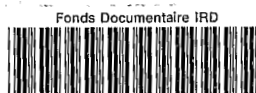


UNESCO/UNFPA Fiji ISLAND REPORTS No. 5 (Canberra, ANU for UNESCO), 1979

## 5.2 THE NATURAL ENVIRONMENT OF LAKEBA

M. Latham  
(ORSTOM, Noumea, New Caledonia)

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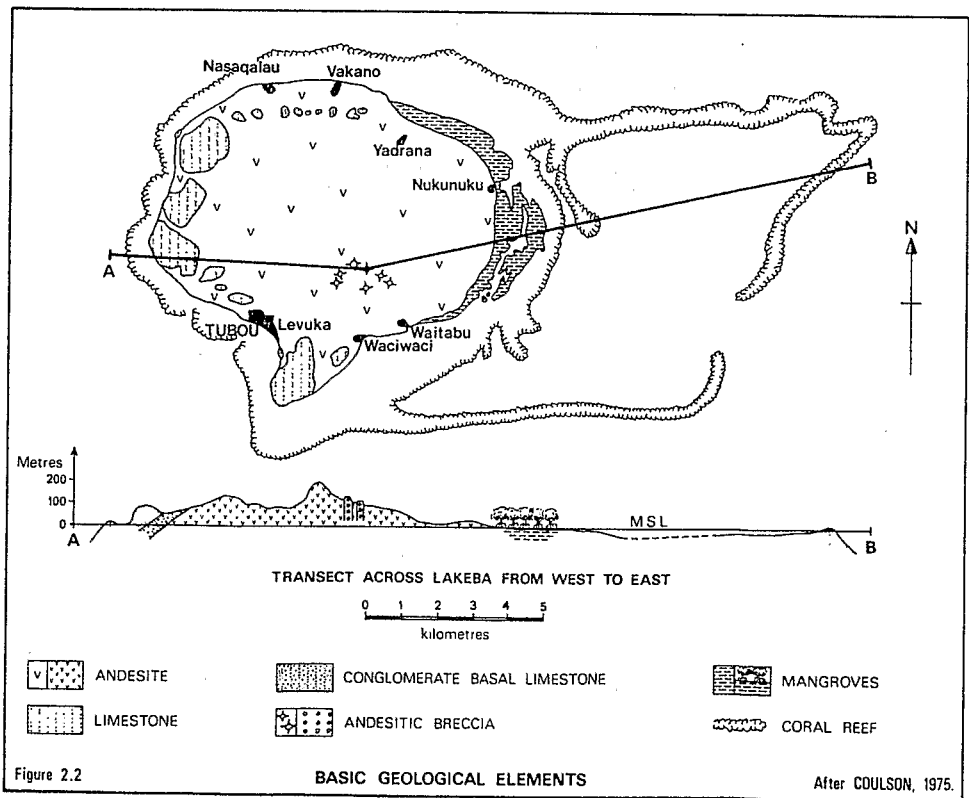
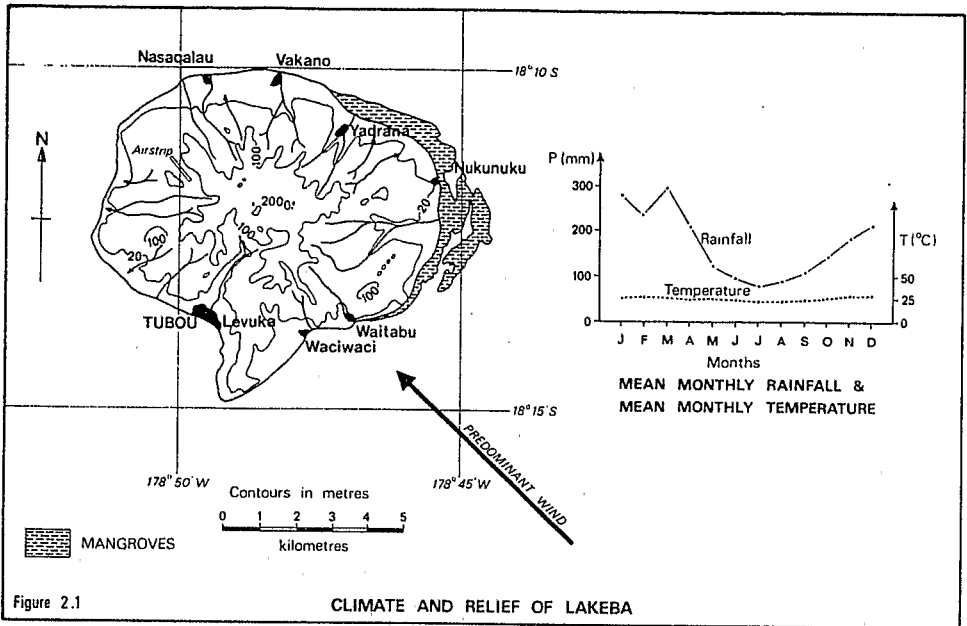
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INTRODUCTION

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## I - CLIMATE, GEOLOGY AND GEOMORPHOLOGY

## INTRODUCTION

This paper reports the first comprehensive survey undertaken of the natural environment of Lakeba. As elsewhere in eastern Fiji, most early work in this area was done by geologists, in particular Gardiner (1898), Ladd and Hoffmeister (1945) and most recently Coulson (1975). The soil and vegetation survey by Twyford and Wright (1965) offers only a reconnaissance sketch of Lakeba, and the botanical material consists only of a few floristic reports at various dates since the 1860s (Parham, 1972). All descriptions of the island in these accounts emphasize the Mio-Pliocene volcanic core and its partial limestone integument, and the great depth of weathering in the volcanic areas, combined with barren soils and a heavily degraded vegetation. Lakeba provides one of the most striking instances of the degraded soil-vegetation complex widely known in Fiji by the name of talasiga<sup>1</sup>, and it was for this reason that the island was selected as an area of concentration by the project.

At the descriptive level, the first conclusion to be drawn from the ecological survey carried out in 1975 and 1976 is that these earlier descriptions conceal very considerable complexity. Indeed, of all the islands studied by the project, Lakeba is ecologically by far the most intricately varied. Moreover, the impress of human activity has had a major role in creating the present mosaic of land types and ecosystems, and in this respect also Lakeba is distinctive in the degree to which human modification of the original condition has moulded the present aspect of the island.

## A VARIABLE TROPICAL CLIMATE

Lakeba has a tropical oceanic climate characteristic of the trade-wind belt (Table 2.1). Rainfall data indicate a moderate seasonality, but mean values mask very considerable year-to-year variation (Table 2.2). Over the ten years from 1966 to 1975 the annual total ranged from just over 1000 mm to more than 3000 mm. Particularly interesting are the changes in both intensity and time of dry periods in this short record. If we assume that the P/E in this area is likely to be over 100 mm/month, it is evident that the annual distribution of dry periods is in a high degree unpredictable. While deficit months occur most frequently in the May to September period, no less than ten 'dry' months occur outside these limits in this one decade alone.

Drought, deluge and hurricane

The data in Table 2.2 show monthly rainfall totals from half a millimetre to almost half a metre within a period as short as ten years. Over a 15 year period, the island has been afflicted by five droughts of more than four months' duration, sometimes in successive years. In 1966 only 158 mm

---

<sup>1</sup> In Fijian, the term talasiga means 'sun-burnt land' (Parham, 1972). The term designates both a pyrophytic vegetation complex dominated by ferns, often in association with *Casuarina equisetifolia*, and also the very degraded and often eroded soils which support the complex. It is used here as a generic term for the complex as a whole.

TABLE 2.1: MONTHLY MEAN RAINFALL AND MAXIMUM AND MINIMUM TEMPERATURES AT TUBOU

	MONTH												ANNUAL
	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Rainfall (1950-1975)	274	239	296	205	120	94	77	88	103	144	183	206	2026 mm
Max. temp. (1971-1975)	29.8	30.0	30.1	29.0	28.3	27.7	26.7	25.9	27.6	28.2	28.8	29.8	28.5°C
Min. temp. (1971-1975)	23.3	23.1	22.6	22.4	22.3	22.2	21.5	21.3	22.1	22.6	23.3	23.6	22.6°C

Data: Meteorological Service, Suva.

TABLE 2.2: MONTHLY RAINFALL AT TUBOU, 1966-1975.

YEAR	MONTH												ANNUAL
	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1975	367	243	311	154	<i>65</i>	<i>85</i>	137	<i>73</i>	261	123	360	181	2360
1974	274	438	263	315	258	<i>59</i>	<i>76</i>	310	139	406	132	262	2932
1973	<i>59</i>	150	161	522	<i>86</i>	<i>77</i>	113	<i>18</i>	136	<i>82</i>	259	163	1826
1972	242	270	231	179	122	<i>49</i>	131	125	101	<i>34</i>	119	202	1805
1971	250	434	331	216	187	143	<i>42</i>	129	136	276	521	369	3034
1970	280	155	206	<i>72</i>	114	179	105	<i>9</i>	105	196	153	185	1759
1969	172	190	371	133	<i>19</i>	<i>0.5</i>	<i>68</i>	<i>3</i>	142	224	<i>71</i>	<i>71</i>	1465
1968	470	114	382	<i>61</i>	104	157	<i>57</i>	<i>29</i>	<i>53</i>	<i>85</i>	183	162	1857
1967	438	168	367	164	<i>76</i>	<i>33</i>	<i>24</i>	<i>14</i>	<i>91</i>	248	<i>9</i>	<i>27</i>	1659
1966	123	104	126	201	<i>33</i>	<i>37</i>	<i>33</i>	<i>40</i>	<i>17</i>	120	<i>46</i>	168	1048

(*Italicized* - Months with less than 100 mm)

Data: Meteorological Service, Suva.

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were received during the five months from May to September, and in 1969 only 89.5 mm in the four months from May to August. Three dry periods longer than two months in duration intervened between these larger events. The effect of drought of this order would be to dry up most springs and small rivers, and starve much of the taro crop of water. Widespread fires are also most likely to occur during these long dry periods. Furthermore, much of the rainfall takes place in the form of heavy showers; Bayliss-Smith (1977, p. 67) notes that during a period of 195 months from 1959 to 1975, 61 per cent of the rain days experienced falls of 25 mm or more; the heaviest daily fall recorded in this period was 224 mm.

In the long term, therefore, the ecological effect of drought and deluge in this island is likely to be considerably greater than that of the rare but violent cyclonic storm, although the project placed emphasis on the latter in its inquiries because of the heavy impact of one major cyclone on Lakeba in early 1975 (Bayliss-Smith, 1977; M. Brookfield, 1977). While cyclonic depressions are frequent visitors to eastern Fiji, the intensity of wind and rainfall in them is very variable (McLean, 1977). A violent storm does, however, do great damage to vegetation, and the torrential rain causes rapid erosion of the soil and floods in the valleys.

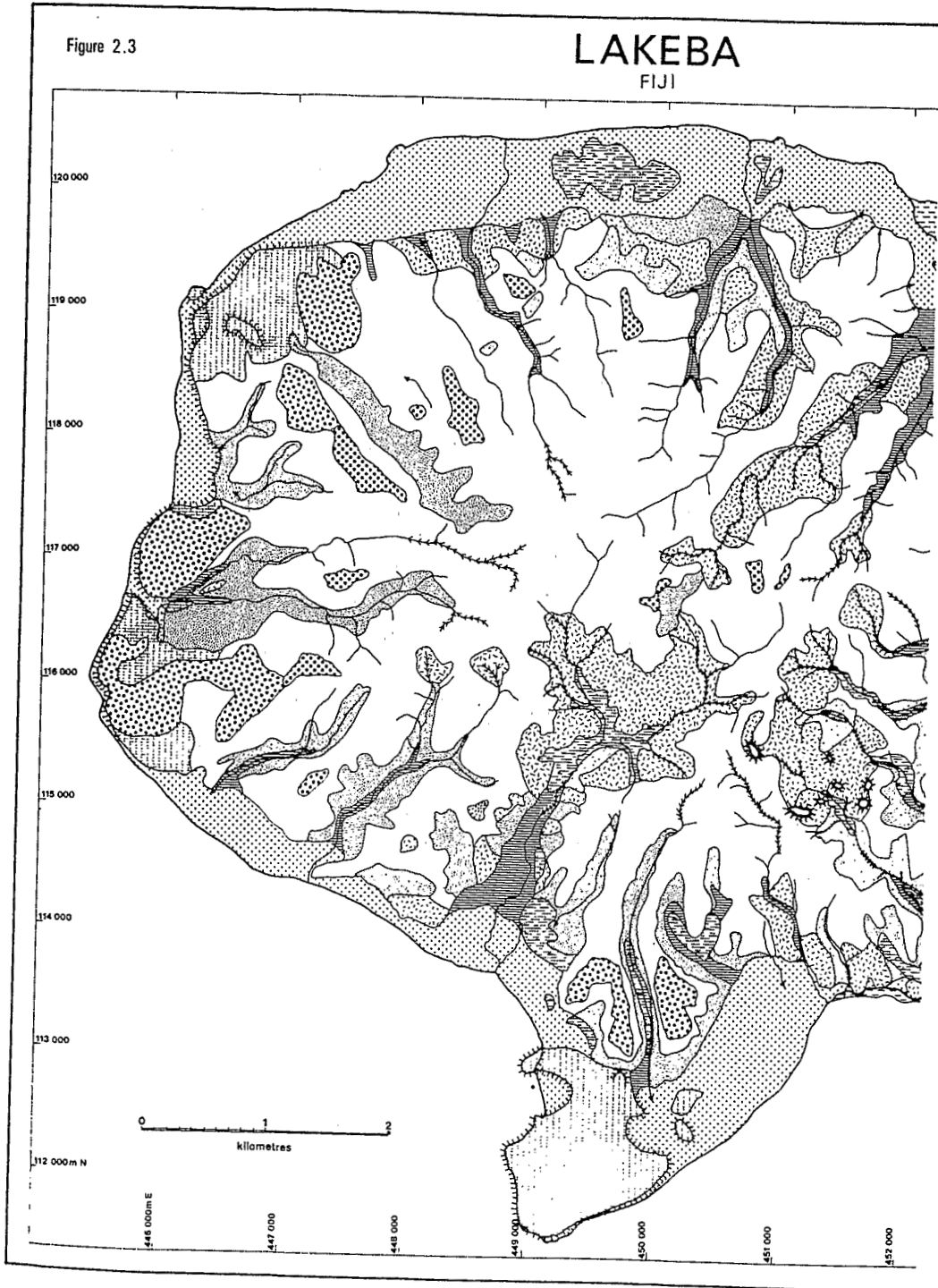
The only meteorological information available for Lakeba is collected at Tubou, almost at sea level on the south coast (Fig. 2.1). The effect of relief and aspect can only be inferred, although the planned erection of a UHF transmitter and receiving station in the centre of the island will in time yield such information, since a rain gauge will be installed as on Taveuni in 1976. The effect of topography is certainly much less than that on Taveuni, for the island is far smaller, and its highest point reaches only 220 m. 'Fiji Air' pilots, however, remark on fairly regular differences between information provided by the station at Tubou and the weather conditions encountered at the airstrip, in a valley on the leeward northwest side of the island. Examination of the vegetation suggests that the high ground in the centre of the island may receive more rainfall than the coast, and the build-up of cumulus cloud over the centre of the island is visible evidence of an orographic effect to be seen on most days of the year. However, the island is too small to experience large differences in climate between different parts of the whole.

#### GEOLOGICAL SIMPLICITY OF LAKEBA

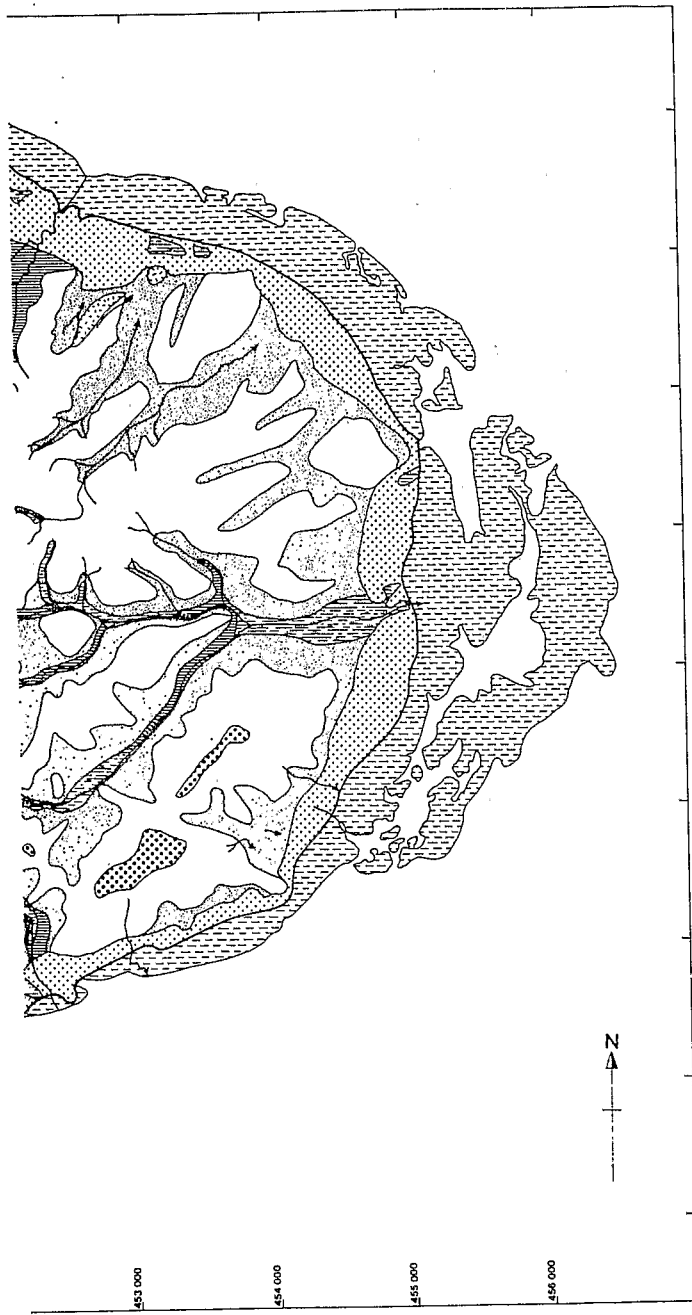
The geological substratum of Lakeba is very uniform. The island is made up of an andesitic volcanic mass belonging to the Lau volcanics, covered on the northwestern and southern fringes by the remains of a calcareous overlay of Futuna limestones (Ladd and Hoffmeister, 1945).

#### The lithological substratum

According to Coulson (1975), the volcanic rocks are formed of a mixture of lava, breccia and lapillaries of andesitic-dacitic composition (Fig. 2.2). Some basaltic elements were recognized in the region inland of Waciwaci, but these are restricted to a very limited area. The vents of the volcanic mass seem to be located in the headwaters of the Waitabu valley, where isolated plugs with sub-vertical walls overlook the landscape. These are made up of massive andesitic breccia, little weathered. Dykes occur throughout the island, and often stand out in the present landscape due to their higher resistance to erosion. Ladd and Hoffmeister (1945) regarded this formation as Lower Miocene in age, but the more recent work of Gill



# GEOMORPHOLOGY



## LEGEND

### EROSIONAL LANDFORMS

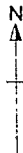
- VOLCANIC CONGLOMERATE PLUGS, BARE ROCK.
- BAD-LANDS ON DEEP VOLCANIC WEATHERING.
- STEEP SLOPES ON VOLCANICS AND LIMESTONE, WITH SHALLOW WEATHERING.
- SLOPES AND SURFACES ON VOLCANICS, WITH DEEP FERRALLITIC WEATHERING.

