
|  | Alluvium | Rewa system | - Rewa |
| | | | Navua |
| | | | Tokotoko |
| | | | Nausori |
|  | Erosional debris | [4] | Davuilevu |
|  | <i>In situ</i> weathered basic tuffs | [1] | Domonuku |
| | | [2] | Waila |
| | | [3] | Sarava |
| | | [4] | Davuilevu |
| | | [5] | Waidina |
|  | <i>In situ</i> weathered acidic tuffs | [6] | Koronivia |
| | | [7] | Naqavoka |
|  | Colluvium | [3] | Sarava |
| | | [4] | Davuilevu |
| | | [5] | Waidina |
| | | [7] | Naqavoka |

Therefore there is a transition zone between soils where the characteristics of the adjacent soils both exist. In a landscape these can be seen and identified as changes in either the landform, relief and/or the vegetation. Thus for the Koronivia hill and plateau landscape (Figure 2.) the soil map shows the relationship of the soils to the profile (landscape) with the transects CC¹ and DD¹ (Figure 2 and 3.).

Figure 3. Koronivia hill and plateau landscape soil series transects



The soil series names in Figure 3. above are those used by Twyford and Wright (1965) and Leslie (1984) and relate to the sites at which they were described as keyed out by using Figures 8. and 9. Soil series are now identified and classified using a universal system developed by USDA Soil Survey Service. The relationship between the system developed by Twyford and Wright (1975), FAO and USDA is given in Soils of Fiji (Leslie, 1965).

In the landscape shown in Figure 4., it is possible to identify several physical features.

Figure 4. Landscape near Waibau, Viti Levu



Exercise 8.
Using tracing paper mark the prominent landscape features and possible soil boundaries. Then compare your tracing with the landscape features and possible soil boundaries shown in Figure 5..

Figure 5. shows the same landscape, as shown in Figure 4., but with the landscape features and possible soil boundaries marked. Such initial identification can also be done using aerial photographs.

Figure 5. Landscape near Waibau showing prominent landscape features and possible soil boundaries.



This analysis of a landscape allows the observer to begin to develop a picture, and begin to understand the relationships between landscapes and the soils within them. This was done to get from Figures 1. to 3. and similarly to derive Figure 5. from Figure 4..

Exercise 9.

What was it that Simonson said? Do you remember?

The skill in identifying soils in landscapes is through practice.

Exercise 10.

Draw a landscape with possible soil boundaries from one of your own photographs.

Parents and their soils - are the relationships obvious? Geologically, the islands of Fiji are formed from igneous, metamorphic and sedimentary rocks. They have evolved through a series of major tectonic events followed by varying episodes of erosion, deposition, and uplift. The islands of Koro, Taveuni and Rotuma are geologically recent volcanic arrivals. With significant variation in rock types (soil parent materials) it is understandable that Fiji has a diverse range of soils. There are clear lines of connection between parent (rock) and soil. Important parent material characteristics include the degree of consolidation or induration (related to mode of deposition), texture, and mineralogy. Types of soil parent materials occurring Fiji are given below -

Parent rocks are divided into three main classes : igneous, sedimentary and metamorphic, depending on how they have formed. Rocks from all three classes are important contributors to soil parent materials in Fiji.

- **Igneous rocks** are formed from magma which crystallises on cooling to form an aggregate of predominantly silicate minerals. Some igneous rocks are formed by the cooling of molten magma below the earth's surface and are referred to as plutonic igneous rocks. Others are formed by the eruption of magma at the earth's surface, i.e., volcanic igneous rocks. Volcanic rocks include the lavas which are erupted in molten form. Volcanic material erupted into the atmosphere and deposited on the surface of the land as airfall material is referred to as tephra.

All igneous rocks consist of assemblages of individual crystals of various minerals. Plutonic rocks have coarse crystal grain size and volcanic rocks are fine grained due to these different rates of cooling.

Different rock types are recognised on the basis of their crystal grain size and mineralogical composition. Broadly these rock types are separated into acidic (granites, rhyolites) and basic (gabbros, basalts) rocks. Acidic rocks are high in silica and aluminium and basic rocks are high in iron and magnesium.

