Soils of the Kingdom of Tonga

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compiled by

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PREFACE

We all need soil; every country in the world is dependent on the wise use of soil. Soil is the resource that has sustained mankind for thousands of years and, with proper use, could continue this support for thousands more to come. Many other resources, which currently appear essential, may not last much past the end of the 20th century. Thus every nation should value, understand and preserve its soil. This booklet has been produced as an aid to achieving this aim.

In 1976 a comprehensive soil survey of the Kingdom of Tonga was carried out by staff of N.Z. Soil Bureau, DSIR, as part of the New Zealand Bilateral Aid Programme. The detailed results of this survey are contained in soil maps and soil survey reports, but it is important that the information should be more widely available, to all concerned with Tongan soils.

This booklet describes the kinds of soils which are found in the Kingdom of Tonga, how they have been formed, where they occur in the landscape, and their and good and bad features. It is the result of a combined effort by the staff of the N.Z. Soil Bureau and the Ministry of Agriculture, Forests, and Fisheries, Kingdom of Tonga.

We hope that it will serve as a useful introduction to the more technical reports that are now being published, and will alert all readers to the value of Tongan soils, the need to protect and preserve them wisely, and the need to continue the well established Polynesian tradition of conservation and efficient land use.

WHY WE NEED TO KNOW ABOUT SOILS

The Kingdom of Tonga needs to grow more crops in order to supports its people and to export to other people. To do this growers, advisers, and planners need to know more about the soils in which these crops grow.

In 1976, the N.Z. Soil Bureau, D.S.I.R., carried out a series of **soil surveys** on selected islands throughout the Kingdom of Tonga. These surveys followed basic surveys on Tongatapu (1965) and Vava'u (1969). They were done to find out what kinds of soils there are in the Kingdom of Tonga and to show on maps where the different soils are found. The results of these surveys are to be printed in the form of technical reports and soil maps. Some of these are already published.

If growers get to know the good and bad points of their soils and how the soils' properties affect crops, they can work out how to use their soils to get better yields. In the same way planners and advisers can use the information to encourage wise land use in the future. For example, the best soils should be left for agriculture; houses with septic tanks should not be built on wet soils.

This booklet explains the soils in a non-technical way. When you have read the booklet, and if you want to know more about the soils of the Kingdom of Tonga, extra information can be found in the reports and soil maps listed on page 46.

WHERE DO SOILS COME FROM?

Soils are formed in the top layers of the land surface from deposits of many different kinds. The deposits may be solid or broken up, and they may be as different as volcanic ash and coral. Before we consider how soils are formed we must look at what kinds of deposits are found in the Kingdom of Tonga, because this makes a big difference to the soils that we find.

The islands of the Kingdom of Tonga are all of different height, size, and shape. This is because of the different ways in which they have been built up and then changed by the rain and sea over many thousands of years. There are **steep volcanic islands** like Tofua, Kao and Late on the western fringe of the Kingdom. Tongatapu, Lifuka, and Ma'afeva are examples of **low coral islands** with a covering of **volcanic ash**. These are the most common types of island throughout the Kingdom. 'Eua and Vava'u are examples of **raised coral islands** with a volcanic ash cover.

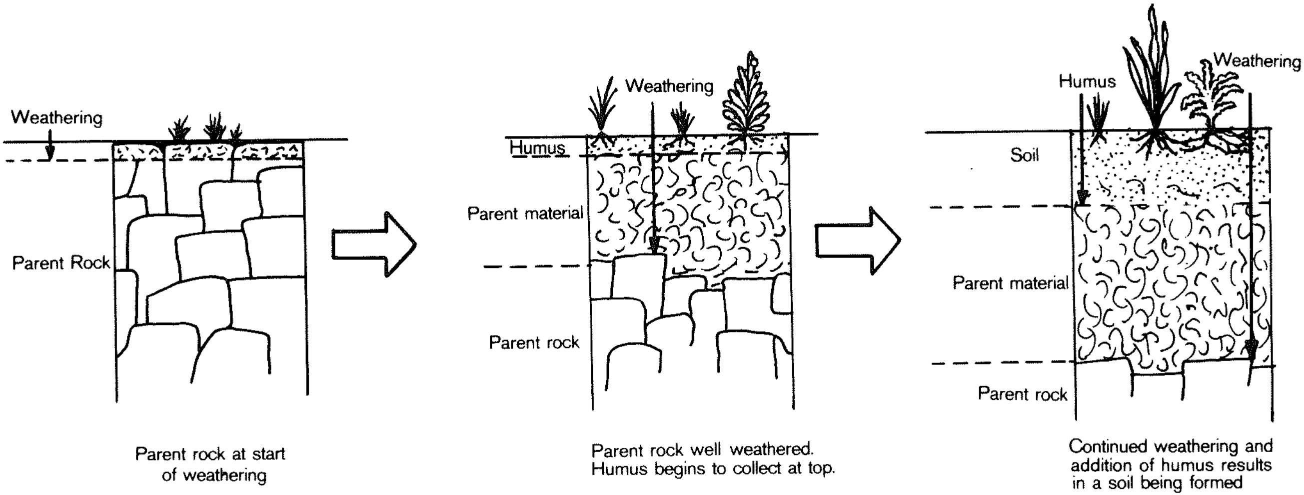


Figure 1 *The beginnings of a soil. Weathering of the parent rock, and formation of humus on top, go deeper and deeper with time.*

PLATE 1 *Oblique aerial view of Tongatapu looking north-west from Toloa towards the hook of Tonga, showing gently undulating surface of the low, ash-covered coral platform. A small remnant of original forest cover is prominent amongst the cultivated apis.*

Tongatapu

This island is about 35 kilometres (21 miles) from east to west and 15 kilometres (9 miles) from north to south. It is a low, raised coral island with a gentle slope rising towards the south-east. The land is flattish and there are no **permanent streams** (Plate 1). Over many years a layer of up to 3 metres of volcanic ash has accumulated on the surface and it is this volcanic ash which forms the major parent material of the soils on Tongatapu. There are smaller areas of **coral sands** around the coast and where old lagoon deposits form flat areas behind some of the present beaches.

PLATE 2 *Oblique aerial view of 'Eua looking north-west. Much original vegetation still clothes this terraced, raised coral island. The bare high areas above the eastern liku coast are windswept and considerably cooler than the lower terraces. Soils are developed primarily from a cover of volcanic ash except on steeper land where it has been eroded away and the underlying limestones exposed.*

'Eua

Lying some 20 kilometres (12 miles) south-east of Tongatapu, 'Eua presents a complete contrast. There are **rolling hills, streams** and **high cliffs** on an island composed largely of **coral limestone** but with some **volcanic rocks**, and covered by a mantle of volcanic ash up to 3 metres deep (Plate 2).