### DEPOSITIONAL LANDFORMS

- SUMMIT LEVELS Ia ON VOLCANICS, COVERED WITH MANGANIFEROUS BAUXITIC FORMATIONS.
- SUMMIT LEVELS Ib ON VOLCANICS & LIMESTONE, COVERED WITH MANGANIFEROUS BAUXITIC FORMATIONS.
- OLDER COLLUVIAL AND ALLUVIAL DEPOSITS.
- RECENT ALLUVIAL DEPOSITS.
- SWAMPS.
- COASTAL PLAIN.
- MANGROVE.

### SPECIAL LANDFORMS

- KARST.
- RAPIDS.
- CLIFFS.
- BLIND VALLEY WITH DISAPPEARING STREAM.
- "V" SHAPED VALLEYS WITH WATERFALLS.



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(1976) has shown the Lau volcanics to be Upper Miocene, between six and nine million years in age.

The overlying Futuna limestones vary in thickness from a few metres to as much as 70 m. They include two distinct facies: a lower, conglomeritic facies enclosing a mixture of limestone and volcanic elements, and an upper crystalline facies. The latter is more readily recognized in the landscape by virtue of its karstic morphology. The basal Futuna limestones, thought by Ladd and Hoffmeister (1945) to be Lower Miocene, have been shown by Gill (1976) to have been formed during a period extending from the Upper Miocene into the Lower Pliocene.

#### Formation of the substratum

Ladd and Hoffmeister (1945) recognized four phases in the geological history of Lakeba:

- a succession of andesitic eruptions during the Miocene, which elevated the western part of the island to about 120 m;
- subsequent marine and terrestrial erosion, and the deposition of about 100 m of limestone. Coral formed only a minor part of this accumulation;
- uplift of approximately 100 m, extending the size of the island and bringing the eastern part into the zone of coral growth;
- further uplift and continued erosion, which denuded the limestone from the eastern side.

Foye (1917) hypothesized a tilting of the island, downward toward the east, in order to explain the absence of limestone from this side of the island. This view was contested by Ladd and Hoffmeister, who explained this asymmetry by reference to greater marine erosion on the eastward side, thus assuming persistence of the present wind and wave climate throughout the island's history. Such asymmetric development is not uncommon in the Lau group; Vanua Balavu and Moce, in particular, possess lagoons similar in form to that of Lakeba. However, this view is not easy to reconcile with the greater protection from wave action which the eastward development of coral reefs would have given to these windward coasts, and it also ignores completely the whole question of changing sea levels during the Pliocene and Pleistocene (McLean, 1979). Gill's work on the Lau ridge suggests that a tilt toward the east probably did occur, and is related to the formation of the Lau basin. The movement would have begun during the Pliocene. Such an eastward tilt, if continued into the Pleistocene and Holocene, would also be sufficient to account for the formation of drowned and silted valleys on the eastern side of Lakeba.

#### COMPLEXITY OF GEOMORPHOLOGICAL EVOLUTION

Erosion, not construction, dominates the formation of the landscape of Lakeba. No trace remains of the original form of the volcano. The island has been gouged by deep sub-radial valleys separated from one another by rounded hills. Only small traces remain of former depositional landscapes. In discussing the evolution of the landforms on this island, it will be convenient to follow Tricart (1965), and distinguish between ablation landforms and those produced by accumulation, or other processes. The geomorphological map of Lakeba (Fig. 2.3) illustrates this section of the paper.

#### Landforms d

Landforms presented mainly consist of terraces of the bare rock surface. A large patch of bare rock is prominent on the eastern side of the island.

The erosion has presented 55 per cent of the island may be divided into:

- gentle weathered slopes
- steep moderate slopes

The most common narrow drainage soils, deep weathered, the formation is notched by erosion.

The same erosion contemporaneous with the present mostly been given to the island and consist of a rise to the eastern side of the island.

#### Landforms c

With the erosion to accumulate terraces are formed on the former gentle slopes in Lakeba, situated on the eastern side of the island at around 100 m above sea level covered by the formation of Millstone Gully.

It is interesting to note that the expanding erosion is to indicate the position of the island. In a study of the dates ranging from 1000 to 100 years ago resembling the eastern side of the island recent times the erosion of Lakeba, mainly on the eastern side.

### Landforms due to ablation

Landforms resulting from ablation dominate the island. They are represented mainly by hills with slopes mantled by soils exhibiting varying degrees of truncation. Two small areas exhibit greater denudation: these are the bare rock of the volcanic plugs in the Waitabu headwaters, and the small patch of 'badland' that is prominent immediately inland of Tubou, and because of its prominence was used as a site for an unsuccessful tellurometer traverse of the Lau islands undertaken a few years ago.

The eroded hills are the backbone of the present relief. They represent 55 per cent of the total surface of the island, and have slopes that may be divided into two main groups:

- gentle slopes, occurring on volcanic rocks, showing deep ferrallitic weathering;
- steep slopes, occurring on volcanic and calcareous rocks, with only moderate weathering.

The more gentle slopes are encountered in the upper parts of very narrow drainage basins. These undulating landforms are covered by ferrallitic soils, deeply weathered and truncated. Altered rock reaches the surface, and the formation of these landforms seems relatively ancient, since they are notched by steep valleys of more recent origin.

The steepest slopes in Lakeba are found in these incised valleys, where contemporary erosion is particularly active. The ferrallitic horizons have mostly been removed and hard rock outcrops in places in the valley bottoms, often giving rise to a series of waterfalls, and rapids. There is strong and consistent evidence of two major downcutting phases, the earlier giving rise to the gentler slopes that are still being carved into by more recent incision.

### Landforms due to accumulation

Within and around the ablation landforms is a series of landforms due to accumulation, the most important being 'plateaux', colluvio-alluvial terraces and the alluvial and coastal plains. Plateaux, or remnants of former gently sloping landforms of small size, occur at several altitudes in Lakeba, ranging from 50 to 220 m. The highest part of the island is situated on one such tableland. Two main groups may be distinguished, one at around 50 m, and the other at altitudes between 100 and 200 m. All are covered by bauxitic manganeseiferous formations of similar form. Sometimes, the formations are underlain by andesitic fragments, moderately weathered. Millstone debris is sometimes encountered on the surface.

It is possible that these formations are the remnants of laterally expanding surfaces derived from greatly altered soils. There are few clues to indicate the date of their origin. Taking account of their topographic position, some at least would appear to be the oldest landforms on the island. In a study of similar formations on Viti Levu, Dickinson (1965) has suggested dates ranging from the Pliocene into the Pleistocene; the absence of anything resembling these plateaux on islands of more recent geological formation in eastern Fiji lends support to this view of very ancient origin. In more recent times, since the present hydrographic system became established in Lakeba, material eroded from these surfaces has been deposited in the valleys and on the coastal plain.

One of the most striking characteristics of the surface geology of Lakeba is the great quantity of colluvio-alluvial deposits in the valleys, especially in the eastern half of the island. In places, the former landscape has been masked to considerable depth by this material. The deposits have a medium texture and are composed of a multitude of small fragments derived from heavily weathered rock. In many places the formation has been incised by subsequent erosion, and hanging valleys have been created, sometimes overlooking other hanging valleys below them characterized by the same colluvio-alluvial formation. They give the impression of having been formed over a long period of time, and with the strong suggestion of sub-humid climatic conditions during the period of origin. Today, they are still being overlain by new material derived from the burned hills above them.

Taking into account the topographic position of these extensive colluvio-alluvial formations, it would seem certain that their deposition began much earlier than the origin of the present alluvial plains. The deposition of such a quantity of material may be related to truncation of the gently-sloping uplands, possibly during a relatively dry period of the middle Quaternary. It is not possible that they have been formed since the arrival of man in Lakeba, only some 3000 years ago, and their presence therefore suggests a massive erosion of the uplands during a period many millennia before arrival of man.

The present alluvial plains are often incised within these older colluvio-alluvial formations. In the eastern part of the island the alluvial plains along the rivers are often swampy, but sometimes the swamps are stepped along the valleys, separated by rapid sections. In the interior valleys they are filled with sediments of mineral origin, and in the sub-coastal valleys by sediments of organic-mineral origin. Organic-mineral sediments in the coastal zone overlie sands dating from the Holocene period (McLean, personal communication). At the present day, the coastal plain has a width ranging from several hundred metres to only a few metres; it is absent only from the promontory southeast of Tubou. The plain is mainly sandy on the western side of the island, and mainly clayey on the east, where it is continued into the lagoon by a large area of mangroves which attains its greatest width between Nukunuku and Waitabu.

In summary, Lakeba would seem to have undergone three major phases of sedimentation, widely separated in time. The first formed the interior plateaux; the second formed the extensive mass of colluvio-alluvial material; the third formed the alluvial and coastal plains. A major problem of interpretation is posed by this brief description.

#### Landforms of other types

The only significant group of landforms not discussed above are the karstic formations encountered on the crystalline limestones. They take the form of limestone pavements, pitted with sinkholes and broken by small cliffs. Blind valleys and caves are both encountered, especially in the large block of limestone east of the airstrip. However, karstic relief covers only four per cent of the surface of the island; other karstic formations may now lie beneath the surrounding lagoon, drowned by the Flandrian transgression, for it must be recalled that during the maximum low sea level of the Pleistocene more than half the area of the then Lakeba would have been formed of limestone (McLean, 1979).

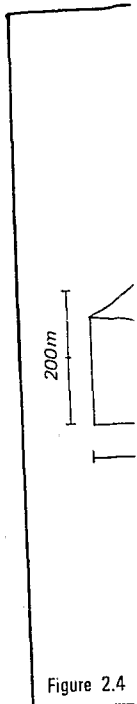


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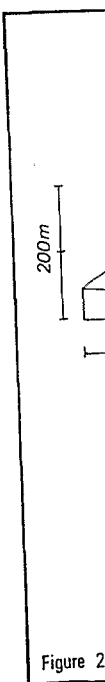
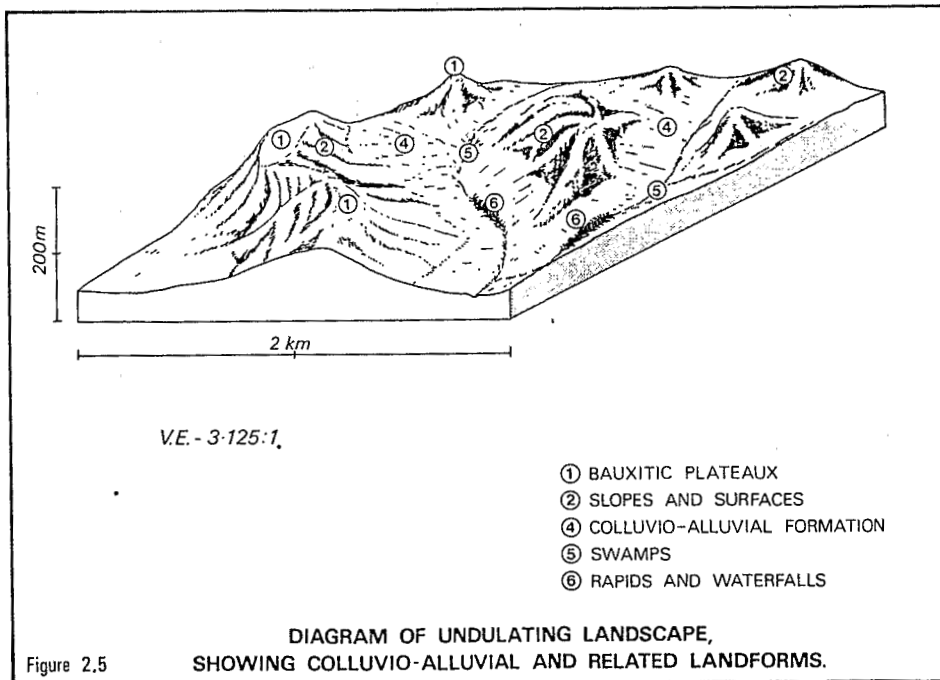
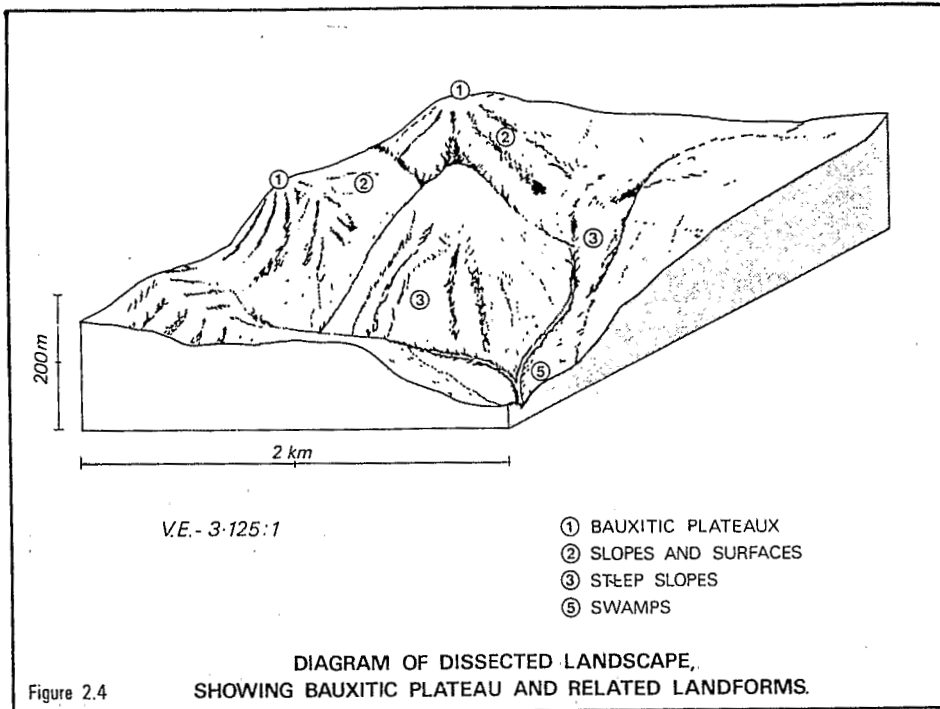


Figure 2.



## HISTORICAL INTERPRETATION OF THE FORMATION OF THE LAKEBA LANDSCAPE

This section of the paper is preliminary. During its writing further analysis and radio-carbon dating of samples collected from the swamps of Lakeba in 1976 were still being undertaken. Part of the results of this work is reported elsewhere in this volume, and a synthesis will be presented in the final report of the ecological survey, to be published by ORSTOM. What follows is based on an interpretation of the evidence to hand at the time of writing, and should not be construed as final.

The geomorphological evidence suggests a number of hypotheses that might be put forward to explain the history of the island landforms, and possibly the palaeo-climatic history of the island. The age of all formations can be stated only in relative terms, for no dateable elements have been found except in the recent swamps, and none are likely to be found in the older formations. A tentative historical reconstruction is proposed, incorporating nine stages and probably originating in the Pliocene, when the limestones emerged from beneath the sea. The evidence is presented later in the paper.

A tentative historical sequence

The sequence may be presented as follows:

1. In the Pliocene the andesites were deeply weathered over a long period, during which humid conditions most probably prevailed. Bauxite would have been formed and silica leached from the soil. This silica would in part have been trapped in rock fissures, forming veins of millstone. It is possible that this first deep-weathering stage corresponds with humid periods noted elsewhere in the region, in Australia (Mulcahy and Churchward, 1973) and in New Caledonia (Latham, 1976). No remaining evidence of this stage is to be found in the landscape, except by inference, but its hypothesized occurrence is essential to the following stages of the sequence.
2. Probably about the end of the Pliocene, a major talus was formed from the previous bauxitic soils. Climatic change would seem to have been required. Fragments of hard rock would have been deposited close to streams, and the whole scree covered again by bauxitic soils. Erosion must have been deep enough to have reached the underlying millstone in places, and thus lead to an inversion of the parent materials. The talus deposit is today represented by the higher level of the remnant plateaux (Figs. 2.4 and 2.5).
3. Another talus layer would have been formed under similar conditions at the level of the lower plateaux (Fig. 2.5). It seems probable that there has been no subsequent humid period sufficiently prolonged to weather completely the layer of rock fragments underlying some of these plateaux.
4. The present-day configuration of landforms would then have originated during the early Quaternary, uplift of the island being accompanied by a fall in sea level. The stream network cut into the late-Pliocene talus, leaving only the remnant plateaux intact. Soil and landform conditions suggest that this might have been a period of relatively dry climate, punctuated by violent rainfall perhaps during hurricanes.

TABLE 2.3: SUGGESTED SUCCESSION OF THE MAIN MORPHOGENETIC PHASE IN LAKEBA

EPISODE	MORPHOGENESIS	CLIMATE PHASE	SUPPOSED AGE
1	Allitic weathering	Perhumid	Pliocene
2	Deposition of a talus of which only the higher plateaux remain	Subarid	Plio-Pleistocene
3	Lowering of the base level and deposition of the lower talus	Subarid	Plio-Pleistocene
4	Cutting of the valleys	Dry and contrasted climate	
5	Ferrallitic weathering of the slopes	Humid	Mid-Pleistocene
6	Strong surface erosion on the slopes and colluvio-alluvial deposition	Dry and contrasted becoming more humid	Mid-Pleistocene
7	Ferrallitic weathering of the slopes and of the colluvio-alluvial deposits	Humid	Upper Pleistocene
8	Valley incision; head erosion at valley heads	Subarid	Upper Pleistocene
9	Deposition of the recent alluvial and coastal plains and of the swamps, bisiallitic weathering on valley slopes.	Contrasted	Holocene to present

5. The intense erosion of phase 4 would seem to have been followed by a period of ferrallitic weathering, probably under a forest vegetation and hence a humid climate. This period, which is represented in the record by deep weathering of soils on the gentler slopes, is probably best located in the middle Quaternary.
6. In the following period soils were truncated widely over the island, leading to the filling of valleys by colluvial and alluvial deposits, especially in the east of Lakeba. The amount of truncation and deposition that occurred during this phase seems to require major transformation of the vegetation cover, and hence in all probability a drier climate. The assymetry in valley filling noted above is a clear feature of this phase, so that if tilting occurred it probably took place during this time. This phase of rapid erosion and sedimentation was probably influenced by rejuvenation of streams during a period of low sea level, and seems to have been terminated during a high sea-level phase, at some time in the middle Pleistocene.
7. There then ensued a new period of ferrallitic weathering, perhaps during a short humid phase. The evidence for this phase is weak, and it seems not to have been sufficiently long or strong to build up the soils of the slopes.
8. Renewed low sea level would probably have been the cause of the period of rapid erosion suggested by the soil and topographic evidence. This is the phase during which the colluvio-alluvial plains were incised, and when the valley bottoms were stripped of any ferrallitic cover.
9. Finally, under a more humid if uncertain climate, ferrallitic weathering has been resumed in the valley heads. Rising sea level would have flooded the lower valleys, and the present lower alluvial plains, and the coastal plain, were formed in the manner described by McLean (1979). It was during this final phase that man arrived in Lakeba.