- Sedimentary rocks are formed by compaction and cementation of sediments laid down mainly in marine environments. They contain material that has already undergone one or more cycles of weathering, transportation, deposition and consolidation. For this reason, the most easily weathered minerals found in igneous rocks are often absent from sedimentary rocks. These rocks have different particle size classes and mineralogies and in Fiji include conglomerates, sandstones, siltstones, limestones, marls, etc.
- Metamorphic rocks are formed by the action of heat or pressure, or both, on pre-existing igneous or sedimentary rocks. In Fiji they include gneisses and quartzites. During metamorphism, existing minerals may be altered, new ones formed, and the fabric of the rock transformed with alternating bands of minerals. These rocks vary in crystal/grain size and mineralogy depending on the type of rocks metamorphosed and the degree of metamorphism.

Exercise 11.

List twenty (20) words from the section **Parents and their soils** and write down their definitions.

Soil parent materials

The general distribution of different types of soil parent material (i.e., parent rock and debris mantle regoliths) in Fiji is quite complex. Soils in the hill country in general are formed in regolith derived directly from the underlying parent rock or in material moved relatively small distances downslope under the influence of gravity (colluvium). Some soils in Fiji

are developed in unconsolidated debris mantle deposits, for example, most soils in Taveuni, Rotuma, and part Koro develop in volcanic tephra. Soil formation can be strongly influenced by the nature of such deposits.

- Colluvium refers to deposits that accumulate on and at the base of slopes as a result of movement by gravity. Such deposits result from a build-up of unconsolidated material which eventually becomes unstable and moves downslope. Colluvium often shows evidence of successive periods of deposition (layering, including buried soils).
- Alluvium refers to sediments deposited by streams and rivers. The particle size of alluvial deposits vary greatly from stones/boulders to fine silts/clays. Stones in the deposits are usually rounded. Alluvial deposits often consist of layers of different textured material, for example, sand and silt layers overlying coarse gravels. Such deposits are common soil parent materials in Fiji's major river systems - Nadi, Sigatoka, Navua, Ba, Rewa, Dreketi, etc.
- Marine sediments refers to deposits that occur in both the tidal and non-tidal zones and comprise coralline sands and sediments 'trapped' in the mangrove ecosystem.

All of these soil parent materials vary in particle size and mineralogy and their modification into a soil will also reflect climatic influences. Climate is one of the key influences that modify soil parent materials.

Exercise 12.

Identify and name areas in Fiji where you may find some of the parent materials discussed above and name a few of them.

Soil scientists have invested considerable time studying and evaluating the relationship between soil parent material and soil; and even greater resources into understanding the processes and the components that 'create' Fiji soils.

For example, soils of the mangrove ecosystem in Fiji have been 'developed' for irrigated rice and elsewhere for residential/industrial purposes and for disposal of waste; without any appreciation (by 'developers') about the sensitivity of these acid sulphate soils and their (extreme) biological and chemical potential for change as a result of disturbing the delicate soil moisture regime through drainage.

Exercise 13.

Name an area in Fiji where this has or is occurring.

The development of a new soil after a natural, albeit unexpected event, such as the deposition of a blanket of volcanic ash, or the dumping of freshly dredged materials on a land disposal site by man, will reflect the properties of the parent material. As a soil ages inherited properties usually become less obvious, as the environmental factors (climate and organisms) change the soil. Thus, the direct effects of the parent material are more obvious and important when soils are young and less so as soils age. Resistant minerals, such as quartz, remain unaltered even when the soil is very old.

The mineral transformations that occur in soils are the subject of many papers, books and treatises.

Does position in the landscape change a soil? Relief, the 'up-hill' or 'down-hill' or shape of the landscape is an influence that acts as a modifier of other factors during soil formation. It can be an initial factor that is in place before soil formation begins, similar to the role that parent material plays. However land surfaces like soils evolve over time, and it is generally impossible to dissociate these. Ruhe (1960) stated that

“the point of departure for any study leading to a better understanding of soil, should be the recognition and evaluation of the elements of the landscape, and the relationships of soils to them”

and noted its recognition in the soil survey manual (Soil Survey Staff, 1951) as

“soils are landscapes as well as profiles”

Major effects of topography or relief on soils in the landscape include:

- local soil associations and the distribution of soils;
- surface and soil moisture distribution;
- erosion and alluviation patterns;
- surface and soil temperature variation caused by aspect and slope orientation; and,
- interaction between temperature and moisture due to altitudinal variation resulting in zonation.