Ha'apai

About 160 kilometres (100 miles) north of Tongatapu lies the thin curving **archipeligo** of the Ha'apai group. The main islands of this group are flat, low-lying coral islands with a mantle of up to 3 metres of volcanic ash. There are significant areas of coral sands near the coasts of most of these islands.

PLATE 3 *Oblique aerial view of Vava'u looking south-west from slightly west of Tefisi. Note the tiered appearance of M'oungalafa to the left of the photograph, indicating irregular uplift of the island, and the gently sloping surface, indicating greater uplift of the western side. The bare areas immediately behind the western liku are exposed to salt laden winds, especially hurricanes, which limit the growth of some plants. The volcanic island Late is in the distance.*

Within the group there are some higher islands showing a considerable range of landforms and slopes, e.g., Nomuka and Mango, and some islands are composed partly of rocks other than coral limestones (**volcanic tuffs, marl, organic sediments**).

Vava'u

This group is 113 kilometres (70 miles) north of Ha'apai, the main island of Vava'u being surrounded by a number of smaller islands which are separated from the mainland by numerous narrow channels. Most of the larger islands of this group are raised coral islands (Plate 3), but there are also many low coral islands in this group. All are covered with a layer of volcanic ash up to 5 metres thick.

Volcanic Islands

On the western fringe of the Ha'apai and Vava'u groups there is a chain of **active** and **recently active volcanoes** such as Tofua, Kao, Late and Fonualei. These islands are made from young volcanic materials and generally have a central core of steeper country (**the volcanic cone**) with a fringe of flatter land. There is little in the way of coral reef material or beach deposits around these islands.

HOW DO SOILS FORM?

The unchanged material or rock from which a soil is made is called the **parent rock** of the soil. Many things help to turn this parent rock into a soil. When a rock becomes 'rotten' or **weathered** the top layer turns first into a softer material known as **parent material**, in which small plants can take root. Then, as the weathering goes on, more and bigger plants take root, and the **soft material** gets darker as **organic matter** or **humus** (matter from the breakdown of dead leaves etc.) builds up. Once this dark layer can be seen, even if it is quite thin, we have a **soil** (Figure 1). In Tonga the original material which **weathered** to give rise to the parent material of the soil was, in most cases, soft volcanic ash. Only in very restricted areas are the soils derived from hard rock.

The kind of soil that is formed in a particular place depends not only on the kind of rock that it comes from, but also on all the things that alter it as it forms (Figure 2). Some of the main things which help to make a soil, and which go on changing it afterwards, are listed below.

Climate

The weather or climate in any place affects the soil directly and controls the process that we call **weathering**. This results from repeated heating by the sun and wetting by the rain. Weathering causes the parent rock to be slowly softened and changed chemically and at the same time to break up into smaller and smaller particles.

Climate also affects the soil by controlling the kinds of plants that can grow there, and the speed at which dead plants and animals can decay (break down) and return to the soil. In the warm wet climate of the Kingdom of Tonga, the speed of weathering and decay is quite fast.

The shape of the land

The shape of the land (its **topography**) and, in particular, its **slope** or **steepness** can have a big effect on soils. In flat or nearly flat places, as in

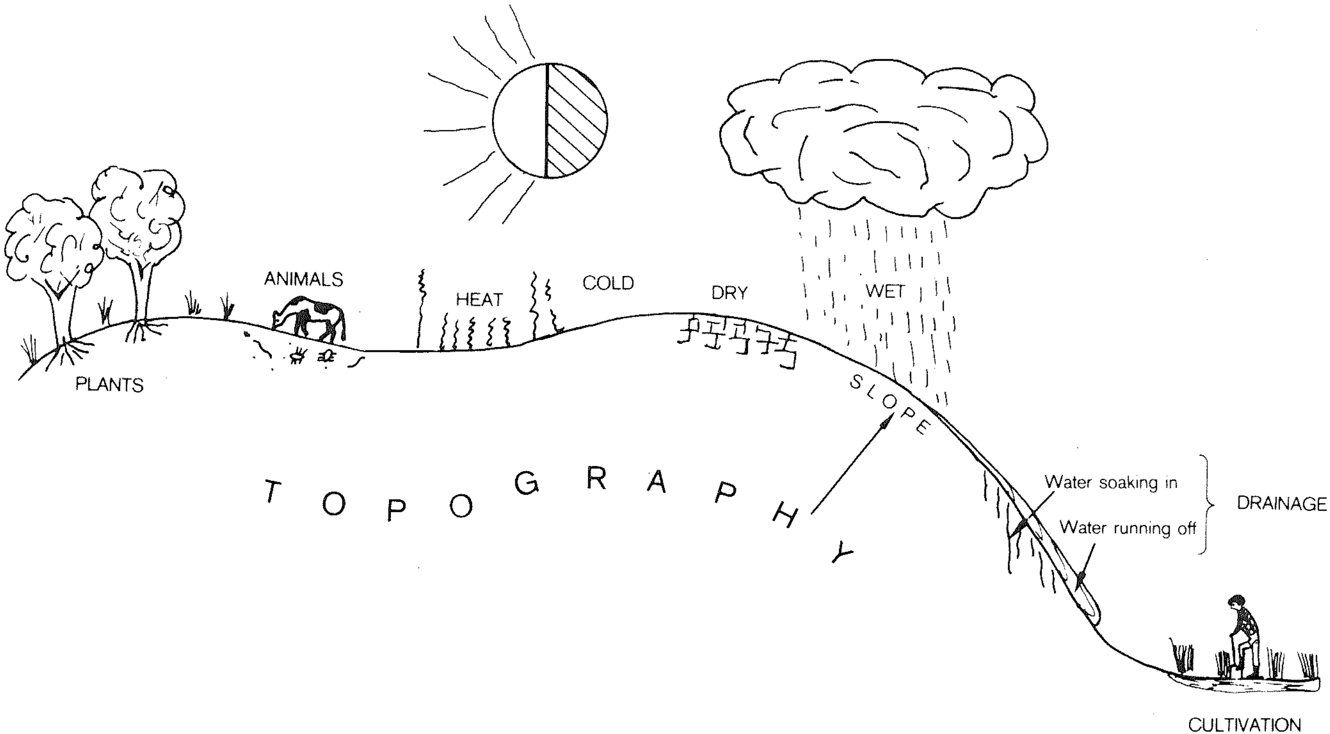


Figure 2 *Things that affect soils. All of these, together with the nature of the parent rock, affect the way and the speed with which soils develop.*

Tongatapu, the soil is often deep, but in steep places as on the liku coast of Vava'u, it is likely to be thin because the top layers slide, or get washed, downhill. This latter factor is very important as it affects the thickness of the layer of volcanic ash which covers most of the land in the Kingdom of Tonga.