Table 2.3 summarizes the stages of this tentative reconstruction.

#### CONTEMPORARY MORPHODYNAMICS OF THE LANDSCAPE

The reliance on alternating wet and dry phases in the palaeo-climate of Lakeba seems rendered necessary by the evidence of the soils, and is rendered possible by the limited evidence of climatic variability in the contemporary period (McLean, 1979). As McLean emphasizes, there is no reason to suppose that the observed variability in external conditions represents the historical limits of variability even within the period of human occupation, or since the Flandrian transgression; the evidence of the soils and topography of Lakeba can hardly be interpreted in any convincing manner without supposing a much greater range of climatic variability in the longer past. Given this need to rely on long-period climatic change, it is not surprising that the present morphodynamics of the Lakeba landscape are of a low order compared with those whose record remains in the surface geology, landforms and soils of the island. At the present time few traces of erosion were visible on the soil surface. Gully erosion is present, but limited in extent, and is probably related to present-day utilization of the land. Yet erosion is certainly continuing. Study of recent sedimentation in the valley and sub-coastal swamps provides unquestionable proof of such erosion. Some discussion of this evidence is therefore appropriate, since

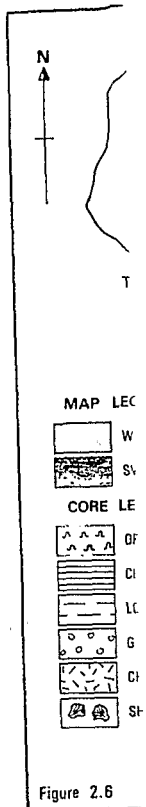
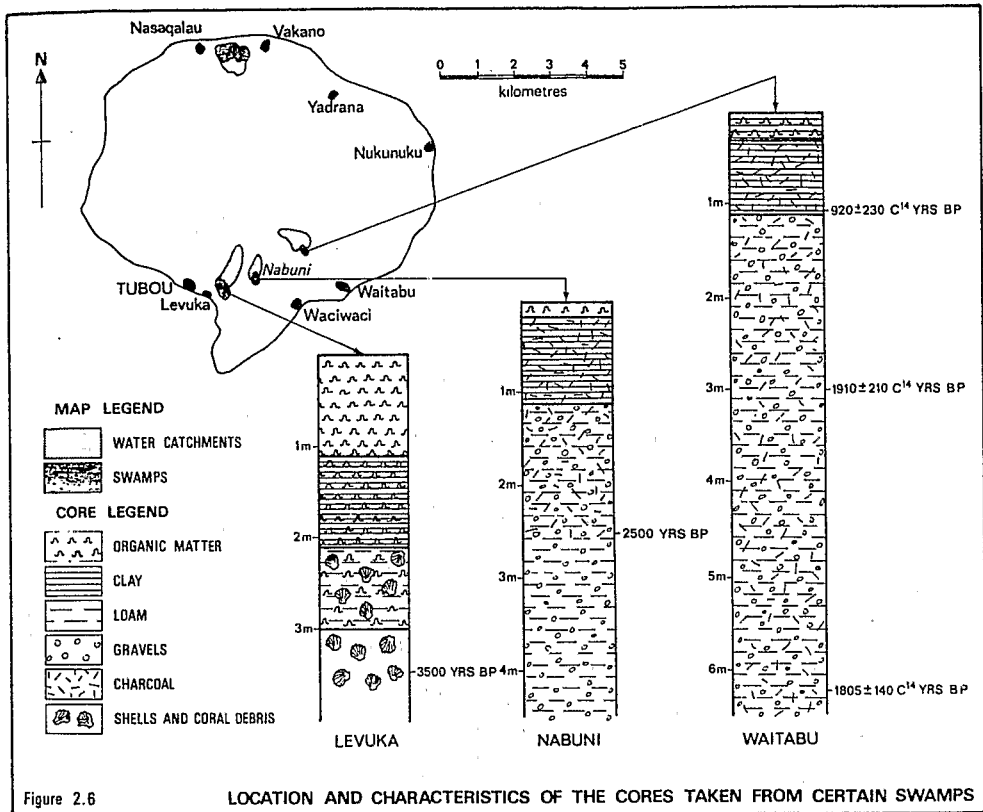
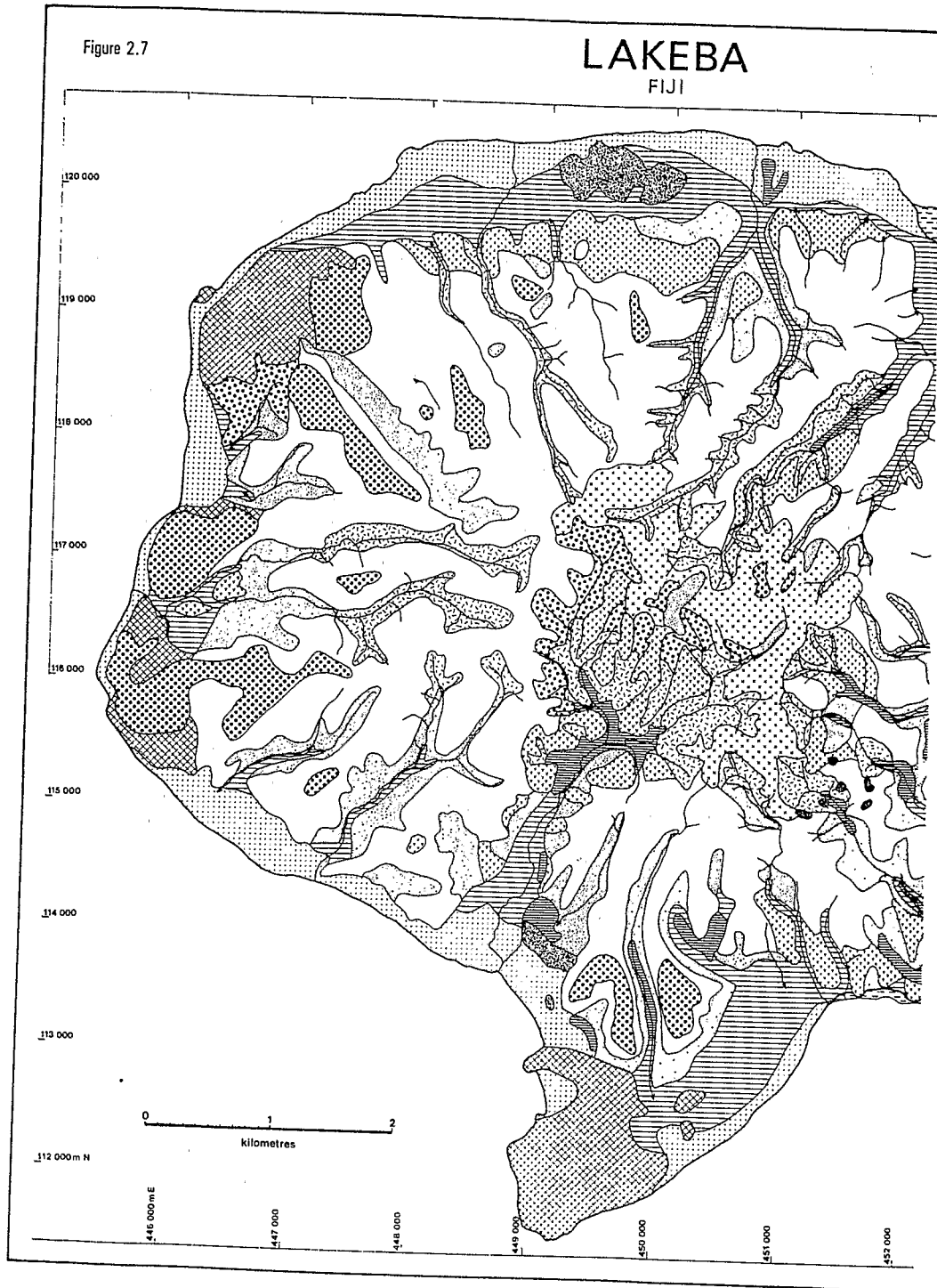


Figure 2.6

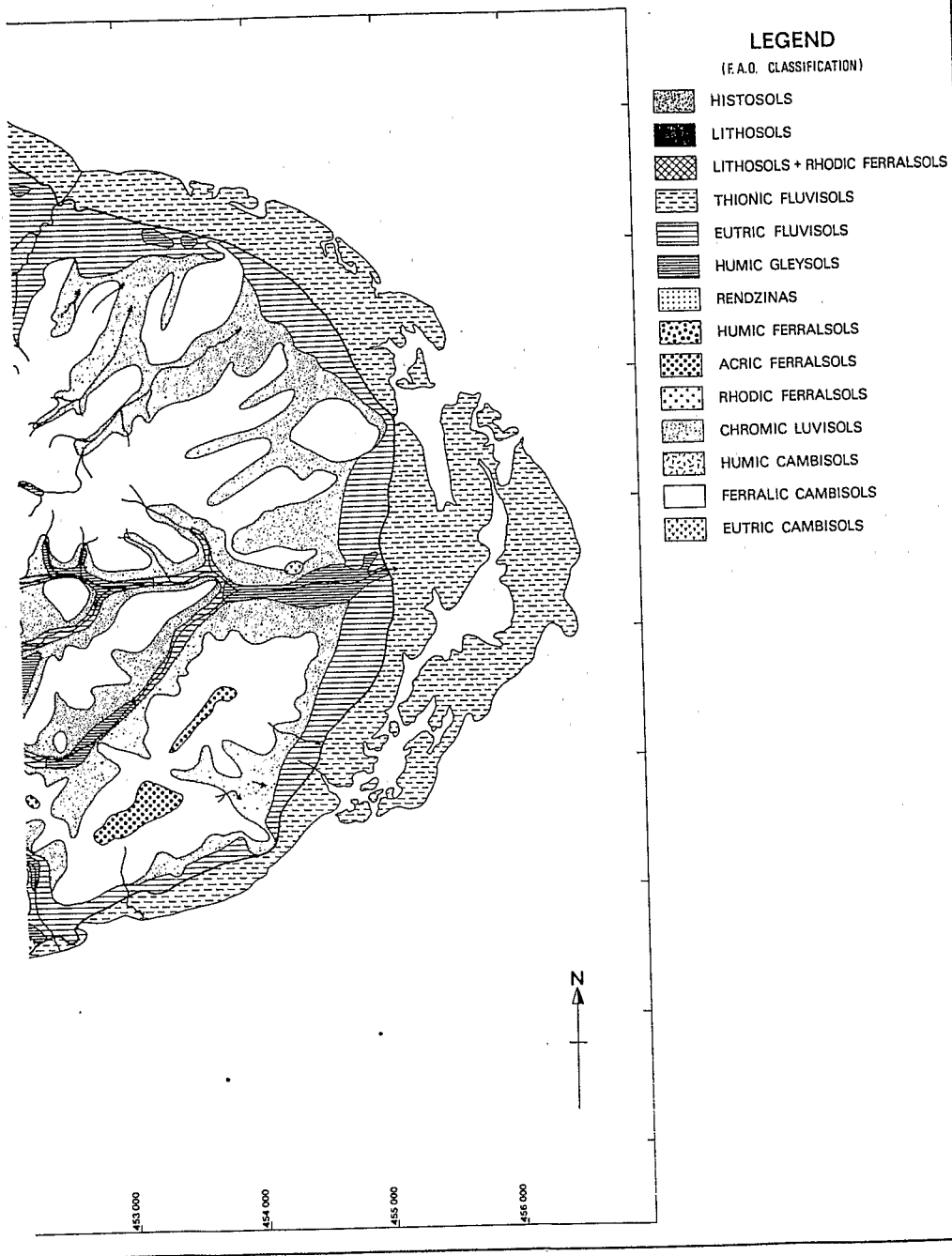


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# SOILS



measurement of the volume of deposition accumulated in these swamps can yield some estimate of the minimum rates of erosion experienced in their catchments.

Sedimentation in the swamps

Three swamps in the southeast of the island have been closely investigated. Only preliminary results are reported here, and some later results are discussed in another context by Hughes *et al.* elsewhere in the present Island Report. The swamps discussed are in the upper valley of the Waitabu creek, at Nabuni west of Waciwaci, and in the Levuka sub-coastal swamp behind Tubou (Fig. 2.6). Cores were obtained in 1976, and C<sub>14</sub> dating of samples has been carried out.

The inland swamps of Waitabu and Nabuni both have mainly a mineral composition. Both show the same succession of two principal strata, an upper clayey layer about one metre thick, and a lower layer of coarser texture which extends to a depth of six metres in the Waitabu swamp. The latter is made up of very weathered small rocky particles associated with charcoal grains and fragments of wood.

The bottom of the upper layer has been dated by the C<sub>14</sub> method at 920± 230 years B.P. in the Waitabu swamp. In the lower layer, in the same swamp, two dates were obtained. At 3.2 m age of 1910± 210 B.P. was obtained, and at 6.2 m in the same core the result was 1805± 140 B.P. These rather contradictory results are possibly due to the weak carbon content of the middle sample, and the result is indicative rather than firm. However, the standard deviations of the two lower dates overlap. No dates have yet been obtained from the Nabuni swamp, but a cessation of charcoal content is visually evident at a depth of 2.5 m. This is in contrast with the persistence of charcoal in quantity of depths exceeding six metres at Waitabu, suggesting incidence of fires of anthropogenic origin over a period of at least 2000 years; very probably a fuller analysis would show the use of fire back much earlier than this, for present evidence suggests that the island has been occupied for about 3000 years (S. Best, personal communication)

The Levuka swamp is much larger than the two inland swamps discussed above (Table 2.4). This is a sub-coastal swamp formed behind a beach bar of Holocene age, and only slightly above sea level. Its upper layer is again about one metre in depth, of organo-mineral content, containing by weight only 25 per cent organic matter and having a very slight bulk density -- approximately 0.5 against 1.5 for the mineral swamps. The volume of mineral matter contained in a cubic metre of these peats is thus one third that contained in a cubic metre of mineral earth. A sample, taken at 1.2 m, was dated at 940± 120 B.P.

Below this level is a mineral layer, ranging from 1.5 to 1.8 m in thickness, containing remnants of organic matter including badly decomposed *Cyperaceae* fragments. At the bottom is a sandy layer rich in coral and shells, at a depth of 2.5 to 3.0 m. This sand has been dated at about 3500 B.P. (McLean, personal communication). The organic composition of the upper level, and the relatively organic nature of the intermediate level, both suggest that terrestrial sedimentation in this area has been insufficient to fill the swamp since its initiation after the Holocene.

Sedimentation in these three swamps seem therefore to have taken place

in two phase. ion was rapid between 2000 on Lakeba and then followed the nature at

Evaluation of

Estimate time should upstream catchment likely to be material carried downstream of swamps, estimated 1000 B.P. -- the lower half field carry

Table This represents years from t

CATCHMENTS

Vegetal cover  
Surface area  
Surface area  
Nature of the  
Evaluation of deposits due years

Evaluation of of eroded soil one thousand Mean erosion in tonnes/k

The mean erosion

$$T = \frac{S}{S} (h)$$

in which:

- T = mean
- s = surface
- S = surface
- h = depth
- d = bulk

calc

in two phases. In the first phase, until about 1000 years ago, sedimentation was rapid leaving coarse deposits. This phase probably commenced between 2000 and 3000 years ago, coincidentally with the settlement of man on Lakeba and his use of fire to clear land for cultivation. This was then followed by a slower sedimentation phase during the last 1000 years, the nature and origin of which is discussed later in this volume.

#### Evaluation of erosion rates

Estimation of the volume of material deposited during a determined time should enable us to evaluate the quantity of material taken from the upstream catchments during the same period. The calculation is, however, likely to be an under-estimate, since at times of peak flood a part of the material carried into the swamps was probably taken out and transported downstream or into the sea. At the present stage of our research on these swamps, estimates can be applied only to the more recent sediments -- since 1000 B.P. -- since there remains too much doubt concerning the dating of the lower horizons. In our paper below, Hughes, Hope, Latham and M. Brookfield carry this analysis further, with interesting results.

Table 2.4 shows fairly high erosion rates, over 100 tonnes/km<sup>2</sup>/yr. This represents removal of from six to ten centimetres of earth per thousand years from the surface area of the upstream catchments.

TABLE 2.4: EVALUATION OF THE EROSION INDEX FOR THE  
WAITABU, NABUNI AND LEVUKA CATCHMENTS

CATCHMENTS	WAITABU	NABUNI	LEVUKA
Vegetal cover of the catchment	Forest	Talasiga	Talasiga
Surface area of catchment in ha	45.6	27.5	51.8
Surface area of the swamp area in ha	3.4	1.9	13.1
Nature of the sediments	Mineral	Mineral	Organic-mineral
Evaluation in cm of the depth of deposits during the last thousand years	110.0	100.0	120/3 = 40
Evaluation in cm of the thickness of eroded soil on the catchment in one thousand years	8.3	6.8	10.0
Mean erosion index on the catchment in tonnes/km <sup>2</sup> /year	124.0	102.0	125.0

The mean erosion index has been calculated by the following formula:

$$T = \frac{S}{s} (h \times d)$$

in which:

- T = mean erosion index in the last thousand years
- s = surface area of the swamp
- S = surface area of the catchment
- h = depth of accumulation during the last thousand years
- d = bulk density of the soil of the catchment, estimated for this calculation at 1.5

These results, which relate to the later and slower period of deposition, are high, but may be compared with those observed in other tropical regions, as follows:

- 2.7 cm/1000 yrs on the Dumbea river, New Caledonia (Trescases, 1973);
- 12.5 cm/1000 yrs as a mean figure for the New Caledonian ultramafic massifs (Bauduin, personal communication);
- 2 cm/1000 yrs on the Kuk site in Papua New Guinea (Golson and Hughes, 1976);
- 7 to 12 cm/1000 yrs on the Ivory Coast under savanna (Lenoir, quoted by Trescases, 1973);
- 5 cm/1000 yrs in Madagascar (Hervieu, 1968).

The values obtained should also be related to indices of the rate of weathering in the tropics, presently estimated in the range 0.5 to 5.0 cm/1000 yrs (Leneuf, 1959; Hervieu, 1968). If these rates are applicable, then morphogenesis would prevail over pedogenesis in Lakeba, leading to the truncation of soil profiles. This truncation seems to be as marked in catchments partly or wholly under forest as in those with only talasiga vegetation, probably because of the effect of clearing and cultivating the forested slopes.

On the basis of these estimates erosion is an important factor in the contemporary soil and landform dynamics of Lakeba. However, the evidence obtained from deeper horizons in the swamps suggests that erosion rates may have been very much higher in an earlier period, two thousand and more years ago; we provide striking confirmation of this suggestion below.

## II - THE EVIDENCE OF DIFFERENTIATED SOILS

### THE SOIL UNITS

It is the varied geomorphological history of Lakeba, not the relative uniformity of its geology and present climate, that is responsible for a rather remarkable degree of soil differentiation for so small and island. The earlier work of Twyford and Wright (1965) recognized not only 'ferruginous latosols' or 'talasiga soils', but also some 'latosolic soils', 'humic latosols', 'nigrescent soils', 'gley soils' and recent alluvial soils.