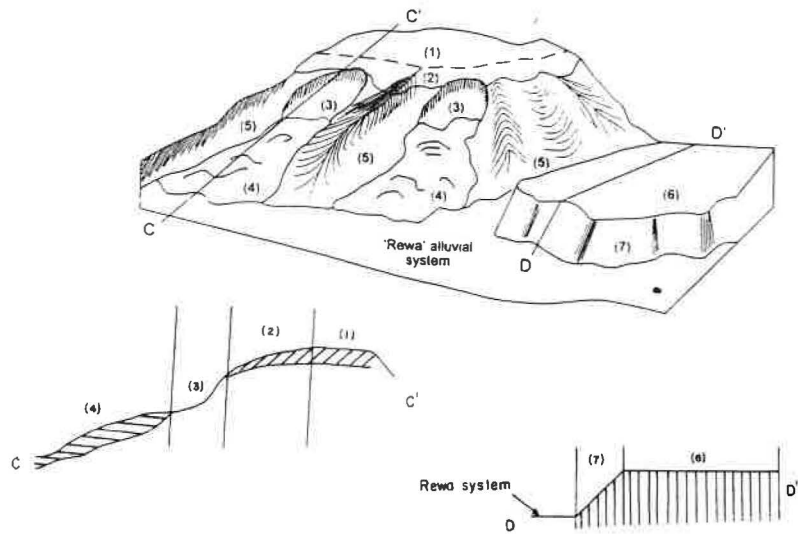
The altitude or elevation effects is also thought of as a climatic effect (Jenny, 1980).

Exercise 14.

Name a location where an altitude effect as described above can be seen. Do you know at what altitude this occurs?

Hill slope models generally follow the geomorphic concepts of Ruhe (1975). These models emphasise the erosional and depositional patterns observed in landscapes, with the summit considered the most stable and the oldest and more developed soils (Figure 6.).

Figure 6. Koronivia hill and plateau slope with soil series sequence



The convex shoulder position (see [2] Figure 6.) is considered highly erodable but may be absent if the retreating slope is a vertical face over which the major process is continuous or seasonal water dispersion and water borne material from further upstream. The backslope may be characterised by the presence of a low hummock microrelief (Hall, 1983). Such a topography has an overall convex slope with a distinct shoulder and a concave footslope (see [3] Figure 6.). The material eroded and then deposited in a mid-slope-footslope (see [4] figure 6.) assemblage can become unstable because of variability in microrelief. The presence of old buried soils (paleosols) is likely. The deposition is often dominant on the toeslope (see [4] Figure 6.). In some cases additional alluvial material from seasonal floodwaters may also be added from a major stream moving through the valley.

Landscape members	Soil series	Description
Alluvium	Rewa series Rewa	Fluventic Eutropept
	Navua	Fluvaquentic Eutropept
	Tokotoko	Aeric Eutropept
	Nausori	Typic Eutropept
Erosional debris	[4] Davuilevu	Aquic Eutropept
<i>In situ</i> weathered basic tuffs	[1] Domonuku	Typic Humotropept
	[2] Waila	Typic Humotropept
	[3] Sarava	Lithic Humotropept
	[4] Davuilevu	Aquic Eutropept
	[5] Waidina	Typic Eutropept
<i>In situ</i> weathered acidic tuffs	[6] Koronivia	Homoxic Tropohumult
	[7] Naqavoka	Typic Tropohumult
Colluvium	[3] Sarava	Lithic Humotropept
	[4] Davuilevu	Aquic Eutropept
	[5] Waidina	Typic Eutropept
	[7] Naqavoka	Typic Tropohumult

Exercise 15.
Which land systems in Fiji can the above topographical effects be observed? Name them.

So what is a soil? Let's remind ourselves what a soil is by repeating Dokuchaev's definition

“independent natural bodies with properties that result from the effects of climate, and living organisms acting on parent materials over time as conditioned by relief”

noting that from this start point Marbut developed a classification system for soils based on the soil profile using the following eight properties to differentiate soils:

- The number of horizons present in the profile
- Colour of the various horizons with special emphasis on the first two
- Texture of the first two horizons

- Structure of the first two horizons
- Relative arrangements of the horizons
- Thickness of the horizons
- Chemical composition of the horizons
- Geology of the soil material as indicated by the parent material

So what is a soil profile? A soil profile is a description of the prominent physical features of the horizons exposed when a soil pit is dug. The effects of the external attributes of the soil, or site characteristics, are reflected in the morphology of the soil profile which is a vertical section of the soil through all its horizons and extending into the parent material or other layers that influence the genesis and behaviour of the soil. A soil profile thus describes a series of measurable morphological features for each horizon recognised in the profile. The profile description is presented in a standard sequence