Living things

Plants: Plants affect soils in a number of ways. They protect the top layer of the soil against erosion. Their roots go into the soil and make many small channels down which water can get into the deeper layers. At the same time they shade the soil from the sun's heat and stop the water from evaporating back into the air too quickly. Lastly, their dead leaves, twigs, roots, etc., which we call **plant litter**, break down and add organic matter and nutrients to the soil.

Animals: Soils are affected by the animals that live in them (such as earthworms and beetles) as well as those that live on them (such as pigs). Animals within the soil speed up the breakdown of dead plant matter and mix it with the rest of the soil. Animals living on top of the soil affect it in other ways; for example, pigs mix it up by rooting in it and make it muddy by trampling on it. However, they also help to make the soil richer by returning droppings to it.

Micro-organisms: The very smallest living things in a soil ('micro-organisms') cannot be seen by eye, but they also help in the breakdown of dead plants and animals. They help to change dead things into organic matter or humus and then into 'foods' or **nutrients** that living plants can use again.

Drainage

When rain falls, some of the water soaks into the soil and some runs off along the surface. Water soaking in is called **infiltration** while water flowing away on the surface is called **runoff**.

Infiltration

Many of the important nutrients that are needed by crop plants, are moved downwards in the soil (**leached**) by water. The speed with which this happens depends on the amount of rain and how easily it sinks through the soil (**soil permeability**). Once these nutrients go too deep in the soil, plant roots cannot reach them.

Runoff

This does not affect the soil unless there is enough to actually wash the top part of the soil away. This, when it happens, is called **soil erosion**, and it must be stopped if a soil is to go on growing crops.

Cultivation

If the soil is cultivated for crops changes occur. For example, deep cultivation (yam pit preparation, etc.) mixes up the top and lower layers. This usually, but not always, has good results. Also fertiliser can greatly change the soil. When a soil has been cultivated for a long time it may become quite different in colour, texture, etc. from what it was like before cultivation.

Time

Time is important to all of the soil forming processes. The amount by which a soil has developed or changed depends on how long the soil forming processes have been acting.

WHAT DOES A SOIL LOOK LIKE?

Usually a soil is formed on top of its parent rock, but sometimes it is formed from material which has been carried by air or water. In the Kingdom of Tonga the most common material from which soils form is volcanic ash (**tephra**). This has been ejected from volcanoes along the western margin of the Kingdom, carried through the air and then has settled over the land (and sea) to build up a 2- to 3-metre (sometimes 5-metre) layer of ash over the land surface. As this ash has accumulated gradually over a long period of time, weathering has kept pace with its accumulation, and there is little evidence of what this material looked like when it had freshly arrived. This means that there is little evidence of parent rock in this material; it has all been transformed to 'parent material' and 'soil'. The rocks (generally coral limestone) which occur below this mantle of volcanic ash are in no way related to the volcanic ash at the surface.

The development of any soil results in the appearance of layers which we call **horizons**. These horizons can easily be seen by looking at soil in a roadside bank, in a ditch or in a pit. The soil face exposed by such a cut is called a **soil profile**.

The soil profile extends from the ground surface down to the parent material. In old soils that have been weathering for a long time the soil may be very deep. In young soils, where there has been only a short time for weathering, the parent material may be close to the surface and the soil very thin. In the Kingdom of Tonga, because the volcanic ash has been built up by eruptions over a long time, we are able to find old soils which have been buried by later volcanic ash.

The **soil scientist** who makes a soil map digs many small pits across the land to expose the soil profiles in different places. The layers or horizons of each profile are then studied and compared with those of other profiles.

When we study soil profiles we look at many properties in each horizon. Some of the properties that the soil surveyor describes are the soil's **colour, texture, consistence** and **structure**.

Soil colour

The colour of a soil tells us much about the parent material and the conditions under which it has formed. For example, **topsoils** are dark coloured because of humus, and usually the darker they are the more humus is present. The amount of humus, in turn, depends on the climate and vegetation. Grey colours in the horizon can mean that it is wet for much of the year. Red colours in a well-drained soil show that the soil is old and weathered and probably rich in iron.

Soil texture

The **mineral** part of a soil (that is, the part that comes from rock and not from plants) is formed as the parent material breaks down. **Soil texture** is a way of describing the size of the particles formed and the amount of humus present.

The texture is worked out in the field by rubbing the moist soil between finger and thumb and estimating the amount of **sand, silt** and **clay** present. Sands have a gritty feel, silts are smooth, and most clays are sticky and 'plastic' (can be pressed into different shapes).

Soil consistence

Soil consistence tells us how well the soil holds together, or how hard it is to break up and crush. If the soil is **loose** it will fall apart easily with little or no pressure. If a small amount of pressure is needed the soil is said to be **friable**, while if a lot of pressure is needed it is **firm** or **very firm**. A very firm soil will crush only under very strong pressure.