The study undertaken by the project distinguished the presence of eight Great Soil Groups according to the FAO (1974) legend, and seven by the French classification (CPCS, 1967, Annexe 2). It is possible to regroup these soils into three main complexes: soils of ferrallitic evolution, soils of fersiallitic evolution, and an aggregate of immature and hydromorphic soils. Figure 2.7, the soil map of Lakeba illustrates this section of the paper.

#### Soils of ferrallitic evolution

Soils of this complex (Acric, Humic and Rhodic Ferralsols, and Ferralic Cambisols) occupy almost 50 per cent of the surface of Lakeba. With the exception of the Humic Ferralsols, they represent what Twyford and Wright (1965) termed the 'talasiga soils'. All are characterized by deep weathering of the parent rock, clearly demonstrated by a silica/alumina ratio of less than 2.0 (Table 2.5) and by sorting out of clay minerals of the kaolinite family, and of iron and aluminium sesquioxides.

TYPE OF PROFILE	
Sample No.	cm
Depth	
Horizons	
Clay	%
Fine silts	%
Coarse silts	%
Fine sands	%
Coarse sands	%
Organic carbon	%
N	%
C/N	%
pH	%
EXCHANGEABLE COMPLEX:	
Ca <sup>++</sup> me/100 g	%
Mg <sup>++</sup> me/100 g	%
K <sup>+</sup> me/100 g	%
Na <sup>+</sup> me/100 g	%
Cation exchange capacity	%
Base saturation	%
TRIACID TOTAL ANALYSIS:	
Loss on ignition	%
Insoluble	%
Si O <sub>2</sub>	%
Al <sub>2</sub> O <sub>3</sub>	%
Fe <sub>2</sub> O <sub>3</sub>	%
Ti O <sub>2</sub>	%
Mn O <sub>2</sub>	%
Ca O	%
K <sub>2</sub> O	%
P <sub>2</sub> O <sub>5</sub>	%
Mol. Si O <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	
Data: analysis of field	

TYPE OF PROFILE	
Sample No.	
Depth cm	
Horizons	
Gibbsite	
Boehmite	
Goethite	
Haemetite	
Magnetite	
Metahalloysite	
Fire Clay	
Montmorillonite	
Amorphous products	
+++ Very abundant	
++ Abundant	
+ Some	
Trace	
Data: analysis of field	

TABLE 2.5: PHYSICO-CHEMICAL CHARACTERISTICS OF SOILS OF FERRALLITIC EVOLUTION

TYPE OF PROFILE	ACRIC FERRALSOLS					HUMIC FERRALSOLS				FERRALLIC CAMBISOLS		
	LK 121 0-8 A <sub>1</sub>	LK 122 30-40 A <sub>3</sub>	LK 123 60-70 B <sub>1</sub>	LK 124 100-110 B <sub>2</sub>	LK 126 180-190 B <sub>3</sub> C	LS 101 0-10 A <sub>1</sub>	LS 102 20-30 A <sub>3</sub>	LS 103 50-60 B <sub>2</sub>	LS 104 102-130 B <sub>3</sub> C	LS 111 0-5 A <sub>1</sub>	LS 112 10-20 A <sub>3</sub>	LS 113 90-100 C
Sample No.												
Depth cm												
Horizons												
Clay %	10.5	22.5	52.0	72.5	66.0	28.5	40.5	33.0	19.0	17.0	29.0	-
Fine silts %	11.5	27.0	26.0	15.0	16.0	33.5	32.0	35.0	34.0	22.5	23.0	-
Coarse silts %	4.5	14.4	2.8	1.9	4.3	4.8	6.5	11.0	10.1	6.8	11.5	-
Fine sands %	31.7	14.5	5.4	2.4	4.9	10.5	9.4	10.2	15.1	13.6	15.7	-
Coarse sands %	33.1	18.1	8.1	3.3	4.4	9.8	3.7	5.8	17.5	27.9	13.6	-
Organic carbon %	3.0	0.35	-	-	-	4.34	1.75	0.25	-	3.34	1.91	-
N %	0.15	0.03	-	-	-	0.3	0.11	0.02	-	0.18	0.1	-
C/N	20	10	-	-	-	14.5	15.9	11.0	-	18.6	19.1	-
pH	5.3	4.5	4.8	4.5	4.8	5.6	4.7	4.8	4.5	4.9	5.0	4.0
EXCHANGEABLE COMPLEX:												
Ca <sup>++</sup> me/100 g	2.2	0.1	0.1	0.1	0.1	6.1	0.16	0.16	0.05	2.2	0.06	0.04
Mg <sup>++</sup> me/100 g	2.3	0.1	0.1	0.1	0.1	6.8	1.6	1.2	0.6	3.5	1.9	0.56
K <sup>+</sup> me/100 g	0.3	0.07	0.02	0.01	0.02	0.23	0.05	0.1	0.35	0.55	0.26	0.04
Na <sup>+</sup> me/100 g	0.2	0.05	0.05	0.03	0.04	0.37	0.23	0.25	0.64	0.28	0.17	0.20
Cation exchange capacity	30.7	10.2	2.7	0.01	0.01	27.6	18.2	7.8	10.6	22.4	27.6	5.2
Base saturation %	16.6	3.1	0.1	-	-	48.9	11.2	21.9	15.5	29.1	10.6	16.2
TRIACID TOTAL ANALYSIS:												
Loss on ignition %	32.0	26.5	25.8	24.6	22.0	20.0	16.1	13.9	14.3	20.1	15.8	13.3
Insoluble %	2.6	3.0	4.2	2.9	2.4	0.50	0.70	0.40	0.50	0.5	0.5	0.7
Si O <sub>2</sub> %	6.5	0.5	0.5	0.6	4.0	34.0	36.7	36.7	39.6	35.0	35.5	28.4
Al <sub>2</sub> O <sub>3</sub> %	38.0	48.5	48.5	47.5	40.9	28.5	32.5	32.0	34.5	25.8	29.2	31.2
Fe <sub>2</sub> O <sub>3</sub> %	16.5	18.5	18.0	24.0	27.3	12.5	12.3	14.5	9.0	12.0	15.8	13.5
Ti O <sub>2</sub> %	1.7	2.1	1.9	2.5	2.6	2.02	1.79	1.67	1.90	1.22	1.7	1.42
Mn O <sub>2</sub> %	3.5	3.5	4.0	0.33	0.22	0.28	0.17	0.25	0.19	0.09	0.09	0.08
Ca O %	0.01	0.01	0.01	0.01	0.01	0.36	0.14	0.18	0.17	0.3	0.18	0.18
K <sub>2</sub> O %	0.01	0.01	0.01	0.01	0.01	0.13	0.09	0.07	0.06	0.04	0.04	0.03
P <sub>2</sub> O <sub>5</sub> %	0.14	0.10	0.12	0.10	0.03	0.20	0.17	0.16	0.16	0.14	0.11	0.05
Mol. Si O <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	0.31	0.02	0.03	0.02	0.15	2.02	1.92	1.94	1.94	2.30	2.06	2.09

Data: analysis of field samples.

TABLE 2.6: MINERALOGICAL CHARACTERISTICS OF SOILS OF FERRALLITIC EVOLUTION

TYPE OF PROFILE	ACRIC FERRALSOLS					HUMIC FERRALSOLS				FERRALLIC CAMBISOLS		
	LK 121 0-8 A <sub>1</sub>	LK 122 30-40 A <sub>3</sub>	LK 123 60-70 B <sub>1</sub>	LK 124 100-110 B <sub>2</sub>	LK 126 180-190 B <sub>3</sub> C	LS 101 0-10 A <sub>1</sub>	LS 102 20-30 A <sub>3</sub>	LS 103 50-60 B <sub>2</sub>	LS 104 90-100 B <sub>3</sub> C	LS 111 0-5 A <sub>1</sub>	LS 112 10-20 A <sub>3</sub>	LS 113 90-100 C
Gibbsite	+++	+++	+++	+++	+++	++	++	++	+	+	+	-
Boehmite	++	++	++	++	++	-	-	-	-	-	-	-
Goethite	+	+	+	+	+	++	++	++	+	+	+	++
Haemetite	+++	+++	+++	+++	+++	-	-	-	-	++	+++	++
Magnetite	-	-	-	-	-	+++	++	+++	+	++	+++	++
Metahalloysite	-	-	-	-	++	-	-	-	-	-	-	-
Fire Clay	-	-	-	-	-	+++	+++	+++	++	+++	+++	+++
Montmorillonite	-	-	-	-	-	-	-	-	-	-	-	-
Amorphous products	++	++	++	++	++	+	+	+	+	+	+	+
++++ Very abundant												
+++ Abundant												
++ Some												
+ Trace												

Data: analysis of field samples.

Acric Ferralsols: The most mature of these soils are undoubtedly the Acric Ferralsols encountered on the upper and lower plateau levels described above. Deep brownish red in colour, they have a loamy clayey texture with high porosity in their upper horizons. They are rich in ferro-manganesiferous concretions which accumulate in the uppermost horizons; sometimes there is also a hard manganesiferous layer lower down in the profile. The mineral composition of these soils consists basically of aluminium, iron and manganese sesquioxides: gibbsite, boehmite, haemetite and goethite (Table 2.6). From their high alumina content these soils can be described as genuine bauxites. Some metahalloysite may also appear in deep horizons, but the A and B horizons are short of phyllites, and thus have a cation exchange capacity virtually restricted to organic matter. There is, however, a very limited supply of organic matter, for these soils are covered only by a sparse vegetation and are subjected regularly to burning. They correspond well with the definition of Acric Ferralsols in the FAO legend, or with the Acrothox in the US taxonomy (United States, Soil Survey Staff, 1975). They are poor in organic matter, nitrogen, potassium and phosphorus; they are acidic, unsaturated in bases, and of low fertility.

Humic and Rhodic Ferralsols: These soils, developed in the centre of the island, have been subjected to a far less intense ferrallitic weathering than the Acric Ferralsols. They are either red or yellow in colour, clayey in texture, and fairly deep. The basic mineral components are 'fire clay' -- an irregular variety of kaolinite, magnetite and goethite. Little gibbsite is encountered in the profiles. The exchange capacity of the mineral matter is much higher than in the Acric Ferralsols; it is, however, below 16 me/100 g of clay, which allows their classification as Ferralsols. They are acidic and highly unsaturated in bases. Where under forest, the higher organic matter content permits classification as Humic Ferralsols, but under a more open vegetation the organic matter content is less abundant, so that the soils become Rhodic Ferralsols. In the Humic Ferralsols, a greater concentration of humus is linked with higher proportions of nitrogen, potassium and phosphorus than in the Rhodic Ferralsols, and hence the former group is chemically of higher fertility than the latter.

Ferralic Cambisols: In terms of areal extent, these are the dominant soils of Lakeba. They cover the denuded hills of the talasiga formation and correspond well with the prototype 'talasiga soils' described by Wyford and Wright (1965). These are truncated soils with a superficial red sandy loam horizon 10 to 40 cm deep topping a weathered horizon in which the original rock structure is preserved. They are acidic, poor in organic matter, nitrogen, potassium and phosphorus. Cation exchange capacity is higher than in the soils discussed above, so that they cannot be classed as Ferralsols, and the cambic character of their weathering horizon places them among the Cambisols. This notwithstanding, their evolution is clearly of ferrallitic type. They have a mineral composition in which 'fire clay', haemetite and goethite are dominant. Some traces of gibbsite may be still found in the upper horizons, and for these reasons they are classed as Ferralic Cambisols. These truncated soils, very poor in nutrients, probably constitute the least fertile edaphic entity to be found anywhere in the eastern island region of Fiji.

#### Soils of ferrallitic evolution

Soils in this group have developed on parent material of much more recent origin. They have in common features such as moderate profile differentiation, the presence of smectites in their clayey complex and the separation

TABLE I	
TYPE OF PROFILE	
Sample No.	
Depth	
Horizons	
Clay.	
Fine silts	
Coarse silts	
Fine sands	
Coarse sands	
Organic carbon	
N	
C/N	
pH	
EXCHANGEABLE CAP	
Ca++ me/100 g	
Mg++ me/100 g	
K+ me/100 g	
Na+ me/100 g	
Cation exchange	
Base saturation	
TRIACID TOTAL AN	
Loss on ignition	
Insoluble	
Si O <sub>2</sub>	
Al <sub>2</sub> O <sub>3</sub>	
Fe <sub>2</sub> O <sub>3</sub>	
Ti O <sub>2</sub>	
Mn O <sub>2</sub>	
Ca O	
K <sub>2</sub> O	
P <sub>2</sub> O <sub>5</sub>	
Mo1. Si O <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	
Data: analysis c	
TYPE OF PROFILE	
Sample No.	
Depth cm	
Horizons	
Gibbsite	
Goethite	
Haematite	
Magnetite	
Metahalloysite	
Montmorillonite	
Amorphous product	
+++ Abundant	
++ Some	
+ Trace	
Data: analysis c	

TABLE 2.7: PHYSICO-CHEMICAL CHARACTERISTICS OF SOILS OF FERSIALITIC EVOLUTION

TYPE OF PROFILE		CHROMIC LUVISOLS				HUMIC CAMBISOLS			EUTRIC CAMBISOLS		
Sample No.	Depth cm	LL 31	LL 32	LL 33	LL 34	LAK 31	LAK 32	LAK 33	LC 91	LC 92	LC 93
Horizons		0-10	20-30	120-130	200-220	0-4	20-25	40-50	0-10	15-25	50-60
		A <sub>1</sub>	A <sub>3</sub>	B <sub>2</sub>	B <sub>3</sub> C	A <sub>1</sub>	A <sub>3</sub>	C	A <sub>1</sub>	A <sub>3</sub>	C
Clay	%	20.8	23.4	26.0	22.0	59.0	59.0	67.5	34.0	29.5	55.5
Fine silts	%	39.5	32.2	29.1	26.8	20.0	22.0	10.5	24.5	29.5	10.5
Coarse silts	%	7.9	5.9	8.4	9.3	5.5	6.5	7.0	8.1	6.8	3.3
Fine sands	%	13.6	13.4	19.9	22.9	8.0	9.0	8.0	10.7	10.8	7.7
Coarse sands	%	12.7	21.9	15.4	18.4	2.0	3.0	5.5	11.4	14.4	13.4
Organic carbon	%	2.9	0.84	-	-	6.0	2.4	-	2.8	2.3	-
N	%	0.14	0.05	-	-	0.55	0.09	-	0.21	0.20	-
C/N	%	20.7	16.5	-	-	11	-	-	13.4	11.4	-
pH	%	5.3	5.3	5.5	5.5	6.0	4.8	5.0	5.8	5.7	5.9
EXCHANGEABLE COMPLEX:											
Ca <sup>++</sup> me/100 g		2.5	2.1	2.5	2.2	9.4	2.9	2.7	10.5	-	12.2
Mg <sup>++</sup> me/100 g		7.3	8.6	19.7	24.1	6.8	3.1	3.7	10.6	-	12.9
K <sup>+</sup> me/100 g		0.4	0.3	0.2	0.2	0.33	0.02	0.05	0.86	-	0.2
Na <sup>+</sup> me/100 g		0.3	0.4	0.3	0.4	1.30	0.67	0.61	0.24	-	0.6
Cation exchange capacity		26.0	20.8	26.6	34.7	23.7	11.9	13.3	29.2	-	37.8
Base saturation %		40.4	54.8	85.3	77.5	75	56	53	76.0	-	68.5
TRIACID TOTAL ANALYSIS:											
Loss on ignition %		15.5	13.1	11.3	11.3	23.5	15.0	15.0	14.7	13.9	12.7
Insoluble %		1.7	1.1	1.1	0.95	4.7	2.4	0.95	8.2	7.8	2.0
Si O <sub>2</sub> %		30.1	35.1	38.7	40.5	32.9	39.1	35.5	31.6	32.1	41.3
Al <sub>2</sub> O <sub>3</sub> %		24.0	26.5	26.0	26.0	20.7	24.3	25.8	19.3	20.0	25.5
Fe <sub>2</sub> O <sub>3</sub> %		24.0	19.8	18.3	17.3	13.9	16.7	18.8	20.0	20.8	14.8
Ti O <sub>2</sub> %		3.2	2.15	2.1	1.9	-	-	-	3.25	3.22	1.57
Mn O <sub>2</sub> %		0.7	0.45	0.48	0.53	0.17	0.14	0.28	0.39	0.24	0.04
Ca O %		0.30	0.26	0.24	0.27	0.44	0.07	0.06	0.53	0.53	0.48
K <sub>2</sub> O %		0.14	0.15	0.15	0.21	0.02	0.01	0.01	0.14	0.14	0.12
P <sub>2</sub> O <sub>5</sub> %		0.21	0.19	0.13	-	0.07	0.06	0.09	0.21	0.18	0.06
Mol. Si O <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>		2.13	2.25	2.53	2.64	2.70	2.73	2.34	2.78	2.72	2.75

Data: analysis of field samples.

TABLE 2.8: MINERALOGICAL CHARACTERISTICS OF SOIL OF FERSIALITIC EVOLUTION

TYPE OF PROFILE		CHROMIC LUVISOLS				EUTRIC CAMBISOLS		
Sample No.	Depth cm	LS 51	LS 52	LS 53	LS 54	LC 91	LC 92	LC 93
Horizons		0-5	20-30	70-80	140-150	0-10	15-25	50-60
		A <sub>1</sub>	A <sub>3</sub>	B <sub>2</sub>	B <sub>3</sub> C	A <sub>1</sub>	A <sub>3</sub>	C
Gibbsite		++	++	++	++	+	+	-
Goethite		++	++	++	++	-	+	-
Haematite		+++	+++	+++	+++	+++	+++	+
Magnetite		+++	+++	+++	+++	+++	+++	+
Metahalloysite		+++	+++	+++	+++	+++	+++	+++
Montmorillonite		-	-	+	+	+++	+++	+++
Amorphous products		++	++	++	++	+	+	+
+++ Abundant								
++ Some								
+ Trace								

Data: analysis of field samples.

of iron oxides and hydroxides. The silica/alumina ratio exceeds 2.0 (Table 2.7 and 2.8).

**Chromic Luvisols:** These soils are formed from the extensive colluvio-alluvial formations in the valleys. They are brownish red in colour, clayey to clay-loamy in texture, and contain clusters of small andesitic fragments. The soils are deep and very weathered, giving them rather loose cohesion. The mineral composition is dominated by metahalloysite, with small amounts of montmorillonite. Among the sesquioxides, haemetite and magnetite predominate, but there are traces of gibbsite and goethite. There is evidence of clay movement in the profile yielded by clay skins on the andesitic fragments which have light, grainy centres. The soils are moderately acidic and only slightly saturated in bases, permitting their classification into Luvisols and Chromic Luvisols in the FAO system, the distinction being on the basis of colour. Talasiga vegetation covers these soils, which are poor in organic matter, nitrogen, potassium and phosphorus, and of low fertility.

**Humic and Eutric Cambisols:** These soils occur on steep slopes under forest or reeds. They are shallow, brown to reddish-brown in colour, clayey in texture. They contain some large blocks and smaller fragments of andesite in process of weathering, giving the soils their cambic character. The main mineral component is metahalloysite, but montmorillonite, magnetite and haemetite, together with small quantities of gibbsite and goethite are also found in the profile. The soils are slightly acidic, and rich in exchangeable bases. Where under forest, the upper horizons of these soils contain humus and they can therefore be classified as Humic Cambisols; where the soils are under reeds they contain little humus, and are therefore classed as Eutric Cambisols. These soils, rich in exchangeable bases and quite high in phosphorus, may be considered as moderately fertile.