- horizon designation
- horizon thickness (cm)
- colour (names and Munsell notation)
- texture
- consistence
- structure (grade, class, type)
- mottles, concretions, coatings (colour, size, distinctness)
- roots (abundance, size)
- etcetera
- horizon boundaries (shape, distinctness)

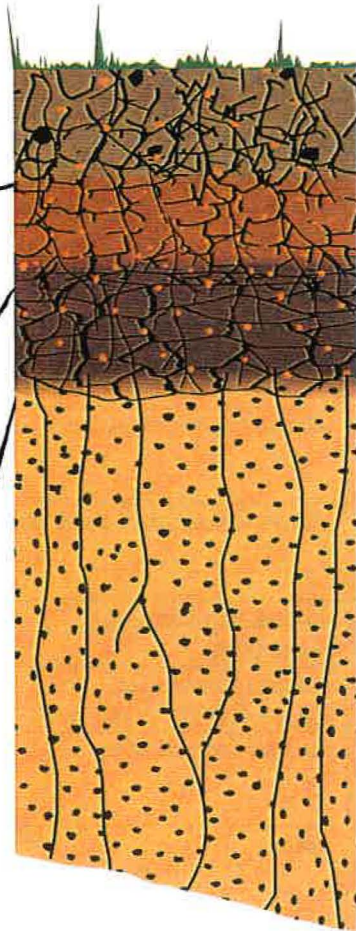
What is meant by ?

horizon designation	= soil profiles are made up of master horizons (O, A, B, C, and R) with subhorizons designated by subscripts (e.g., B ₁)
horizon thickness (cm)	= the vertical distance between the top of one horizon and the next below
colour (names and Munsell notation)	= reddish-brown (2.5 YR 5/4) where 2.5YR denotes the hue, 5 the value, and 4 the chroma
texture	= the feel of the soil and reflects the proportions of sand-silt-clay particles that make up the soil. Sandy soils are gritty; silts are smooth; clays are sticky or plastic when moist
consistence	= reflects the force required to break up a soil by hand. Soils are loose if the clod easily falls apart; friable if minimal pressure is required to break it up; firm/very firm as more force is required
structure (grade, class, type)	= the shape, size, degree of development of the soil aggregates; it also describes the voids (porosity) between soil aggregates
mottles (colour, size, distinctness)	= highlights of colour, other than the colour described above, within the matrix of the horizon
concretions (colour, size, distinctness)	= concentrations of insoluble mineral fragments
coatings (colour, size, distinctness)	= on all or parts of the soil structural surface. Often from clay or humus
roots (abundance, size)	= indicates the depth to which roots penetrate (the root zone) and their shape, size and abundance within a horizon
etcetera	= other features which are specifically noticeable at the time of the soil survey and profile description, e.g., coarse particles
horizon boundaries (shape, distinctness)	= the description of the sharpness or otherwise and shape of the boundary between adjacent horizons

The above is put into practice when describing the Matavelo clay (Figure 7.).

Figure 6. Soil Profile and Description of Matavelo Clay

<p>A_p (0-20cm)</p>	<p>Yellowish-brown (10YR 5/4) clay; friable, slightly sticky; weakly developed coarse blocky structure; many coarse reddish-yellow (7.5YR 6/8) mottles; common black (10YR 2/1) manganese nodules; many fine fibrous roots; diffuse boundary,</p>
<p>A_B (20-35cm)</p>	<p>Dark brown (10YR 3/3) clay; firm, slightly sticky; weakly developed coarse nut structure; common fine reddish-yellow (7.5YR 5/6) mottles; few fine fibrous roots; diffuse boundary,</p>
<p>B_{g1} (35-60cm)</p>	<p>Very dark greyish brown (10YR 3/2) clay; very firm, slightly sticky; slightly plastic; strongly developed coarse blocky (tending prismatic when dry) structure; common small distinct reddish-yellow (7.5YR 6/8) mottles; few fine fibrous roots; diffuse boundary,</p>
<p>B_{g2} (60-120cm+)</p>	<p>Yellow (10YR 5/8) silty clay; very firm, very plastic; massive; common medium distinct grey (2.5YR 7/0) mottles.</p>



Do soils drink, or just let water pass through them? An important question when considering the role and cycle of water in the landscape. Though the question is critical in the study of plant growth, in soil formation

the importance of water lies in the role it plays in particle and solute movement, chemical dissolution, and weathering. Soils behave as sponges with water absorbed, moved on down or through the horizons to become part of the groundwater at depth, or seeping out on the surface at various points on a slope (these are usually intermittent and seasonal).