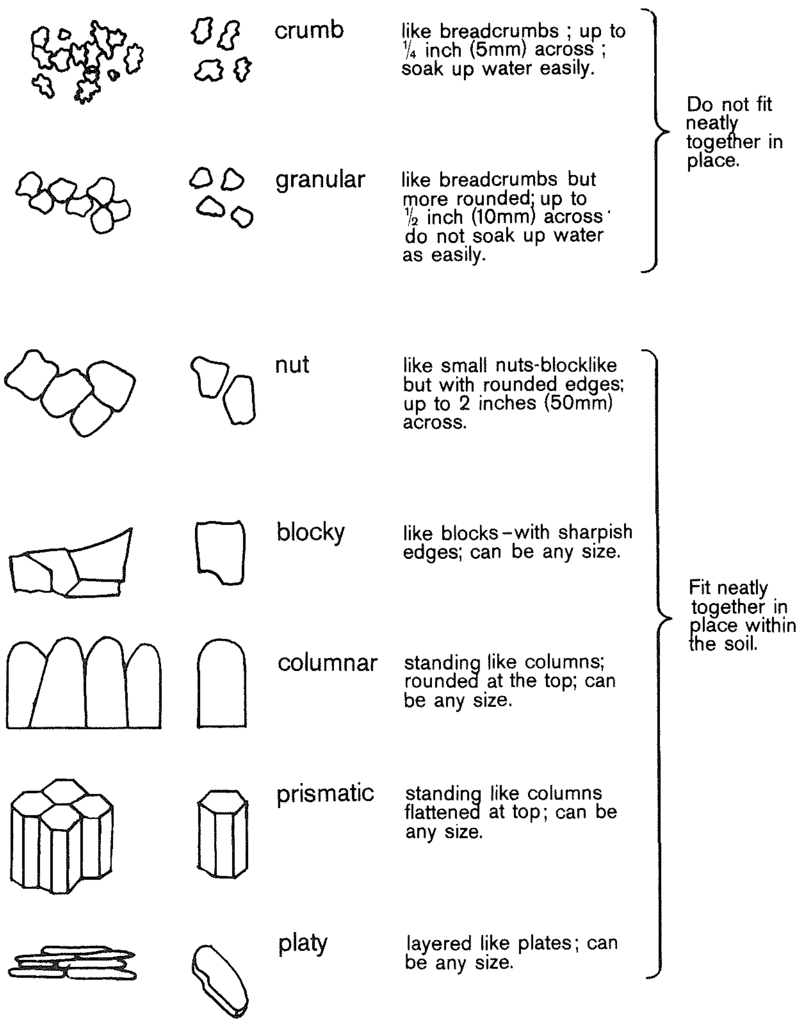


Figure 3 *Soil structure – the shape of peds. Soil lumps(peds), large or small, are classified according to their shape.*

Soil structure

The way in which soil mineral particles and organic matter are arranged together, leaving spaces between them, is called the **soil structure**. Lumps of small particles stuck together are called **peds** or **aggregates**. They are described by their size (fine, medium or coarse), their shape (see Figure 3), and how strongly they are formed (weakly, moderately or strongly).

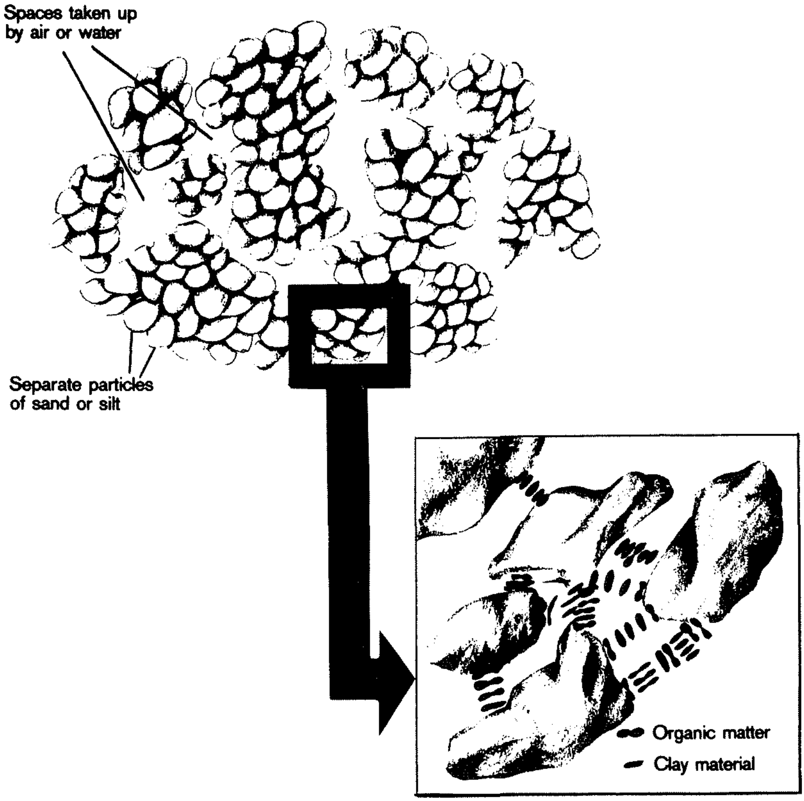


Figure 4 *Magnified view of a soil ped. This is an exploded and magnified view of a single ped – the spaces between the clumps are really much smaller than they appear here. The enlargement in the box shows how soil particles are joined together by organic matter and/or clay material.*

The presence of peds is important because spaces are left between them and within them (Figure 4). These spaces are very necessary for root growth and the movement of water and air within the soil. Unless a soil is well structured, crop yields will be low and erosion of the soil may occur. The structure of many soils may be damaged by too much cropping, or by the movement of machinery (such as tractors) over the soil when it is too wet. Intense treading by animals when the soil is too wet will also damage soil structure.

Figure 5 is a drawing of a soil profile in which different horizons can be seen. Nearest to the surface is the dark-coloured **topsoil**. This horizon is the most workable because the soil structure is better developed, and the peds are smaller and more easily parted from each other than in the lower

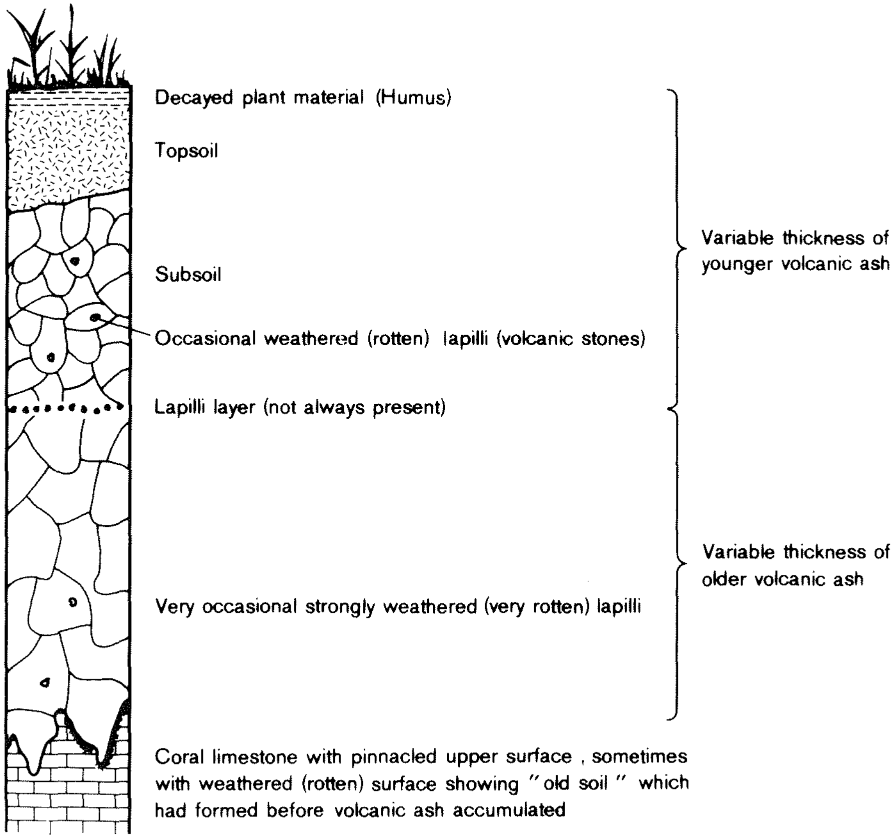


Figure 5 *The soil profile. This is a diagrammatic view of a small section of a typical Tongan soil as it might appear in a road cutting or pit. The different parts are described in detail by a soil scientist when he studies the soil.*

horizons. Beneath the topsoil is the **subsoil**. It is usually paler in colour or may be redder in colour. Generally it has larger but more weakly developed structures than the topsoil. It is also sticky when wet as it contains more clay. Usually subsoils can be expected to merge gradually into the parent material, which in turn rests on parent rock, but in the volcanic ash soils common throughout the Kingdom the subsoils often rest on older ash showers with buried soils.