These soils are transitional between the weathered ferrallitic soils and newly fersiallitic soils. They are certainly relatively young soils, in which minerals such as smectite and gibbsite occur together. Though of medium to rather low fertility, they are quite heavily used for agriculture.

#### Immature and hydromorphic soils

Soils classed in this broad group lack the uniformity of the previous classes. They occur on the recent alluvial and coastal plains, on uplifted calcareous beaches and on limestone. They have in common a recent history and weakly developed profiles (Table 2.9).

**Fluvisols:** Soils of this type are widely developed in the valley bottoms on the eastern and coastal plains. They are deep and clayey, and sometimes show hydromorphic staining at depth. A well-structured humiferous horizon overlies a subsoil in which horizons can barely be distinguished. These soils are fairly rich in organic matter, nitrogen, phosphorus and exchangeable bases. The lack of any diagnostic horizon, and their weakly saturated bases, put them among the Eutric Fluvisols. Because of their depth and fertility, these are the best agricultural soils on the island.

**Gleysols and Histosols:** These are the soils of the valley and sub-coastal swamps. Gleysols are found mainly in the inland swamps. They are deep, marked by permanent ground-water saturation reaching to the surface. They are humiferous and acidic, though quite rich in exchangeable bases, yet they often quite lean in potassium and phosphorus. There is generally a gley

TABLE 2.9: PHYSICO-CHEMICAL CHARACTERISTICS OF IMMATURE AND HYDROMORPHIC SOILS

TYPE OF PROFILE	HISTOSOLS	GLEYSOLS	FLUVISOLS	RENDZINAS
Sample No.	LAK 11	LAK 21	LAK 11	LC 111
Depth	0-15	0-10	0-10	0-10
Horizons	O <sub>1</sub>	A <sub>1</sub>	LL 11	LC 113
			LL 12	55-60
			LL 13	
			LL 23	
			LAK 23	
			50-60	
			(n)	
			LAK 22	
			25-35	
			(n)	
			LAK 12	
			50-60	
			D <sub>n</sub>	
			LAK 12	
			50-60	
			D <sub>n</sub>	
			LAK 11	
			0-15	
			O <sub>1</sub>	

TABLE 2.9: PHYSICO-CHEMICAL CHARACTERISTICS OF IMMATURE AND HYDROMORPHIC SOILS

TYPE OF PROFILE		HISTOSOLS			GLEYSOLS			FLUVISOLS			RENDZINAS	
Sample No.	cm	LAK 11	LAK 12	LAK 21	LAK 22	LAK 23	LL 11	LL 12	LL 13	LC 111	LC 113	
Depth		0-15	50-60	0-10	25-35	50-60	0-10	30-40	120-130	0-10	55-60	
Horizons		O <sub>1</sub>	O <sub>3</sub>	A <sub>1</sub>	A <sub>3</sub>	(B)	A <sub>1</sub>	A <sub>3</sub>	C	A <sub>1</sub>	C	
Clay	%	43.0	38.0	50.0	72.5	71.0	29.7	51.4	48.8	11.5	-	
Fine silts	%	9.0	11.0	12.5	15.5	16.5	33.4	30.4	37.3	15.5	-	
Coarse silts	%	3.0	4.5	3.5	5.0	6.0	5.9	5.5	7.9	1.3	-	
Fine sands	%	2.0	8.0	2.0	2.0	2.5	8.5	6.1	4.6	14.9	-	
Coarse sands	%	0.7	0.9	0.1	0.5	0.5	12.7	2.8	0.8	30.1	-	
Organic carbon	%	13.5	13.9	12.7	2.2	2.4	5.7	1.5	-	8.33	-	
N	%	0.13	0.5	0.35	0.26	0.14	0.42	0.09	-	0.68	-	
C/N	%	-	-	-	-	-	13.7	17.4	-	12	-	
pH	%	4.4	2.6	5.6	3.9	4.1	6.5	6.3	6.0	7.1	7.1	
EXCHANGEABLE COMPLEX:												
Ca <sup>++</sup> me/100 g		14.1	11.3	19.6	4.1	4.4	24.4	15.2	9.7	-	-	
Mg <sup>++</sup> me/100 g		3.9	4.1	11.8	2.6	2.8	7.8	7.3	4.7	5.9	50.4	
K <sup>+</sup> me/100 g		0.18	0.28	0.64	0.04	0.03	0.3	0.1	0.1	0.50	0.07	
Na <sup>+</sup> me/100 g		1.7	2.71	1.6	0.77	0.84	0.4	0.2	0.2	5.7	5.9	
Cation exchange capacity		-	47.9	-	27.2	24.0	45.0	31.5	20.9	-	-	
Base saturation %		-	38.4	-	28	34	73.1	72.3	70.3	-	-	
TRIACID TOTAL ANALYSIS:												
Loss on ignition	%	44.9	38.3	36.2	16.7	14.6	19.7	13.5	12.1	-	-	
Insoluble	%	0.6	0.6	3.4	6.4	6.9	5.4	3.0	1.5	-	-	
Si O <sub>2</sub>	%	30.5	28.5	28.5	42.0	40.7	30.7	35.5	38.8	-	-	
Al <sub>2</sub> O <sub>3</sub>	%	15.8	20.5	13.1	22.0	19.9	21.3	25.5	28.5	-	-	
Fe <sub>2</sub> O <sub>3</sub>	%	4.4	7.9	13.2	9.0	12.4	17.8	17.5	15.5	-	-	
Ti O <sub>2</sub>	%	-	-	-	-	-	2.5	2.3	2.0	-	-	
Mn O <sub>2</sub>	%	0.05	0.05	0.22	0.06	0.07	0.4	0.3	0.2	-	-	
Ca O	%	0.57	0.60	1.31	0.35	0.38	1.11	0.65	0.48	-	-	
K <sub>2</sub> O	%	0.01	0.01	0.04	0.02	0.02	0.12	0.10	0.11	-	-	
P <sub>2</sub> O <sub>5</sub>	%	0.12	0.04	0.13	0.05	0.06	0.24	0.12	0.04	0.18	0.04	
Mol. Si O <sub>2</sub> / Al <sub>2</sub> O <sub>3</sub>		3.28	2.36	3.69	3.24	3.47	2.39	2.36	2.31	-	-	

Data: analysis of field samples.

horizon quite close to the surface, and this characteristic, together with their richness in organic matter, places them among the Humic Gleysols.

The Histosols characterize mainly the sub-coastal swamps, most of which have limited water catchments. They too are saturated to the surface with ground-water, and may have an accumulation of peat to a depth of two or three metres. Often these soils are very acidic, and poor in plant nutrients. Though both groups of soils have traditionally been cultivated for irrigated taro and both seem to have a fairly high production potential, the potential of the Gleysols of the inland swamps is higher than that of the sub-coastal Histosols.

Rendzinas: Soils of this group occur on the sandy coastal plains of western and southern Lakeba. They are shallow and sandy, with calcareous sands, and often have a brackish water table quite close to the surface. Generally, these soils are high in organic matter, but have small reserves of potassium and phosphorus. These are, *par excellence*, the soils of the coconut plantation and groves.

#### Discussion

The lowland soils of Lakeba are very heterogenous. Some have been formed from volcanic parent material, and some from calcareous material provided both by the limestone, and from the reef and lagoon. The depth of the water table varies greatly. Taken as a group, however, they are the most fertile soils of the island, and are heavily cultivated, though generally under coconuts except where the water table is close to the surface.

It is clear from this outline that the soils of this island are both varied and unusual. The variety emerges as much from their physico-chemical characteristics and mineral content, as from their index of fertility. In a small island with only 56 km<sup>2</sup> of land, plus a fringe of mangroves on the eastern side, eight great soil groups of the FAO legend can be recognized -- a circumstance remarkable enough in itself. The contrast with the pedological homogeneity of younger volcanic islands such as Taveuni, or elevated atolls like Kabara, is of a major order.

Certain of the Lakeba soils, in particular the bauxitic Acric Ferralsols on the plateaux, and the Chromic Luvisols on the colluvio-alluvial deposits in the higher parts of the valleys, are soil types that have hardly been studied anywhere in the world before the present inquiry. This individuality of the soils of Lakeba is underlined by the difficulties experienced in applying the classification systems; the French and American systems, in particular, were found poorly adapted to the description of the soils of the island.

#### PEDOGENESIS AND THE DISTRIBUTION OF SOILS

##### Pedogenesis under contemporary conditions

The diversity and individuality of the soils of this island reflect great diversity in pedogenetic conditions. Climate, geology, geomorphology and the plant cover all need to be taken into account. The present tropical oceanic climate permits a moderate degree of ferrallitization, of a type well represented in the central uplands by the formation of Rhodic and Humic Ferralsols. Slow eluviation of silica and a moderate concentration of gibbsite characterize the soil-forming processes of this area. These conditions are favoured both by the undulating topography of the central uplands, and

by the forest

These covered by s over infiltration in the soil ratio which this level is formed in the more abundant influence of

In terms between the the Medrausa and a drier hypothesis b andesitic is drought is n

#### Palaeoclimat

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Moreover soils. Trun phases discussed Cambisols co to the phase montmorillio however, the geology of t

#### Vegetation a

The ef above. Both infiltration Lakeba is to the Yadrana vegetation, hour of an e taken in com slope under Talasiga cov in sharp con

by the forest or para-forest cover.

These conditions are greatly modified on steep slopes, and in areas covered by sparse talasiga vegetation. In these areas, runoff may prevail over infiltration, and weathering seems to be less active. This shows up in the soil through the slower elimination of silica, and a silica/alumina ratio which slightly exceeds 2.0 in the Ferralic Cambisols and is far above this level in the Eutric and Humic Cambisols. Some montmorillonite may be formed in the profiles of the latter soils, and this element becomes much more abundant in the Gleysols and Fluvisols of the valley bottoms, under the influence of silica inputs linked to the flow of ground water.

In terms of present processes, Lakeba seems close to a climatic limit between the truly ferrallitic environment of wetter regions, as observed in the Medrausutu Range of southeastern Viti Levu, and in the north of Taveuni, and a drier environment generating bisiallitic soils, such as are found on the western coast of New Caledonia. It would be interesting to test this hypothesis by investigation of the soils of Ono-i-Lau, a heavily eroded andesitic island at the southern end of the Lau chain, where liability to drought is much greater than at Lakeba.

#### Palaeoclimates and pedogenesis

Pedogenesis under present climatic conditions cannot, however, explain all the observed pedological forms observed on Lakeba. Compared with the present moderately ferrallitic environment, the bauxitic plateaux would appear to be relics of an older and much more dynamic pedogenesis (Latham, 1977). These distinctive soils compare with the most evolved soils found elsewhere in the archipelago, and are of a type characteristic of hot and wet climatic conditions. In the geomorphological discussion above, we have suggested a means for their formation from some very deep allitic soils. The fact that their present incidence is strictly confined to the small relict plateau areas is further evidence that they represent a survival from an earlier period of quite different climate.

Moreover, palaeoclimatic evidence is not restricted to these bauxitic soils. Truncation of hillslope soils, and the evidence for two erosive phases discussed above, are also represented in the soils. The Ferralic Cambisols correspond to the earlier phase, and the Eutric and Humic Cambisols to the phase of greater incision. Formation of these shallow soils rich in montmorillonite would seem to require a drier climate. For such a phase, however, the most convincing evidence lies in the landscape and the surface geology of the island, with its huge areas of colluvium.

#### Vegetation and pedogenesis

The effect of vegetation has emerged at several points in the discussion above. Both the input of organic matter, and the balance between runoff and infiltration, are greatly affected by the nature of the plant cover. Most of Lakeba is today sparsely vegetated. Bayliss-Smith (1977) has shown that in the Yadrana catchment, 71 per cent of which is covered by talasiga and related vegetation, discharge reached 34 per cent of the rate of input by the sixth hour of an eight-hour storm. This is a high rate of runoff, especially when taken in comparison with the finding of Roose (1975) that on a 23 per cent slope under tropical rain forest the mean runoff rate was only 0.7 per cent. Talasiga cover facilitates both runoff and erosion, and in this respect stands in sharp contrast with forest cover. On several soils, furthermore, soil

fertility is virtually concentrated in the humiferous horizons; this is especially the case with the Acric and Humic Ferralsols. Removal of vegetation from such soils is inevitably followed by a significant decline in fertility.

#### The distribution of soils

The close correspondence of soil formations with landforms has been noted at several points. Soils of ferrallitic evolution are essentially confined to the hills, plateaux and moderate slopes (Figs. 2.3 and 2.7). They correspond with older landforms, and their present distribution is governed by their topographic position. By contrast, soils of fersiallitic evolution are encountered on slopes produced by subsequent incision, and in the colluvio-alluvial zones. They are not youthful, but on the contrary show advanced evolution in their profile development, and the beginning of rubefaction and clay movements. The only slightly differentiated soils on Lakeba are those formed in the recent alluvial plains. The pattern of variation is summarized in Table 2.10.

TABLE 2.10: DISTRIBUTION OF THE SOILS OF LAKEBA

SOIL	AREA IN HA	PERCENTAGE OF TOTAL
Histosols	8.7	0.2
Lithosols	-	-
Lithosols + Rhodic Ferralsols	260.3	4.2
Thionic Fluvisols (Mangroves)	532.3	8.6
Eutric Fluvisols	647.1	10.5
Humic Gleysols	186.4	3.0
Rendzinas	374.1	6.0
Humic Ferralsols	70.7	1.1
Acric Ferralsols	264.8	4.3
Rhodic Ferralsols	204.4	3.3
Chromic Luvisols	851.5	13.8
Humic Cambisols	332.9	5.4
Ferralsols Cambisols	2167.0	35.1
Eutric Cambisols	277.4	4.5
TOTAL	6177.5*	100

\* Includes mangroves

### III - VEGETATION: DOMINANCE OF PYROPHYTIC FORMATIONS

The initial impression of the vegetation of this island is one of poverty and uniformity. The landscape is dominated by the very open talasiga. A more detailed inspection, however, reveals a wide variety of environments, and even the talasiga association itself is far from homogenous. There are

significant associations and their pattern of vegetation is

#### VEGETATION

The form of vegetation is of great complexity. The invaluable floristic distribution

#### Closed forest

Together with the island, coconut grove forest, and account of groves are Four main types (2.8):

Forest with the centre about six percent of isolated investigation and all vegetation particular middle strata manghas, *P. brackens* (*Lygodium r. oides*, *Linn* make way for bananas; *C. yaqona* or three years, some *gracilis*). shallow soil

Forests with These close part of the ed, and of limited to probably be compared *insularis* osols and to increase tends to be

significant areas of forest, thicket and herbaceous vegetation. These associations overlap in a complex mosaic and, despite the influence of fire, their pattern forms a good indication of edaphic conditions. Fig. 2.8, the vegetation map of Lakeba, illustrates this section of the paper.

#### VEGETATION TYPES OTHER THAN TALASIGA

The following discussion is based on the international classification of vegetation proposed by UNESCO (1973), but in view of the scale and complexity of Lakeba it is necessary to subdivide some of the main units. The invaluable compendium of Parham (1972) was the source reference for floristic determination. A list of plants collected, together with their distribution, appears as Appendix 3 below.

##### Closed forest and coconut groves

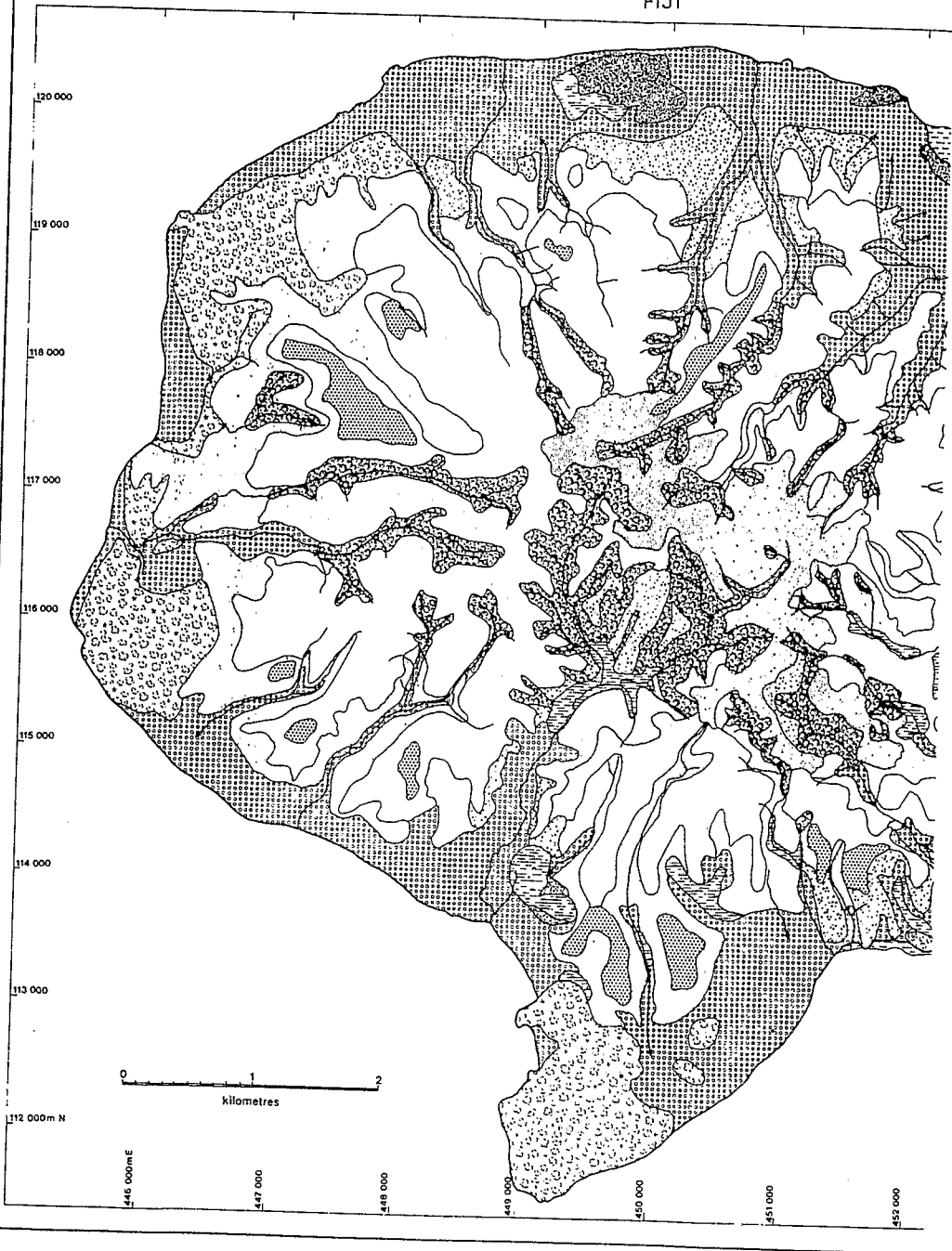
Together, these two units occupy some 40 per cent of the surface of the island. They are grouped together because, in many instances, the coconut groves have occupied areas formerly under beach forest and gallery forest, and both are tree communities. The UNESCO system does not take account of cultivated species, but in dealing with an island where coconut groves are so important a formation, they cannot reasonably be excluded. Four main types of forest are distinguished, and are described below (Fig. 2.8):

Forest with *Geissois ternata*: This type of forest has developed mainly in the centre of the island, on steep slopes overhanging the valleys. It covers about six per cent of the island surface, but its distribution is a series of isolated pockets. The floristic composition is rather poor; in a short investigation only 29 species were counted. The forest is of medium height and all vegetal strata are represented. There are only a few big trees (in particular *Geissois ternata*, *Cananga odorata*, *Ficus fulvo-pilosa*). The middle stratum on the other hand is quite abundant (*Cyathea* sp., *Cerbera manghas*, *Pandanus odoratissimus*). The herbaceous stratum is fairly rich in brackens (*Nephrolepis* sp., *Culcita straminea*, *Microsorium scolopendria*, *Lygodium reticulatum*). In addition, there are many creepers (*Entada phaseoloides*, *Lindsea ensifolia*). These forests have been cleared several times to make way for subsistence crops (*Cocos nucifera*, coconut trees; *Musa nana*, bananas; *Colocasia esculenta*, taro; *Dioscorea alata*, yams; *Piper methysticum*, yaqona or kava). These latter ground crops are carried for a period of two or three years, then the patches are abandoned and rapidly invaded by creepers, some of which are relative newcomers to Fiji (*Mikania micrantha*, *Ipomoea gracilis*). These secondary forest remnants survive on clayey but often shallow soils, in wet situations.