So what are the influences of water in the landscape and in the soil? In the landscape, free water is involved in moulding the physical features - and so changing the shape and general relief. In soils, free water occurs only where the input exceeds the storage capacity of the soil. Excess water percolates under gravity down to the groundwater or horizontally through a permeable horizon down slope.

Soil water moving through the soil is responsible for the distribution and accumulation of soluble salts, carbonates, organic matter, clays and oxides within the profile because of changing solubility or porosity at sites conducive for their deposition (i.e., voids, pores, above impermeable layers, etc.). Plant nutrients are similarly moved in solution within the soil profile and their availability within the root zone, for plant growth is an interaction between soil physical properties, soil chemistry and soil water content.

In areas experiencing seasonal moisture deficits water can commonly rise through the soil profile and with it soluble salts. This can lead to salinisation of the soil, a change in pH and availability of nutrients.

Ponded water on the soil surface is an indication of a high water table, poor infiltration and percolation. Waterlogging can lead to reduction/oxidation changes in the anaerobic (no air within the profile) soil again changing soil pH and nutrient availability.

Exercise 16.

Name an area in Fiji where some of the events that relate to water movement in the soil may occur. Do you know the name for this type of soil at that location?

Knowing the profile description of a soil, can we classify it? and answer yes. As mentioned before there are a number of soil classification systems available. The most universal system is Soil Taxonomy (Soil Survey Staff, 1975) and MAFF&A adopted this system for Fiji in 1981. A series of simple steps by which the name of a local soil series can be identified and is outlined for soils of the hilly land (Figure 8) and soils from alluvium (Figure 9). With this information a more complete characterisation and classification can be obtained by referring to Soils of Fiji (Leslie, 1997).

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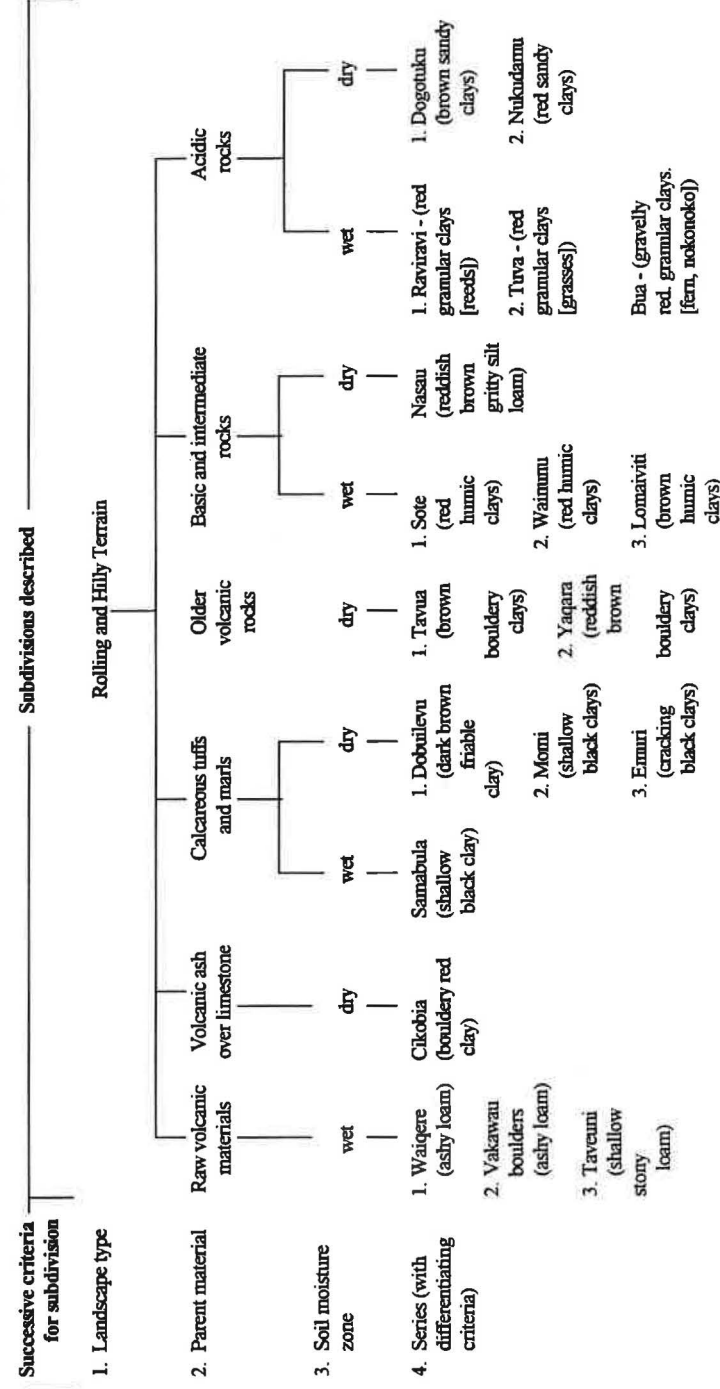