Parent rock is found in only a few soils in the Kingdom. Each soil horizon has certain properties of colour, texture, consistence and structure that occur only in that horizon and are often quite different from the properties of the horizons above and below it. By examining the whole profile, and not just the topsoil, the soil scientist is able to learn a lot more about the soil and how it might best be used.

WHAT IS A SOIL MAP AND HOW IS IT USED?

When a soil scientist has looked at a number of soil profiles in a certain area he will find that some soils are very similar while others are quite different. Areas of soils that have mostly the same profile properties, even if they are a long way apart, are given the same name. An example is Vaini soil — all areas of soils that are labelled Vaini soil on a soil map will have similar properties. There might be some small differences between separate profiles of Vaini soils, but if a profile is very different then we are in an area of another soil.

The soil scientist draws a line on the map to show where one soil stops and another one starts. This is called a **soil boundary**. Often, however, one soil changes only slowly into the next. Here the soil boundary indicates a 'half-way' point between the two soils. The scale of the soil map puts a limit on how small an area of a particular soil can be shown on the map. This means that the soil scientist sometimes has to ignore small areas of different soils which he finds within a larger area of the main soil. Also, more than one soil may be present in any particular area. Some soils are found in small pockets in a very complex pattern. In such cases the whole area is mapped as a **soil complex**. The complex of Vaini and Lapaha soils on the eastern side of Tongatapu is an example of this relationship of soils.

Once the soil map is drawn, areas of similar soil can easily be picked out. Wherever a particular kind of soil is shown on the map the soil surveyor, agricultural advisory officers or farmers can expect to find mainly soil with these particular properties.

The **physical properties** of the soil (that is, its colour, texture, consistence, structure etc.) are important because they are the properties seen in the field. For this reason they are also the properties that the soil map shows best. However, the soil scientist often needs information on the **chemical properties** as well, to find out about the nutrients in the soil, so he collects soil material from several profiles, and this material is tested in the laboratory.

Once all of this information is obtained, records of past crop or pasture production collected, and perhaps some crop plants grown in pot and field trials, the soil map can be 'interpreted' to provide special purpose maps. These maps might show, for example, the areas most useful for bananas or yams, etc. ... or even houses. Now the soils best suited to a particular crop or use can be picked out and the use of soils can be properly planned. Each grower can be told what sorts of crops will grow best on his soil.

GOOD AND BAD POINTS OF SOILS

Whether a soil is good or bad depends a lot on what it is to be used for. A soil that is good for pineapples may not be so good for yams, and the soil that is on slopes too steep for ordinary crops might still be used for trees. Therefore, very few soils are just plain 'good' or 'bad' — most soils can be put to some use.

The very best soils are those that can be used to grow many different, valuable, high-producing crops without any problems of cultivation, drainage, irrigation, etc. The worst soils are probably the steepest soils which are very thin, impossible to cultivate and are liable to wash down slope. These soils are important in water conservation, however, and must be protected. Between those two extremes there is a wide ranges of soils suitable for many different uses. However, soils of different texture, drainage conditions, etc. will require different kinds of management. Coarse-textured soils, such as sandy soils (Tongan 'Tu'one'), usually drain easily and are also easy to cultivate, but may suffer from drought in the dry season. Some clay soils are slow draining and more difficult to cultivate, but they hold more moisture and dry out more slowly.

In the Kingdom of Tonga, temperatures are high throughout the year, with only a small difference between summer and winter. The rainfall is quite high, but most rain comes in summer, and during winter the soils become drier. The low levels of water in the soils from September to November may affect crop yields.

SOIL CONDITIONS PREFERRED BY COMMON CROPS

The following is a quick guide to the particular soil conditions preferred by some of the common crops.

Coconuts

Coconut palms will grow on almost any soil. However, for high yields of good-sized nuts giving high oil content and good cropra recovery they need a **deep, well-drained soil** without any compact layer or horizon near the surface. The use of a cover crop for **mulching** and increasing the soil's organic matter is recommended on coral sand soils (e.g., Uoleva soils). This practice will also reduce the risk of soil erosion caused by wind.

Root crops (kumala, cassava, yams, etc.)

All of them thrive on a wide range of soils, but **deep, well-drained, friable soils** are the best. Root crops need large amounts of plant nutrients and thus grow best on soils with good nutrient reserves. They also require adequate moisture, so the best soils for growing these crops should be capable of storing and supplying adequate moisture without being excessively wet. Any lack of nutrient may be made up by applying fertilisers to the soil, lack of moisture corrected by irrigation, and excess of moisture overcome by providing drainage.

Bananas

These can grow on a wide range of soils, but do best on those with plenty of **organic matter**. Soils affected by waterlogging or drought are not suitable. Bananas need moderate amounts of phosphorus and potassium, as well as nitrogen, and these may have to be added as fertiliser if there is not enough in the soil.

Pineapples

To grow pineapples, soils should be **deep, well-drained** and **acid**. Pineapples need large amounts of nitrogen and potassium, medium amounts of magnesium and smaller amounts of phosphorus and calcium. Some of these may need to be added as fertiliser if there is not sufficient in the soil.

Other crops (melons, tomatoes, peppers, cabbage, lettuce, beans, corn, carrots)

These all have different nutrient needs. In general, however, well drained, easily cultivated soils that are not affected by water-logging or drought and have good structure and reasonable nutrient reserves will be suitable.

GENERAL SOIL PATTERN OF THE SOILS OF THE KINGDOM OF TONGA

The majority of the islands mapped are raised coral islands with a mantle of **fine volcanic ash**. There are some exceptions to this generalisation but by far the greatest proportion of the soils of the Kingdom are derived from **fine-grained, andesitic volcanic ash**. These soils have excellent physical properties. They are **friable***, **well structured, well drained** soils with moderate **plant-available soil moisture**. This combination of factors means that they can be put to a wide variety of uses, and with sufficient fertilisers are able to give long-term production for a large number of various crops. There are of course a few crops for which the soils are not suited.