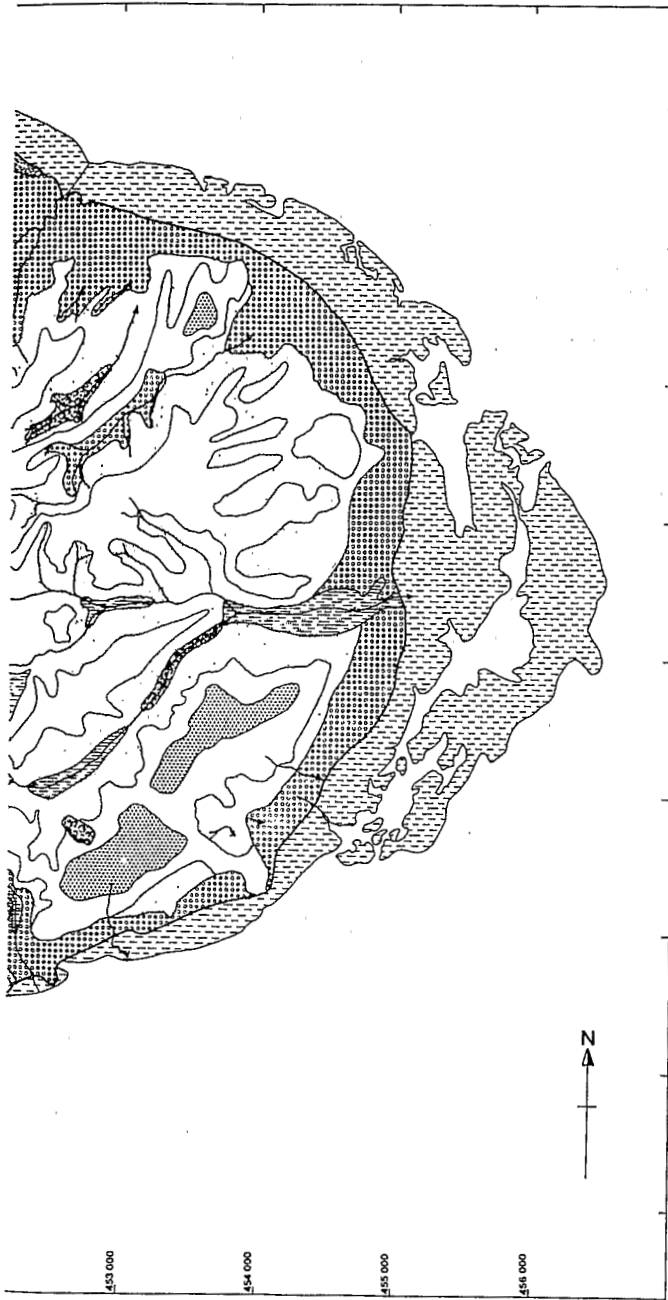
Forests with *Cyathocalyx insularis*, *Ficus obliqua* and *Litsea pickeringii*: These closed forests develop on the limestones in the western and southern part of the island. Their spread, like that of the first group, is restricted, and occupies only four per cent of the vegetated area. Considering the limited time spent on survey in this formation, the floristic composition is probably richer than appears on our lists, but is still likely to prove to be comparatively small. The formation is dominated by big trees (*Cyathocalyx insularis*, *Ficus obliqua*, *Litsea pickeringii*), and occurs mainly on the lithosols and shallow soils on limestone. As soon as the thickness of soil begins to increase away from the outcrops of bare rock, this vegetation community tends to be replaced by an open vegetation of talasiga type.

Figure 2.8

# LAKEBA FIJI





VEGETATION




LEGEND

CLOSED FOREST


TROPICAL EVERGREEN OMBROPHILOUS FOREST

-  Forest with *Geissois ternata*.
-  Forest with *Cyathocalyx insularis*, *Ficus obliqua* and *Litsea pinkeringii*.


TROPICAL OMBROPHILOUS SWAMP FOREST

-  Forest with *Inocarpus fagiferus* and *Pandanus odoratissimus*.

MANGROVE FOREST


-  Forest with *Rhizophora sp.*

COCONUT PLANTATIONS

-  Formation with *Cocos nucifera*.



SCRUB

EVERGREEN SCRUB



-  Thicket with *Miscanthus floridulus* (reeds) predominating.

HERBACEOUS VEGETATION


TALL FORB COMMUNITIES (TALASIGA)

-  Fern thicket with *Pteridium esculentum* and *Dicranopteris linearis* and a rich woody synusia.
-  Mixed thicket with *Dicranopteris linearis* and *Miscanthus floridulus* and a poor woody synusia.

LOW FORB COMMUNITIES (TALASIGA)

-  Fern thicket with *Dicranopteris linearis* predominating and a poor woody synusia.
-  Mixed thicket with *Dicranopteris linearis*, *Pteridium esculentum*, *Miscanthus floridulus* and a poor woody synusia.

HYDROMORPHIC FRESH WATER VEGETATION

-  Rooted tropical communities with Cyperaceae *Ludwigia octovalvis* and *Mikania micrantha*.

Like the previous formation, this forest type has been cleared in many places in order to grow coconuts and subsistence crops wherever the soil permits. The growth of forest on these limestones remains rather difficult to understand, though it is common on the limestones throughout Lau, because the plants have no easy access to water. We have to suppose, as we have elsewhere done for Kabara and as Tercinier (1971) has done for similar formations in the Loyalty Islands east of New Caledonia, that the necessary hydrologic nutrition is produced by capillary action through the limestone.

Swamp forests with *Inocarpus fagiferus* and *Pandanus odoratissimus*: These forests develop on some of the sub-coastal swamps, and cover very small areas, principally near the villages of Levuka and Nasaqalau. The following tree species are dominant; *Inocarpus fagiferus*, *Barringtonia racemosa*, *Ficus fulvo-pilosa*. A fairly well-developed middle stratum of *Pandanus odoratissimus* and *Cerbera manghas* is also visible. These forests have often been cleared for taro plantations, and the soil surface is covered with *Acrostichum aureum* bracken and *Mikania micrantha* creepers. The forests stand in areas saturated to the surface and sometimes above with fresh water, but are sometimes invaded by sea water during very high tides, and in storm surges and tsunami.

Mangrove forests: Mangroves cover more than eight per cent of the total vegetated surface of Lakeba. Put another way they add a vegetated surface equal to some 9.4 per cent of the land area of the island. They grow almost entirely on the eastern side of the island, extending more than a kilometre from dry land. The mangroves consist mainly of *Rhizophora* sp. and *Bruguiera gymnorhiza*, both species common throughout Fiji. However, the floristic variety is much less than around the main islands of Viti Levu and Vanua Levu, for in Lau mangroves are approaching the eastern limit of their extension into the Pacific.

#### The coconut groves and the forest they replaced

These groves are generally old -- often as old as 70 years -- and are rarely well tended. Their management is described in greater detail below by M. Brookfield, and is not further discussed here. They occupy two favoured locations, though they spread also onto less suitable land. These locations were formerly the domain of beach forest and clay-plain forest. It is impossible accurately to reconstruct the floristic composition of these old forests, so completely have they been replaced. However, a few pockets remain, and some individuals of the primitive communities are scattered through the coconut groves. Two communities seem to have occurred, differentiated according to the nature of the soil: forests on sand and coral debris, and forests on clayey plains.

On the sandy beaches, there is evidence of a low ligneous formation with *Guettarda speciosa* and *Messerschmidia argentea* predominating, similar to the formation encountered on coral beaches throughout the Pacific (Fosberg, 1961). On clayey soils, some remnant patches indicate a formation particularly rich in *Barringtonia racemosa*, *B. asiatica*, *Inocarpus fagiferus*, *Hibiscus tiliaceus* and *Terminalia catapa*. However, the floristic changes due to coconut planting are often almost complete. The original ligneous species have disappeared over wide areas. The amount of light penetrating the crowns of even densely-planted coconuts has permitted and invasion of undergrowth dominated by herbaceous and bushy species: *Malvaceae*, *Gramineae*, *Leguminales*, *Compositae*, *Labiatae* and *Verbenaceae*. More than half of these species are either cultivated plants,

or recently a thicket of coconuts, or to be enriched with established

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or recently introduced weeds. Some have great dynamism, and tend to form a thicket under the palms which makes it difficult to collect the fallen nuts, or to permit cattle to graze. In some areas, graminaceous pastures enriched with Koronivia grass (*Brachiaria humidicola*) are deliberately being established.

#### Herbaceous formations

Reed thicket: This dense formation, often impenetrable without the heavy use of cane knives, appears on steep slopes in the main. There is also a block in the north on the plain between Nasaqalau and Vakano, that appears to have extended considerably since the time of the last air photography taken in 1972. Most of the reed thicket is on shallow soils, rich in montmorillonite (Eutric Cambisols). It covers more than four per cent of the island surface. The formation is dominated by reeds (*Miscanthus floridulus*) forming a dense growth to a height of two or three metres, with occasional trees and bushes (*Pandanus odoratissimus*, *Cerbera manghas*, *Alphitonia viellardi*), some brackens (*Nephrolepis* sp., *Pteridium esculentum*) and some weeds (*Psidium guajava*, *Mimosa pudica*, *Hyptis pectinata*, *Ocimum gratissimum*, etc.).

These areas are frequently burned and cleared in order to cultivate cassava (*Manihot esculenta*) or sweet potato (*Ipomoea batatas*). These crops are grown in alternation with fallow, and give good yields. The soils on which they grow are relatively fertile, but often dry, so that moisture demanding crops such as taro and yam are rarely cultivated on this land. In many instances reed thicket is found around the borders of dense forest, and might therefore be a secondary or deflected succession following forest clearance.

Hydromorphic rooted fresh-water vegetation: These grasslands occur in the swamps of the valleys and the coastal plain, and cover only small areas. They are dominated by a dense, low herbaceous vegetation with *Cyperaceae* (*Carex* sp., *Scleria ploycarpa*) and ferns (*Nephrolepis* sp.). Introduced plants (*Ludwigia octovalvis*, *Mimosa pudica*, *Tripsacum laxum*) and cultivated species (*Cyrtosperma chamissonis* and *Dioscorea alata*, neither of major continuing importance in Lakeba agriculture) occur in considerable numbers. These areas have been cleared for irrigated taro cultivation for a very long time, probably for many centuries; the floristic composition is therefore rather heterogeneous, and bears direct relation to the intensity of human use.

#### THE TALASIGA

The name talasiga groups together a range of communities with an herbaceous stratum dominated by forbs (non-graminaceous herbaceous species). Brackens are the principal component (*Dicranopteris linearis*, *Pteridium esculentum*). The ligneous synusia is more or less abundant, varying from locality to locality. By contrast with the talasiga areas of Viti Levu in particular, mission grass (*Pennisetum polystachyon*) is almost completely absent from the talasiga areas of Lakeba. The Lakeba talasiga has been divided into four associations according to their physiognomic aspect, floristic richness and the dominance of certain species. A description follows.

Tall forb vegetation: dense fern thicket with *Pteridium esculenta* and *Dicranopteris linearis* and an abundant ligneous synusia

This vegetal community is especially associated with the deep ferrallitic

soils of the higher and lower plateau levels (Acric Ferralsols). It covers only a small surface area, some three per cent of the island, and is regularly burned. This community sometimes has a para-forest aspect. The tree stratum can be relatively dense, and is dominated by *Casuarina equisetifolia* (nokonoko) and *Pandanus odoratissimus*. Moreover, numerous bushy species occur and sometimes produce a canopy effect. These include *Cerbera manghas*, *Dodonaea viscosa*, *Commersonia bartramia*, *Metrosideros collina* and *Wikstroemia foetida*. The herbaceous stratum is also dense, and is dominated by bracken (*Pteridium esculentum* and *Dicranopteris linearis*). Traditionally, this formation is rarely exploited, and only for light timber or firewood. Now many of the areas on the western side of the island are being planted over with *Pinus caribaea*.

Tall forb vegetation: mixed fern thicket with *Dicranopteris linearis* and *Miscanthus floridulus* and a restricted ligneous synusia

This formation is found in the large valleys, on deeply leached soils (Chromic Luvisols). It includes a fairly open tree layer dominated by individual *Pandanus odoratissimus* and a few *Casuarina equisetifolia*. In the herbaceous layer, *Miscanthus floridulus* reeds predominate, but do not form real thickets. They are scattered among a fern carpet (*Dicranopteris linearis* and to a lesser extent *Pteridium esculentum*) and some introduced plants.

Moister patches have for long been selected for clearance for cassava cultivation, and although these plots yielded a little less well than other and more fertile land, our informants urged that the taste of the crop is better. This cropping causes local weed enrichment to flourish, but the extension of weeds remains limited due to the poverty of the soil. Some *Pinus caribaea* have been planted, and their growth is more rapid than that of trees of similar age elsewhere on the talasiga. In older plantations, some floristic enrichment of the understory is already visible.

Low forb vegetation: fern thicket with *Dicranopteris linearis* and a restricted ligneous synusia

This community is developed mainly on hills with rejuvenated ferrallitic soils (Ferralic Cambisols). Of all vegetal associations on Lakeba, this is the most widespread. It covers some 30 per cent of the island surface, and is primarily responsible for the barren, open aspect of the uplands, so different from the characteristic Pacific island. Tree and bushy layers scarcely exist. As in the community discussed above, a few *Casuarina equisetifolia*, *Pandanus odoratissimus* and *Dodonaea viscosa* occur, but with very few other species. At ground level, there is a fern thicket in which *Dicranopteris linearis* is overwhelmingly dominant. This formation is regularly burned, but is little used by the population. With the sole exception of the mangroves, this community contains the smallest proportion of introduced plants. However, it is interesting to note that the opening-up of access roads to serve the pine plantations, and the movement of vehicles and some horses along these roads and the footpaths which join them, has led to growth of some introduced plants, particularly *Gramineae* along the worked sectors. *Pinus caribaea* have been found to grow rather well on these soils.

Low forb vegetation: fern thicket with *Dicranopteris linearis*, *Pteridium esculentum*, *Miscanthus floridulus* and many weeds, with a small ligneous synusia

This fourth association is found in the centre of the island, in the highest and most humid part, and occupies only a relatively small area. It is

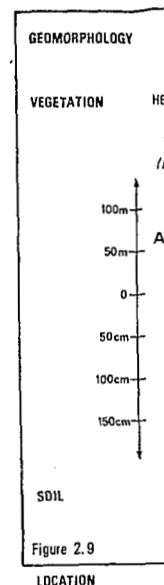


Figure 2.9

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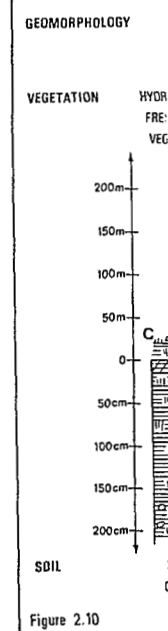


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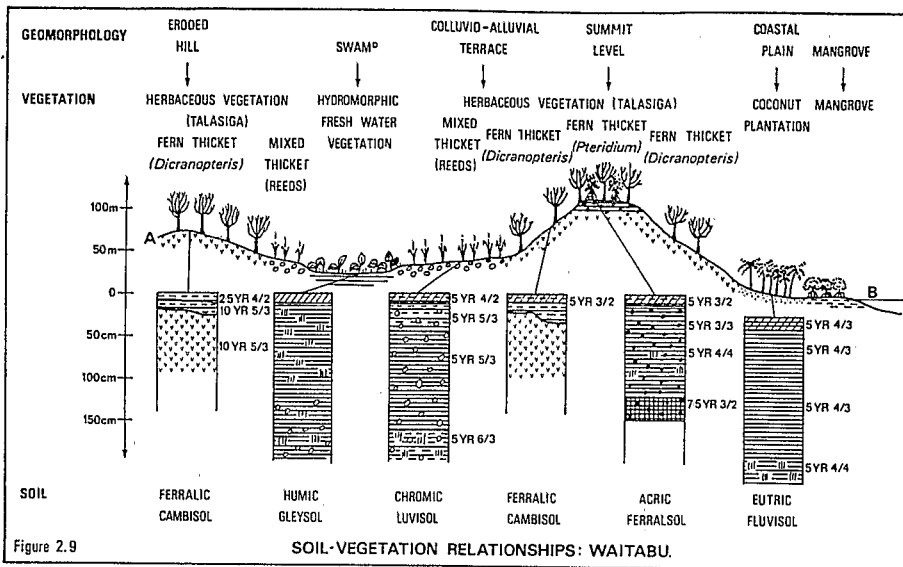


Figure 2.9

SOIL-VEGETATION RELATIONSHIPS: WAITABU.