Figure 8. Soils of Rolling and Hilly Terrain : Criteria for Subdivision and Subdivisions described

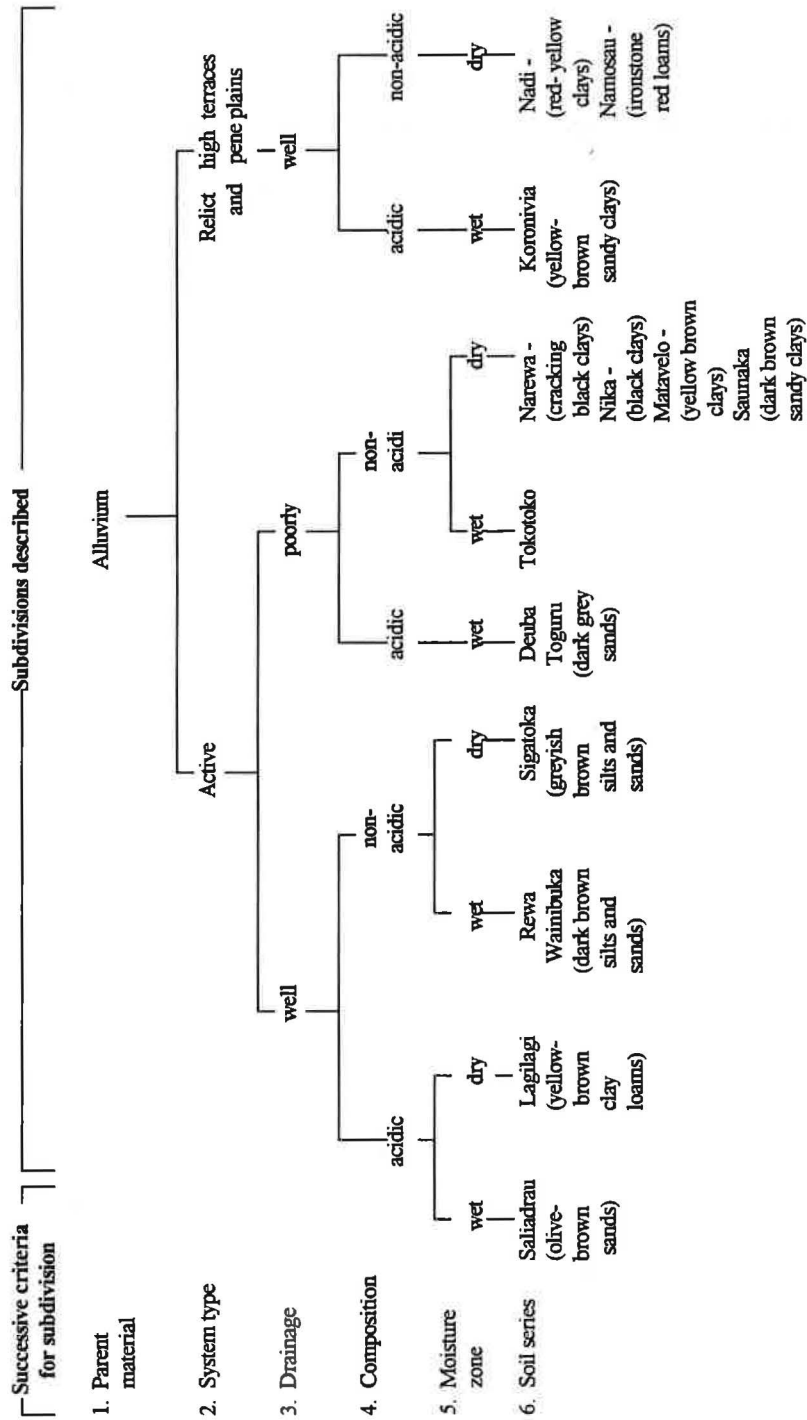


Figure 9. Alluvial Soils : Criteria for Subdivision and Subdivisions Described

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