*'Friable' means that the soil crushes easily between finger and thumb, but sticks together when pressed.

Of the soil-forming factors previously discussed, parent material appears to be the one which is of most importance in the soils of Tonga. To fully understand the effect of parent material on soil formation in Tonga, it is important to know how the parent material for the soils developed. On the western margin of the country there is a north-easterly line of **volcanic islands**, including **Tofua, Kao, Late** and **Fonualei**. The volcanoes forming these islands are the source of the blanket of ash which covers most of the raised coral and raised volcanic islands of the main group of Tongan islands, from Tongatapu and 'Eua in the south, through the Ha'apai Group to the Vava'u Group in the north. These volcanoes must not be considered to be the only ones which have contributed volcanic ash, as many old volcanoes have probably sunk beneath the sea. Volcanoes of the type found in this western line of Tongan volcanoes generally produce quite large amounts of fine volcanic ash. In the Tongan situation most of the ash produced will have been blown away from the rest of islands by the prevailing south-east trade winds, but some has been able to accumulate on land, either having been blown there by winds from a westerly direction or as a result of volcanic eruptions actually directing the ash towards the east.

On close examination the ash layer is found to vary in two ways. Firstly, the size of the particles making up the ash becomes smaller as one travels eastward from the volcanoes. Secondly, it appears that there have been two main periods during which the ash accumulated. However, it must be pointed out that the volcanic ash was not all erupted from one volcano. Rather it came from a number of different volcanoes all or some of which may have been active at the same time. Also the two main periods of accumulation were not necessarily everywhere exactly the same two periods, though it is probable that they are roughly the same age. No accurate determination of the ages of the ashes has been carried out, but it is probable that the age of the older ash is about 20,000 years and the younger ash about 5000 to 10,000 years.

At first sight there appears to be little difference in the **vegetation** of Tonga, but close examination shows some remarkable differences. Such differences have had some effect on **soil development**. Although all of Tonga lies within the tropics, it is hardly fair to describe the climate as tropical. There are marked wet and dry seasons, but the persistent south-east trade winds tend to keep the temperatures lower than would otherwise be expected. Most of the main islands of Tonga have gentle slopes and it is only on steeper sites of some of the higher islands ('Eua, Mango, Vava'u) that the effects of slope become marked. Quite small differences in slope appear to have large effects on plant growth. Soils are separated into areas of different slopes (phases) which have been mapped on the detailed soil map of the research farm at Vaini, and broader scale slope phases are indicated where possible on the general soil map.

Soils of Tongatapu

Tongatapu is a raised coral platform which has been blanketed by the two distinct layers of volcanic ash previously described. These two layers of ash have weathered to form fertile soils over much of the island, but smaller areas of soils have also developed from **coastal deposits** associated with the **lagoons** and from **beach sands**. Six main soil units have been recognised and named Lapaha, Vaini, Fahefa, Fatai, Sopu, and Nuku'alofa soils. Figure 6 shows how the shape of the land and the kinds of soil parent materials affect the soils formed on Tongatapu.

Lapaha soils (Plate 4) occur on the eastern part of Tongatapu and are traditionally known as kelekeleumea, or clayey soils. They have a slight limitation of drying out at times when rainfall is low, but otherwise, with fertiliser added, they are suitable for a wide range of crops, though care should be taken not to attempt machine cultivation when the soil is very wet. Their parent material is a thin layer of younger volcanic ash overlying the older volcanic ash.

The **Vaini soils** (Plate 5) occupy the central part of the island and they also dry out in the periods of low rainfall. However, they are a little less clayey and are better structured than the Lapaha soils and are also suitable for growing a wide range of crops. Because of their better structure and lower clay content, they are marginally less sensitive to mechanical cultivation when wet but still require care. These soils would be included in the Tongan class of kelekelefatu, their parent material being a moderately thick layer of the younger volcanic ash over the older ash.

Fahefa soils (Plate 6) are also known as kelekelefatu, and are found in the western part of the island. They are loamy textured and well structured and are capable of producing sustained high yields of a wide range of crops if soil fertility is maintained by fertiliser applications. These soils are developed on deep deposits of the younger ash.

Fatai soils (Plate 7) are derived from volcanic ash which has been washed into slight depressions in the lowest part of the landscape, especially near the coast. They are poorly drained soils with a compact hard subsoil and they are not suitable for deep-rooting crops or crops which cannot tolerate a waterlogged soil for lengthy periods.

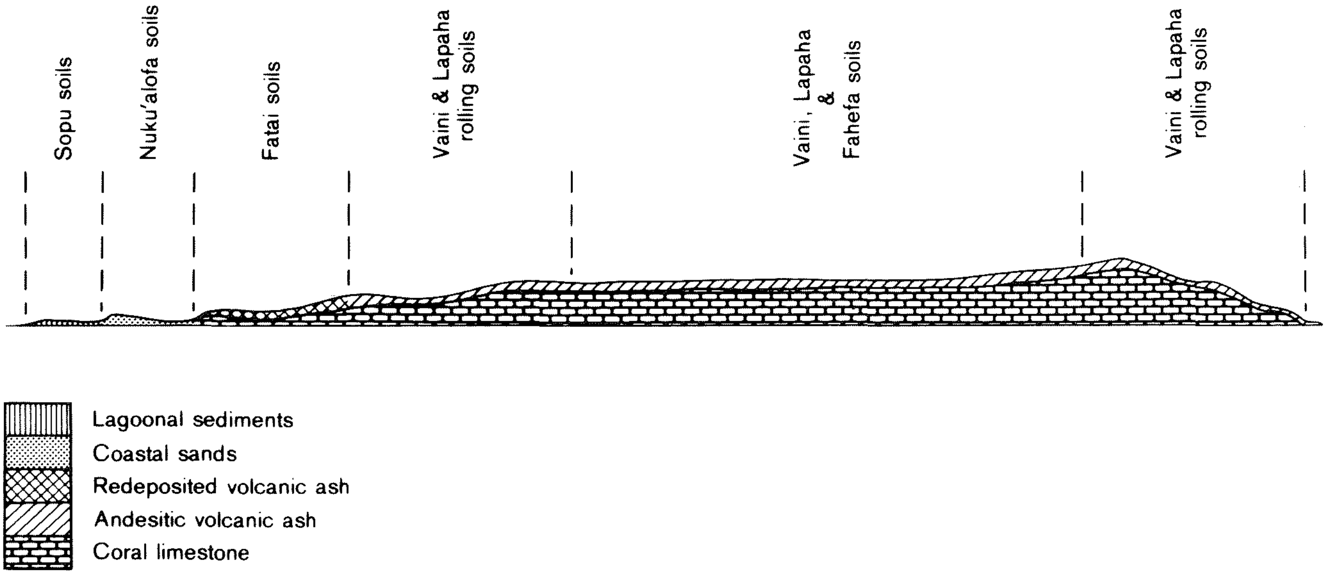


Figure 6 *The land rocks, volcanic ash and soils of Tongatapu represented by a cross-section north to south through the island a little west of Nukua'lofa. (Note that seldom would a single cross-section of the island show all the soils present on the island.)*

Sopu soils are developed on old lagoon sediments around the margin of the present lagoons. They are very poorly drained and include areas which are very acid. They are not very suitable for crops as they are frequently inundated with **saline** water (salty water) and at most times have a water table which is only a few centimetres from the surface, if not at or above the surface.