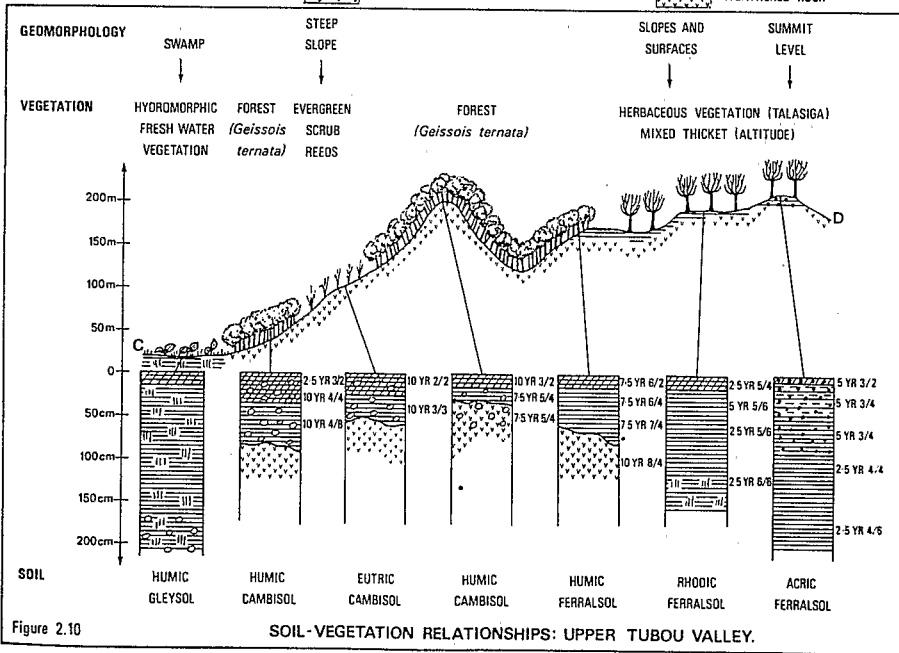
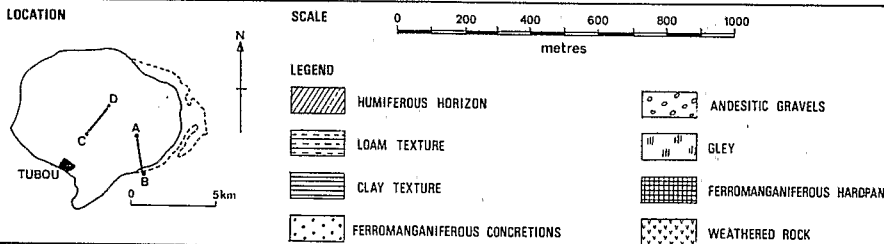


Figure 2.10

SOIL-VEGETATION RELATIONSHIPS: UPPER TUBOU VALLEY.

possible to find all the same tree and bushy species as in the formations discussed above, but they are more abundant and the ratio between species is somewhat different. Certain species such as *Metrosideros* which are sparse elsewhere in the talasiga here become abundant. Species related to the forest associations such as *Geissois ternata* can also be found. Among the herbaceous plants, *Dicranopteris linearis* still predominates, but is associated with many other species, some of which have been introduced -- *Hyptis pectinata*, *Agave sisalana*, *Clidemia hirta* and *Erechtites valerianae-folia* for example. Nearly 20 per cent of the species have been introduced. Several factors probably favour their establishment: the clayey soils are slightly richer than in the other talasiga zones, and the climate is more humid. Man's use of this formation is, however, very slight.

#### THE VEGETATION COMPLEX AND THE NATURAL ENVIRONMENT

The dominant influences on the nature of the plant cover are climate, parent rock and soil, together with human interference through fires, cultivation, wood-cutting and the introduction of new species. In the present conditions under which a strong human impact on the environment is evident, it is worthwhile to enquire whether something like an equilibrium between vegetation and environment has been achieved, or whether a process of degradation is still under way. The impression of a measure of equilibrium is strong, and it will be explored further.

#### Climate and soil climate

The influence of climate, and of the soil climate in particular on vegetation, is particularly clear in this island. We have taken note of some differences in the talasiga vegetation between the more humid higher parts of the island and the lower slopes and valleys. We must also call attention to the fact that forest formations are confined to the wetter sections of the upper valleys and valley sides, to limestone areas, alluvial and coastal plains, and the mangroves. In all these situations, hydrological nutrition appears to be the determining factor in the preservation or implanting of forest vegetation. Indeed, if we re-examine the variations in soil fertility between these areas, and adjacent areas covered by open vegetation, these variations seem linked more to the inputs of organic matter than to the nature of the soils themselves (Table 2.11). The most marked variations in the physico-chemical characteristics of soils under talasiga, reed thicket or forest concern the humiferous A horizons, not the B horizons. It can therefore be concluded that soil climate is the principal determining factor in present vegetal cover.

#### Parent rock

The parent rock is also an important factor. We have indicated the variations between vegetation on andesitic rocks and on limestone; to this should be added the former vegetation pattern of the beach and gallery forest. Differences in the floristic composition of forest are very noticeable across geological boundaries.

#### The influence of soil

The soil itself is also a major factor in vegetation differentiation. Close comparison of the soil and vegetation maps demonstrates this association very clearly, and it is also brought out in the transects shown in Figs. 2.9 and 2.10. Soil affects vegetation in two different ways: by its water re-

#### HORIZON

Clay %	10
Mo % %	2.5
N % %	0.1
C/N	18
pH	4.9
Ca++ me/100 g	2.2
Mg++ me/100 g	2.3
K+ me/100 g	0.3
Na+	0.2
P <sub>2</sub> O = total	0.1

#### SOIL TYPE

Ferralic Cambisols  
 Acric Ferralsols  
 Chromic Luvisols  
 Eutric Cambisols  
 Humic Cambisols )  
 Eutric Fluvisols)

$$Q \text{ in mm} = \sum_0^h + 15$$

Where: Q = water re  
 d = bulk der  
 z = depth of  
 h = depth of  
 H<sub>0</sub> - H<sub>1</sub> = us

#### VEGETATION TYPE

Indigenous species  
 Introduced species  
 Cultivates species

No. of species iden

TABLE 2.11: RANGE OF CERTAIN PHYSICO-CHEMICAL CHARACTERISTICS OF THE A<sub>1</sub>  
AND B HORIZONS OF SOILS UNDER TALASIGA, REEDS AND FOREST

HORIZON	TALASIGA		REEDS		FOREST	
	A <sub>1</sub>	B	A <sub>1</sub>	B	A <sub>1</sub>	B
Clay %	10 - 50	25 - 80	30 - 40	60 - 70	10 - 70	30 - 70
Mo % %	2.5 - 3	4 - 5.5	2.8 - 3.8	-	4.3 - 13	-
N % %	0.14 - 0.18	0.1 - 2.5	0.21 - 0.27	-	0.3 - 0.7	-
C/N	18 - 20	-	15 - 20	-	11 - 13.5	-
pH	4.9 - 5.3	4.5 - 5.5	5.8 - 6.2	5.9 - 6.2	5.6 - 6.5	4.4 - 6.0
Ca++ me/100 g	2.2 - 2.5	0.1 - 2.5	10 - 16	4 - 12	6 - 20	0.16 - 12.2
Mg++ me/100 g	2.3 - 7.3	0.1 - 19.7	10 - 16	4.3 - 13	7 - 11	1.2 - 12.9
K+ me/100 g	0.3 - 0.5	0.01 - 0.2	0.4 - 0.9	0.07 - 0.2	0.23 - 0.86	0.03 - 0.2
Na+	0.2 - 0.3	0.03 - 0.13	0.21 - 0.7	0.6 - 0.9	0.24 - 1.3	0.25 - 0.6
P <sub>2</sub> O <sub>5</sub> = total	0.14 - 0.21	0.10 - 0.13	0.21 - 0.27	0.06 - 0.2	0.13 - 0.24	0.05 - 0.13

TABLE 2.12: RELATIONSHIP BETWEEN WATER-RETENTION CAPACITY  
OF CERTAIN SOILS AND THE VEGETATION COVER

SOIL TYPE	Q <sup>1</sup> IN MM	VEGETATION
Ferralic Cambisols	50 - 70	Talasiga: low forbs
Acric Ferral soils	80 - 95	Talasiga: tall forbs
Chromic Luvisols	120	Talasiga: tall forbs
Eutric Cambisols	110	Reed thicket
Humic Cambisols ) Eutric Fluvisols )	140 - 160	Forest or coconuts

$$Q \text{ in mm} = \sum_0^h + 15 \frac{d}{10} (H_0 - H_1) \Delta z$$

Where: Q = water retention capacity of the soils  
d = bulk density of the soils  
z = depth of the soil  
h = depth of the root zone  
H<sub>0</sub> - H<sub>1</sub> = usable moisture

TABLE 2.13: DISTRIBUTION OF IDENTIFIED SPECIES OF  
DIFFERENT ORIGIN WITHIN EACH MAPPED VEGETATION TYPE

VEGETATION TYPE	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Indigenous species	19	11	13	2	14	7	27	14	18	19	8	70
Introduced species	3	0	4		19	5	10	6	5	5	6	31
Cultivates species	7	5	3		9	3	5	3	1	1	2	14
No. of species identified	29	16	20	2	42	15	42	23	24	25	16	115

tention possibilities, and by its chemical composition.

The water retention possibilities of the soil are governed by the scope for root penetration, and also by the retention capacity of the soil itself. There is a close relationship between the water retention capacity of the principal soils and the height of the plant formations (Table 2.12). Chemical factors are of secondary importance. The abundance of cations in Eutric Cambisols and in Chromic Luvisols may be important for the growth of reed thicket. The sodium contained in some coastal soils may be of significance in facilitating the development of swamp forest. Soil thus reacts on the vegetation by either accentuating or reducing the effect of soil climate, and thus governing the nature of the flora.

#### The impact of human use

While at least a short-term equilibrium may therefore be recognized in the relationship between environment and vegetation on Lakeba, in the longer term there is evidence that man's impact by fire, cultivation and wood-cutting tends to homogenize, gradually reduce and transform the vegetation into more degraded forms. In opposition, however, the introduction of new species increases the range of plants capable of adapting to the environment.

#### The effect of fire

Especially on the talasiga, the effect of repeated burning is often to hide the complexity of the soil-vegetation relationship. This is particularly clear in the case of the tall forb vegetation with *Pteridium esculentum* and *Dicranopteris linearis* which, under repeated fires, changes into low forb formation with a predominance of *Dicranopteris linearis*. Fire does not operate with the same intensity each year; in wet years the impact is likely to be much less than in dry years, even given the accidental nature of many spreading fires. We therefore seem to have at best a fairly unstable edaphic equilibrium, especially around the outskirts of the forest patches where we often find many specimens of *Geissois ternata* among the forbs. The implication is of a fluctuating boundary between the formations. In the wetter zones the forest sustains a considerable dynamism. Clearings made by fire, and then cultivated, are fairly swiftly overgrown by forest type vegetation during the fallow period. In the long run, however, the impact of fire is particularly degrading in edaphically unstable areas. The forest tends to retreat under its impact.

#### The effect of cultivation

Cropping has important effects through clearing, the resulting exhaustion of soils and the introduction of new species. Especially in edaphically unstable areas on the forest edge, cultivation tends to accelerate the retreat of the forest caused by fire. In many areas, reed thicket has become established in the place of forest after repeated cassava plantings. Some swampy grasslands long cultivated for taro, and abandoned several years ago, did not return to swamp forest because the soil had become exhausted and more acid. This is especially the case of the Levuka swamp in the south of the island, which has now lain uncultivated for almost 20 years. Where coconuts have been planted, however, the regrowth of secondary forest and undergrowth is facilitated; even though we may decry the use of good land for coconuts during the past century, therefore, it is possible that the state of the land will ultimately be better, when it comes to be used again for other purposes, than it would have been if the former system had continued.

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#### CONCLUSION

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The introduction of new species has had major effects on the flora throughout Fiji, especially on the main islands (Parham, 1958). Despite the isolation of Lakeba, a considerable number of new species has reached this island, though the effect is less devastating than in other parts of Fiji. With the exception of the mangroves, there is not one of the vegetation communities described above that does not contain some introduced species. Some introductions have been deliberate and a whole range of new crops is in this category. Others, however, have been accidental, and are either neutral in their effect on man or even to his disadvantage. A case in point is the over-running of many coconut groves with weeds, greatly reducing the rate of nut collection and inhibiting use of the land under the palms for cattle or cultivation. Taro fields and cassava patches may also be invaded by weeds such as *Stachystarpheta urticaefolia*, *Mimosa pudica*, *M. invisa* and *Malvastrum coromandelianum*, which impede growth unless labour and time are employed to eradicate or control them. As in many other parts of the world, floristic introductions such as these can become an increasing nuisance, and a disincentive to agricultural production.

Finally, mention should be made of the cutting of wood for houses, canoes and firewood; over time, this extraction has greatly reduced the number of large trees in the forests, and Lakeba has for many years, perhaps centuries, imported large-timber articles such as house-posts and canoes from other islands. The introduction of a portable sawmill as part of hurricane relief in 1975 encouraged new depredations on the remaining forest areas around the limestone massif in western Lakeba.

In sum, it would appear that the 'equilibrium' is somewhat illusory, and that the long term trend is toward retreat of the forest and impoverishment of the vegetal cover of the island. Recent plantings of *Pinus caribaea* has, however, led to control over the use of fire, and this replanting of an impoverished area encourages hope for a reversal of the trend toward degradation. On the other hand, the recent expansion of yaqona cultivation in the forests, discussed below by M. Brookfield, is a contemporary trend in the opposite direction.

#### CONCLUSION

This paper can only conclude on a number of questions. It has been established that the soil-vegetation complex of Lakeba has changed very greatly through several phases since the island was formed, and that even before the advent of man some of these changes have been of a very major order. Since the arrival of man, however, a new and disruptive force has entered the scene, and this force has wrought great change on a fragile natural ecosystem. An anthropogenous origin is postulated for the talasiga, which now covers almost 60 per cent of the island. More than a third of the plant species identified have been introduced to Lakeba, whether intentionally or unintentionally. Burning has exposed slopes to erosion, and it is clear that erosion continues to predominate over weathering in this island, though probably with a lesser margin than in an earlier period when sedimentation in the swamps was much more rapid than today. Erosion regularly truncates the soil horizons, and degrades the soil by removal of the humiferous and most fertile horizons. The relation to these modern changes to earlier changes is, however, a continuing question of major importance. Later papers in this Island Report seek to shed more light on this problem.

#### ACKNOWLEDGEMENTS

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by M. Brookfield, and the whole was then partly re-cast in free translation by the editor. The author acknowledges this assistance, but while he is thereby freed from responsibility for errors in translation, he remains responsible for all material and views presented in this paper.

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APPENDIX I: CORRELATION BETWEEN THE FAO/UNESCO LEGEND AND THE CLASSIFICATION OF TWYFORD AND WRIGHT C.P.C.S AND U.S.

SOIL TAXONOMY

FAO/UNESCO	TWYFORD AND WRIGHT CLASSIFICATION	CLASSIFICATION C.P.C.S. (FRENCH SYSTEM)	SOIL TAXONOMY
HISTOSOLS	Organic soils	Sols hydromorphes organiques	Typic Tropohemist
FLUVISOLS			
Thionic Fluvisols	Saline soils of the marine marsh	Sols peu évolués d'apport marin	Typic Sulfaquepts
Eutric Fluvisols	Recent soils from alluvium	Sols peu évolués d'apport alluviaux	Typic Udifluvents
GLEYSOLS			
Humic Gleysols	Gley soils	Sols hydromorphes moyennement organiques a gley	Typic Tropaquepts
RENDZINA	Recent soils from coastal sand	Sols calcimagnésiques, carbonates, rendzinas	Rendolls
FERRALSOLS			
Humic Ferralsols	Humiferous latosols	Sols ferrallitiques fortement désaturés typiques humiques.	Oxisols Haplohumox
Acric Ferralsols	Ferruginous latosols	Sols ferrallitiques fortement désaturés appauvris	Typic Acrorthox
Rhodic Ferralsols	Latosolic soils	Sols ferrallitiques fortement désaturés typique modaux	Haplorthox
LUVISOLS			
Chromic Luvisols	Ferruginous latosols	Sols ferrallitiques moyennement desatures lessives	Typic Rhodudalf
CAMBISOLS			
Humic Cambisols	Latosolic soils	Sols brunifiés des pays tropicaux, bruns eutrophes humiques.	Humitropepts
Ferralic Cambisols	Ferruginous latosols	Sols ferrallitiques fortement désaturés rajeunis	Dystropepts
Eutric Cambisols	Nigrescent soils	Sols brunifiés des pays tropicaux bruns eutrophes peu évolués	Eutropepts

Acric ferri  
 Location:  
 Climate:  
 Position:  
 Parent Ma:  
 Vegetation  
 A<sub>1</sub> - 0 - 1  
 A<sub>3</sub> - 8 -  
 B<sub>1</sub> - 52 -  
 B<sub>2</sub> - 85 -  
 B<sub>3</sub> - 120 -  
 B<sub>3</sub>C - 150  
Humic Fer  
 Location:  
 Climate:  
 Position:

APPENDIX II: DESCRIPTION OF THE MAIN SOIL PROFILES

Acric ferralsols LK 12

- Location: Lakeba, central zone of the island; elevation 220 m.
- Climate: oceanic tropical with a marked dry season, precipitation: 2000 mm/year.
- Position: Upper plateau level; flat.
- Parent Material: andesite.
- Vegetation: Herbaceous vegetation; low forb communities (talasiga); herbaceous strata: *Dicranopteris linearis*, *Pteridium esculentum*, *Gramineae*, *Compositae*; ligneous strata: *Dodonaea viscosa*, *Metrosideros collina*, *Miscanthus floridulus*, *Pandanus odoratissimus*, *Casuarina equisetifolia*.
- A<sub>1</sub> - 0 - 8 cm: Moist; dark reddish brown; 5 YR 3/2; with non-visible organic matter; sandy loam; many small ferro-manganesiferous concretions; some millstone grits on the soil surface; weak fine subangular blocky structure; great macroporosity; friable; abundant fine and medium roots; clear smooth boundary.
- A<sub>3</sub> - 8 - 52 cm: Moist; dusky red; 5 YR 3/4; silt loam; many small ferro-manganesiferous concretions; weak fine to medium subangular blocky structure; great macroporosity, many tubular pores; very friable; abundant fine and medium roots; gradual smooth boundary.
- B<sub>1</sub> - 52 - 85 cm: Moist; dusky red; 5 YR 3/4; clay; some ferro-manganesiferous concretions; weak medium blocky structure; some pores in the aggregates; firm; some fine to medium roots; gradual smooth boundary.
- B<sub>2</sub> - 85 - 120 cm: Moist; red; 2.5 YR 4/6; clay; some ferro-manganesiferous concretions; moderate medium blocky structure; slightly porous; shiny peds; weakly cemented; some fine roots; gradual smooth boundary.
- B<sub>3</sub> - 120 - 150 cm: Moist; red; 2.5 YR 4/6; clay; few ferro-manganesiferous concretions; moderate medium blocky structure; slightly porous; shiny peds; friable; no roots; gradual smooth boundary.
- B<sub>3</sub>C - 150 - 190 cm: Moist; red; 2.5 YR 4/6; clay; weak medium blocky structure; some tubular pores; friable; no roots.

Humic Ferralsols LS 10

- Location: Lakeba, central zone of the island, close to the Yadrana - Levuka track; elevation 130 m.
- Climate: oceanic tropical with a marked dry season; precipitation: 2000 mm/year.
- Position: undulated landscape; 30 per cent slope.

- Parent material: andesite.
- Vegetation: closed forest with *Geissois ternata*, *Ficus fulvopilosa*, *Pandanus odoratissimus*, *Melicope robusta*, *Cyathes* sp., *Nephrolepis* sp., *Entada phaseoloides*, *Mikania micrantha*.
- A<sub>1</sub> - 0 - 12 cm: Wet; pinkish gray; 7.5 YR 6/2; with non-visible organic matter; clay loam; strong fine granular structure; great macroporosity; some pores in the aggregates; friable; abundant fine, medium and coarse roots; clear smooth boundary.
- A<sub>3</sub> - 12 - 30 cm: Wet; light brown; 7.5 YR 6/4; clay; strong medium to fine blocky structure; great macroporosity; some pores in the aggregates; plastic; slightly sticky; abundant medium to fine roots; clear wavy boundary.
- B<sub>2</sub> - 30 - 60/80 cm: Wet; pink; 7.5 YR 7/4; some fine distinct red mottles; clay loam; strong medium to coarse blocky structure; slightly porous; shiny peds; plastic; slightly sticky; medium to fine roots; gradual irregular boundary.
- B<sub>3</sub>C - 60/80 - 180 cm: Wet; very pale brown; 10 YR 8/4; loam; many more or less weathered andesitic fragments; weak medium blocky structure; slightly porous; slightly plastic; non-sticky; little roots.