Nuku'alofa soils are young soils developed on coral sand just behind the active beach on the coast. The parent material, coral sand, is frequently within 25 centimetres of the ground surface. These soils are droughty, but if well fertilised can be used successfully for quick-growing crops in the wet season, or at any time if irrigated.

Soils of 'Eua

The island of 'Eua is situated about 20 kilometres (12 miles) south-east of Tongatapu and has an area of about 8000 hectares (20 000 acres) and is 20 kilometres (12 miles) long and 8 kilometres (5 miles) wide at its widest part. It consists of three well defined **coral limestone terraces** leading up to an older and **higher landmass** made up of volcanic rocks overlying very hard limestone. Beneath the old, hard limestone there are some very old volcanic rocks which form the base, or core, of the island. Each coral terrace has been deposited as a reef near sea level and has later been raised, together with the older part of 'Eua, to form the three terraces we see today (Figure 7). At the present time there is another bench forming, and this can be seen below O'honua village. The coral terraces and the older parts of 'Eua have all been covered with andesitic volcanic ashes that were probably erupted from volcanoes somewhere north-west of Tongatapu.

The lower terraces of 'Eua are flat to gently undulating. Gently sloping **scarps** or small hills lead from one terrace level to the next. The higher parts of 'Eua are more rugged and there is rolling and hilly land as well as the flat land. Along the east coast of 'Eua steep cliffs drop from the terraces to the sea.

Most of the soils of 'Eua have formed from the volcanic ash layers which range in thickness from 30 centimetres (1 foot) to 2 metres (6 feet) or more in places. However, in parts of 'Eua other rocks contribute to the soil-forming materials. For example, near the coast, soils have formed from coral sands. In the 'Central Valley' they have formed from volcanic ashes washed down by water and mixed with older volcanic rocks and possibly limestones. On the steep east coast hillsides, limestones and old volcanic rocks are mixed with the volcanic ash. On the higher and older parts of

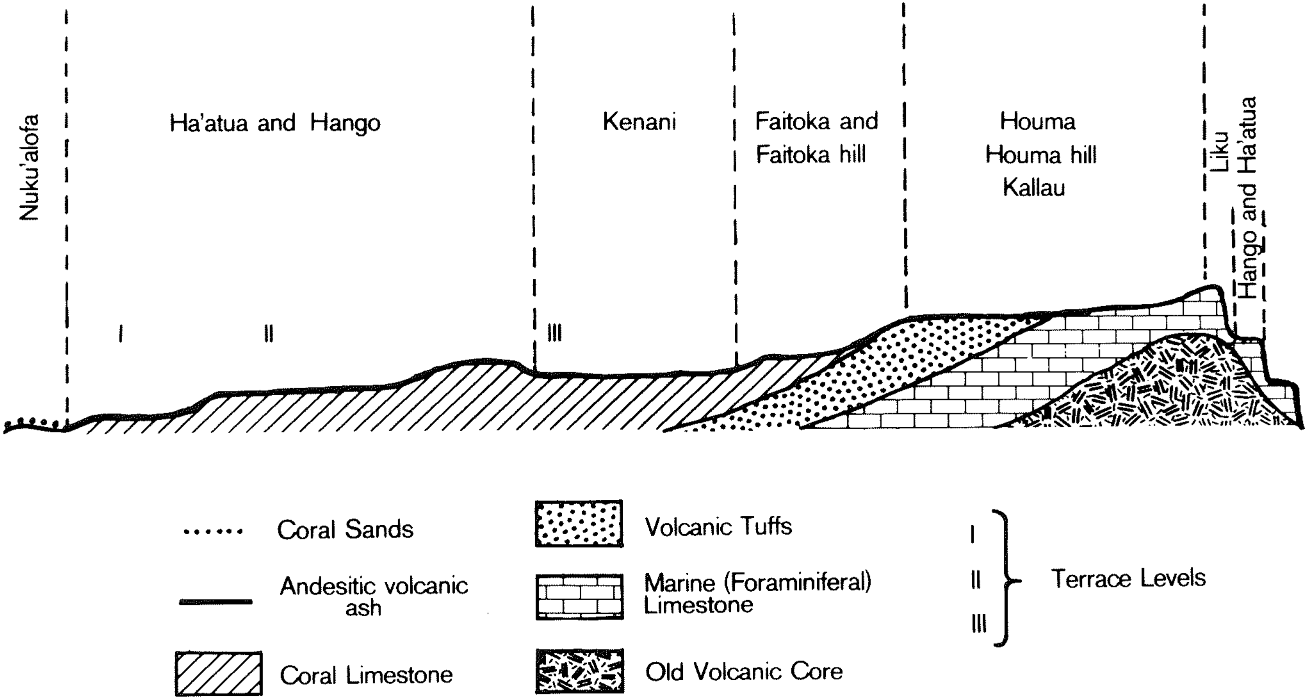


Figure 7 *Cross-section of 'Eua Island showing the soil pattern and main features of the geology.*

'Eua, soils have been forming for a longer time than on the lower younger terraces and they show this in their appearance, especially their redder colours.

Eight main soil units hae been recognised on 'Eua. Each of these soils looks different to the other soils and has some small, but important, chemical differences. **Ha'atua soils** occur on undulating and sloping land on the lower and intermediate levels of 'Eua. They are the more friable and browner soils of the island and show the least amount of **soil profile development** of all the soils of the flatter land. (By soil profile development we mean the development of **soil structure, clay coatings, stickiness** and **plasticity**). On the lower part of 'Eua, **Hango soils** (Plate 8) also occur. They are similar to Ha'atua soils but show stronger structures that do not break down easily under cultivation and are firmer.

Nearer the centre of the island, on undulating and sloping land and on some hilly land, **Faitoka soils** occur. They generally, but not always, occur at higher elevations than Ha'atua and Hango soils. Faitoka soils are redder than Ha'atua and Hango soils and have greater development of structure and clay coatings.