#### Ferralsolic Cambisols LS 11

- Location: Lakeba; hill between Tubou and the airstrip; elevation 80 m.
- Climate: oceanic tropical with a marked dry season; precipitation: 2000 mm/year
- Position: Summit of an eroded hill; 3 per cent slope.
- Parent material: andesite
- Vegetation: Herbaceous vegetation; low forb community (talasiga); herbaceous strata: *Dicranopteris linearis* predominating; ligneous strata: *Dodonaea viscosa*, *Wickstroemia foetida*, *Casuarina equisetifolia*, *Pandanus odoratissimus*, *Morinda citrifolia*.  
On the soil surface, some pinkish grits of weathered andesite.
- A<sub>1</sub> - 0 - 7 cm: Wet; weak red; 2.5 YR 4/2; with non-visible organic matter; sandy loam; many little grits of weathered andesite; moderate fine subangular blocky structure; great macroporosity; non-porous aggregates; non-plastic; non-sticky; numerous fine roots; clear smooth boundary.
- A<sub>3</sub> - 7 - 20 cm: Wet; weak red; 10 R 5/3; clay loam; weak medium to fine blocky structure; great macroporosity; slightly plastic; non-sticky; numerous fine roots some medium; clear wavy boundary.
- C<sub>1</sub> - 20 - 120 cm: Moist; weak red; 10 R 5/3; some fine distinct green gray and white mottles; silt loam; rock preserved structure; friable; porous, with tubular pores; no roots; gradual irregular boundary.

C<sub>2</sub> - 120 andChromic luvisol

Location:

Climate:

Position:

Parent material:

Vegetation:

A<sub>1</sub> - 0 - 12A<sub>3</sub> - 12 - 30B<sub>1</sub> - 30 - 50B<sub>2</sub> - 50 - 100

B C - 160 -

Eutric cambisol

Location:

Climate:

Position:

Vegetation:

A<sub>1</sub> - 0 - 12

C<sub>2</sub> - 120 and more: Hard rock sometimes little weathered with onion skin weathering features.

#### Chromic Luvisols LL 5

Location: Lakeba, Nukunuku valley behind Waitabu; elevation 20 m.  
 Climate: oceanic tropical with a marked dry season; precipitation: 2000 mm/year.  
 Position: linear valley bottom.  
 Parent material: colluvio-alluvial formation derived from andesite.  
 Vegetation: Herbaceous vegetation, tall forb community (talasiga); herbaceous strata: *Dicranopteris linearis*, *Nephrolepis* sp.; ligneous strata: *Pandanus odoratissimus*, *Leucosyke corymbulosa*, *Dodonaea viscosa*, *Geniostoma uninervium*, *Melastoma denticulatum*, *Morinda citrifolia*.

A<sub>1</sub> - 0 - 12 cm: Moist; dark reddish gray; 5 YR 4/2; with non-visible organic matter; loam; strong fine blocky structure; some fine weathered grits; great macroporosity; slightly porous aggregates; abundant fine to medium roots; clear smooth boundary.

A<sub>3</sub> - 12 - 30 cm: Moist; reddish brown; 5 YR 5/3; loam; abundant rounded weathered rock gravels; moderate medium blocky structure; great macroporosity; porous aggregates; friable; some fine to medium roots; gradual smooth boundary.

B<sub>1</sub> - 30 - 50 cm: Moist; reddish brown; 5 YR 5/3; clay loam; abundant small rounded weathered rock gravels; weak medium blocky structure; great macroporosity; friable; some fine roots; clear smooth boundary.

B<sub>2</sub> - 50 - 160 cm: Moist; reddish brown; 5 YR 5/3; clay loam; abundant rounded weathered rock gravels; weak medium subangular blocky structure; great macroporosity; clay skin on pores; friable; some medium to fine roots; gradual smooth boundary.

B C - 160 - 230 cm: Moist; light reddish brown; 5 YR 6/3; some gray and green faint mottles; loam; single grain structure; very porous; friable; no roots.

#### Eutric cambisols LC 9

Location: Upper Tubou valley; elevation 30 m.  
 Climate: oceanic tropical with a marked dry season; precipitation: 2000 mm/year.  
 Position: Lower part of a steep slope; 30 per cent slope.  
 Vegetation: Evergreen shrub (reeds); herbaceous strata: *Mimosa pudica*, *Nephrolepis* sp., *Hyptis pectinata*; ligneous strata: *Miscanthus floridulus*, *Pandanus odoratissimus*, *Psidium guajava*.

A<sub>1</sub> - 0 - 12 cm: Wet; dark brown; 7.5 YR 4/2; with non-visible organic matter; clay; compound very strong fine granular and fine blocky structure; great macroporosity; friable plastic; slightly sticky; very abundant medium to fine

- roots; clear smooth boundary.
- A<sub>3</sub> - 12 - 25 cm: Wet; brown; 7.5 YR 5/2; clay some slightly weathered andesitic stones; strong medium to fine blocky structure; great macroporosity; plastic; sticky; abundant medium to fine roots; clear smooth boundary.
- (B) C 25 - 25 cm: Wet; light brown to pinkish brown; clay; many slightly weathered andesitic stones; very strong medium blocky structure; great macroporosity; plastic; sticky; clear smooth boundary.
- C - 45 - 60 cm: Wet; pinkish gray; 7.5 YR 6/3; clay; abundant slightly weathered andesitic stones and blocks; strong medium blocky structure; plastic; sticky; some fine roots.

A<sub>3</sub> - 10 - 25B<sub>G</sub> - 15 - 45B<sub>G</sub>C - 45 - 12

C - 120 - 24

Eutric fluvisols LL 1

- Location: Lakeba; coastal plain; south of Nukunuku; 150 m from the mangrove.
- Climate: oceanic tropical; precipitation: 2000 mm/year.
- Position: coastal plain; flat.
- Vegetation: coconut plantation, *Cocos nucifera*, *Inocarpus fagiferus*, *Melicope robusta*, *Psidium guajava*, *Ocimum gratissimum*, *Stachytarpheta urticaefolia*.
- A<sub>1</sub> - 0 - 15 cm: Moist; reddish brown; 5 YR 4/3; with non-visible organic matter; clay; strong fine blocky structure; great macroporosity; some pores in the aggregates; friable; very abundant medium to fine roots; clear smooth boundary.
- A<sub>3</sub> - 15 - 55 cm: Moist; reddish brown; 5 YR 4/3; clay; strong medium to coarse blocky structure; slight macroporosity; some pores in the aggregates; firm; abundant medium to fine roots; gradual smooth boundary.
- C - 55 - 155 cm: Moist; reddish brown; 5 YR 5/3; clay; some sandy pockets; moderate fine blocky structure; slight macroporosity; some tubular pores; firm; some fine roots; clear smooth boundary.
- C<sub>g</sub> - 155 - 175 cm: Wet; red; 5 YR 4/4; many yellow and black distinct fine mottles; sandy clay; single grain structure; many small weathered andesitic gravels.

Humic gleysols LAK 2

- Location: Lakeba, upper Tubou valley swamp.
- Climate: oceanic tropical; precipitation: 200 mm/year.
- Position: swamp.
- Parent Material: recent mineral sediments.
- Vegetation: Hydromorphic fresh water vegetation; *Nephrolepis* sp., *Scleria polycarpa*, *Mikania micrantha*, *Ludwigia octovalis*, *Malvastrum coromandelianum*, *Hyptis pectinata*.
- A<sub>1</sub> - 0 - 10 cm: Wet; very dark gray; with visible organic matter; clay; moderate medium granular structure; great macroporosity; plastic; slightly sticky; very abundant medium and fine roots; clear and smooth boundary.

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to
- A<sub>3</sub> - 10 - 25 cm: Wet; mottled brownish gray, blue and rusty; with non-visible organic matter; clay; weak medium subangular blocky structure; slightly porous; very abundant fine roots; clear smooth boundary.
- B<sub>G</sub> - 15 - 45 cm: Wet; bluish gray with rusty channels around the roots with non-visible organic matter; clay; some small weathered andesitic grits; moderate medium blocky structure; plastic; very sticky; abundant fine roots; clear smooth boundary.
- B<sub>G</sub>C - 45 - 120 cm: Wet; grayish black; some brown and blue mottles; some weathered andesitic grits; weak medium blocky structure; plastic; sticky; some very fine roots; gradual smooth boundary.
- C - 120 - 240 cm: Wet; weathered rock with red, pink and gray veins; loam; firm; some fine roots.



## APPENDIX III: LIST OF PLANTS IDENTIFIED AND LOCATION IN THE DIFFERENT VEGETATION UNITS (CONTINUED)

GENUS, SPECIES	FAMILY	ASSOCIATIONS											ORIGIN	
		1	2	3	4	5	6	7	8	9	10	11		
<i>Elatostema eximium</i> . A.C. Smith	Urticaceae												+	N
<i>Eleocharis dulcis</i> . Burm. F.	Cyperaceae												+	N
<i>Emelia sonchifolia</i> . Linn.	Compositae				+									I
<i>Entada phaseoloides</i> . Linn.	Mimosaceae	+					+					+		N
<i>Epipremnum pinnatum</i> . Linn.	Araceae	+												N
<i>Erechtites valerianaeifolia</i> . Wolf	Compositae											+		I
<i>Erythrina variegata</i> . Linn.	Papilionaceae					+								N
<i>Euphorbia hirta</i> . Linn.	Euphorbiaceae							+						N
<i>Ficus fulvo-pilosa</i> . Summerhayes	Moraceae	+	+	+										N
<i>Ficus greenwoodii</i> . Summerhayes	Moraceae													N
<i>Ficus obliqua</i> . Forst.	Moraceae		++			+								N
<i>Fimbristylis dichotoma</i> . Linn.	Cyperaceae							+	+	+	++			N
<i>Geissois ternata</i> . A.C. Smith	Cunoniaceae	++									+			N
<i>Geniostoma uinarnivum</i> . A.C. Smith	Loganiaceae			+				+						N
<i>Grewia prunifolia</i> . A. Gray	Tiliaceae			+										N
<i>Glochidion seemanni</i> . Muell. Arg.	Euphorbiaceae		++											N
<i>Guettarda speciosa</i> . Linn.	Rubiaceae			+		+								N
<i>Hibiscus diversifolius</i> . Jacq.	Malvaceae											+		N
<i>Hibiscus tiliaceus</i> . Linn.	Malvaceae			+		+								N
<i>Hyptis pectinata</i> . Linn.	Labiatae			+		+	+	+			+			I
<i>Inocarpus fagiferus</i> . Parkinson	Caesalpiniaceae		++			+								N
<i>Ipomoea aquatica</i> . Forsk	Convolvulaceae												+	N
<i>Ipomoea batatas</i> . Linn.	Convolvulaceae					+					+			C
<i>Ipomoea congesta</i> . R. Br.	Convolvulaceae			+										N
<i>Ipomoea gracilis</i> . R. Br.	Convolvulaceae	+		+		+					+			N
<i>Leucosyke corymbulosa</i> . Wedd.	Urticaceae								+					N
<i>Lindsaea ensifolia</i> . Swartz	Pteridaceae	++									+			N
<i>Litsea pickeringii</i> . A. Gray	Lauraceae		++											N
<i>Ludwigia octovalvis</i> . Raven	Onagraceae											++		I
<i>Lycopodium cernuum</i> . Linn.	Lycopodiaceae							+						N
<i>Lygodium reticulatum</i> . Schkuhr.	Solizaeaceae	++												N
<i>Maesa tabacifolia</i> . Mez.	Myrsinaceae							+						N
<i>Malvastrum coromandelianum</i> . Linn.	Malvaceae	++				+		+						I
<i>Mangifera indica</i> . Linn.	Anacardiaceae			+		+		+						C
<i>Manihot esculenta</i> . Crantz	Euphorbiaceae	++	+			+	+	+						C
<i>Melastoma denticulatum</i> . Labill.	Melastomataceae							+	+	+	+			I
<i>Melicope robusta</i> . A.C. Smith	Rutaceae	+				+								N
<i>Messerschmidia argentea</i> . Linn.	Boraginaceae					+								N
<i>Metrosideros collina</i> . Forst.	Myrtaceae							+		+	+			N
<i>Microsorium scolopendria</i> . Burm.	Polypodiaceae	+								+	+			N
<i>Mikania micrantha</i> . H.B. et K.	Compositae	++		+		+	+					+		I
<i>Mimosa invisa</i> . Mart.	Mimosaceae												+	I
<i>Mimosa pudica</i> . Linn.	Mimosaceae					++	+	+						I
<i>Misconthus floridulus</i> . Labill.	Gramineae					+	+++	+	++	+	++			N
<i>Morinda citrifolia</i> . Linn.	Rubiaceae					+	++	++	+	+	+			N
<i>Musa nana</i> . Lour	Musaceae	+	+			+								C
<i>Mussaenda ratateensis</i> . J.W. Moore	Rubiaceae							+	+					N
<i>Nephrolepis</i> sp.	Davalliaceae	++	++			+	+	++	++	+	+	++		N
<i>Ocimum gratissimum</i> . Linn.	Labiatae					+	+							I
<i>Pandanus odoratissimus</i> . Linn.	Pandanaceae	++	+	+++				+	++	++	+	+		N
<i>Passiflora foetida</i> . Linn.	Passifloraceae					+		+	+	+				I

## APPENDIX III: LIST OF PLANTS IDENTIFIED AND LOCATION IN THE DIFFERENT VEGETATION UNITS (CONTINUED)

GENUS, SPECIES	FAMILY	ASSOCIATIONS											ORIGIN
		1	2	3	4	5	6	7	8	9	10	11	
<i>Pennisetum polystachyon</i> Linn.	Gramineae							+			+		I
<i>Physalis peruviana</i> Linn.	Solanaceae					+							I
<i>Pinus caribaea</i> Morelot	Pinaceae							+	+	+			C
<i>Piper methysticum</i> Forst.	Piperaceae	+	+										C
<i>Piper timothianum</i> A.C. Smith	Piperaceae	+	+										N
<i>Pittosporum braekenridget</i> A. Gray	Pittosporaceae												N
<i>Polygala paniculata</i> Linn.	Polygalaceae							+		+	+		N
<i>Pometia pinnata</i> J.R. and G. Forst	Sapindaceae					+							N
<i>Premna taitensis</i> Schaver	Verbenaceae					+							N
<i>Psidium guajava</i> Linn.	Myrtaceae			+		++	+	+	++	+			I
<i>Pteridium esculentum</i> Forst.	Pteridaceae							+	+++	+++	++	++	N
<i>Rhizophora</i> spp.	Rhizophoraceae				+								N
<i>Santalum yasi</i> Seem.	Santalaceae					+							N
<i>Soaveola floribunda</i> A. Gray	Goodeniaceae	+						+					N
<i>Schizaea dichotoma</i> Linn.	Schizaeaceae							+					N
<i>Scleria polycarpa</i> Boeck.	Cyperaceae											+	N
<i>Sida rhombifolia</i> Linn.	Malvaceae					+							I
<i>Spathoglottis pacifica</i> Reichb.	Orchidaceae									+	+		N
<i>Spilanthes paniculata</i> Wall.	Compositae					+							I
<i>Stachytarpheta urticaefolia</i> Salish	Verbenaceae					++		++	+	++			I
<i>Tacca maculata</i> Seem	Taccaceae						+	+	+	+			N
<i>Terminalia catappa</i> Linn.	Combretaceae					+							N
<i>Tripsacum lamn.</i> Nash.	Gramineae											++	I
<i>Urena lobata</i> Linn.	Malvaceae			+									I
<i>Wikstroemia foetida</i> Linn. f.	Thymelaeaceae							++	+	++			N
<i>Xanthosoma sagittifolium</i> Linn.	Araceae	+				+							I

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II

III

REFERE

TABLE

FIGUR

UNITED NATIONS EDUCATIONAL  
SCIENTIFIC AND CULTURAL  
ORGANIZATION (UNESCO)

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THE UNESCO/UNFPA POPULATION AND  
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ISLAND REPORTS

NO. 5

LAKEBA: ENVIRONMENTAL CHANGE,  
POPULATION DYNAMICS AND RESOURCE USE

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## GENERAL NOTE

The 'Island Reports' of the UNESCO/UNFPA Population and Environment Project in the Eastern Islands of Fiji are supplementary reports to the General Reports of the Project. Being on specific topics of more restricted scope than the General Reports, they are produced in only a limited edition. Subject to the general approval of the editor they are the responsibility of the authors concerned. The views presented in these Reports are not necessarily those of UNESCO and UNFPA.

The series replaces the 'Project Working Papers', which were preliminary statements published before the General Reports of the project were in draft. One of the Project Working Papers is reproduced in this series, being of a definitive nature; the others, of which only small stocks now remain, are not republished. However, a statement of the formerly-proposed numbers of Project Working Papers, as advertized in our General Report No. 1, is appended to each Report to facilitate cross-reference.

There are five issues of these 'Island Reports', as follows:

1. The hurricane hazard: natural disasters and small populations
2. Koro in the 1970s (reprinted from Project Working Paper No. 7)
3. Land, population and production in Taveuni District
4. The small islands and the reefs
5. Lakeba: environmental change, population dynamics and resource use

The series has been edited in Melbourne, by the former Chief Technical Adviser of the project, assisted by Tyna Charles. It is published for UNESCO at the Socpac Printery, Australian National University, Canberra. The series is not for sale, and is distributed by UNESCO and for UNESCO by the Australian National Commission for UNESCO to individuals and institutions in Fiji and elsewhere. A limited number of additional copies is available from UNESCO, Paris, and from the Department of Geography, University of Melbourne, on payment of a nominal charge to cover handling costs and postage. All enquiries should be addressed either to the Division of Ecological Sciences, UNESCO, or to the Secretary, Department of Geography, University of Melbourne, Parkville, 3052, Australia.

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## A NOTE ON PRONUNCIATION AND SPELLING

The standard Fijian spelling is used through this Island Report as in all reports of the project. It departs from normal English usage in the following:

b is pronounced mb as in lumber  
 c is pronounced th as in this  
 d is pronounced nd as in hand  
 g is pronounced ng as in ring  
 q is pronounced ngg as in singer (i.e. with greater stress)

There are differences in practice between hard and soft use of these consonants, and the pre-nasalization of 'b' and 'd' ranges from very slight to very strong, but these differences are not reflected in the spelling of the word.

Thus in this report:

LAKEBA is pronounced LAKEMBA  
 TUBOU is pronounced TUMBOW  
 YADRANA is pronounced YANDRANA  
 NASAQALAU is pronounced NASANGGALAU  
 KEDEKEDÉ is pronounced KENDE-KENDE  
 YAQONA is pronounced YANGGONA

The stress in Fijian words of two syllables is either on the first syllable, or equal between both syllables. In longer words it is usually placed on the second syllable.

prede  
 analy  
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