On the high, undulating, rolling and hilly parts of 'Eua, **Houma soils** (Plate 9) are found. These are the firm red soils that show the strongest development of structure and the greatest degree of clay movement down the profile. They also show the greatest amount of movement of nutrients down the profile. These soils are also more eroded than other soils on the island.

In the southern part of the higher areas of 'Eua, friable red soils occur and are mapped as **Kallau soils**. These are very similar to the Houma soils and should be used in the same way.

Soils from rewashed parent materials are mapped as **Kenani soils**. These occur on gently sloping sites just west of the high central ridge. They are reddish soils with poor drainage. Coarser textures at depth suggest that older volcanic rocks are mixed in with the parent material.

On the steeper eastern side of 'Eua, **Liku steepland soils** are mapped. They show little soil profile development and have formed from mixed parent materials.

Along the coast, especially to the west, there are some small occurrences of **Nuku'alofa soils** developed on the young coral sand deposits immediately behind the present day beach. Figure 7 is a cross section of the island of 'Eua showing the soil pattern and main features of the geology.

Soils of the Ha'apai Group

Nineteen different soils have been recognised in the Ha'apai Group. The relationship of soils to parent materials for various islands in the group is shown in Figures 8–13. These soils are derived mainly from a moderate (approximately 1 metre cover of younger volcanic ash over older ash. Some soils are also found developed on other parent materials, but the greatest differences in the most extensively occurring soils relate to either the **particle-size distribution** (size of the individual grains) of the volcanic ash parent material, especially the number of stones (**lapilli**) included, or the amount of windblown corraline sands mixed in with the volcanic ash. Most of these soils have clay textures, friable consistence and moderately developed blocky structure. As such they are generally suited to growing a wide range of crops.

Ha'apai, Ha'afeva, Uiha, Tungua, Nomuka, Lifuka, Foa, and **Koulo soils** are developed on andesitic volcanic ash and lapilli (stones) on very gently undulating land on the interiors of low, ash-mantled, coral islands, and are the principal agricultural soils of the Ha'apai Group. These soils are deep and friable with good structure and aeration and store relatively high amounts of plant-available moisture after rain. All these soils are rated as being well suited to food crop production, ground cash-crop production, tree cash-crop production, pastoral use, and forestry, provided nutrient limitations such as nitrogen, phosphorus, potassium and sulphur are corrected by appropriate fertiliser application.

On flat to very gently undulating land in the low interiors of Uiha and Lifuka islands, restricted areas of **Felemea soils** are developed from andesitic volcanic ash and lapilli. In these areas natural drainage leads to the formation of ponds in broad depressions. Once the nitrogen, phosphorus and sulphur deficiencies of this soil are corrected, it is suitable for coconut and food crop production, but the moderate limitation of poor natural drainage somewhat limits its use for cash cropping.

On the island of Foa, just west of Faleloa village, **Faleloa soils** have been mapped where volcanic ash overlies coral sands at depths of less than 1 metre from the surface. This is a well drained, well structured, friable soil with a relatively high amount of plant-available moisture. Soils of the

Figure 8. FOA

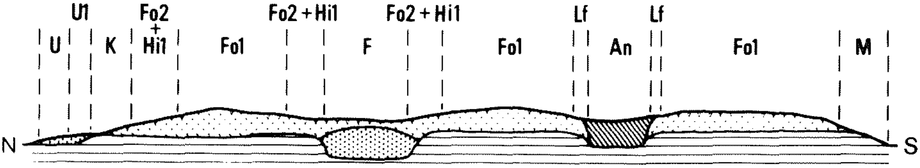
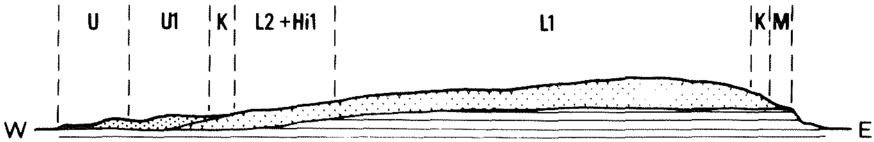


Figure 9. LIFUKA



LEGEND

Organic sediments
Sand
Coral limestone
Andesitic volcanic ash
Calcareous marls
Calcareous tuffs
Volcanic tuffs

An — Ano soils
Av — Ava soils
F — Faleloa soils
Fm — Felemea soils
Fo1 — Foa soils
Fo2 — Foa soils, gentle sloping phase
Hf — Ha'afeva soils
Hi1 — Ha'apai soils
Hi2 — Ha'apai soils, rolling phase
HpH — Halapua soils
KmH — Kotomaka soils
K — Koulo soils
Lh — Lahe soils
L1 — Lifuka soils
L2 — Lifuka soils, gentle sloping phase
Lf — Lotofoa soils
M — Maka soils
Mg — Mango soils
N1 — Nomuka soils
N2 — Nomuka soils, rolling phase
Uh — Uiha soils
U — Uoleva soils
U1 — Uoleva soils, sandy loam variant

Figures 8–13 *Cross-sections of a selection of other islands.*

Figure 10. UIHA

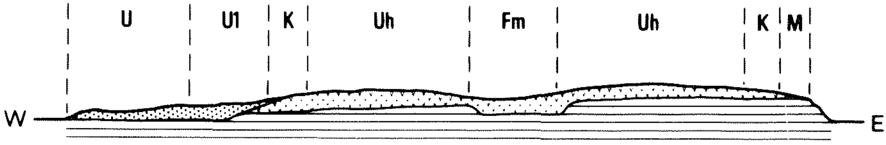


Figure 11. NOMUKA

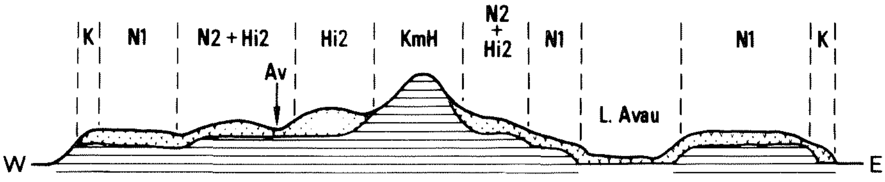


Figure 12. HA'AFEVA

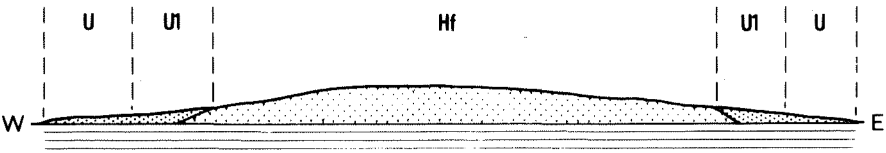
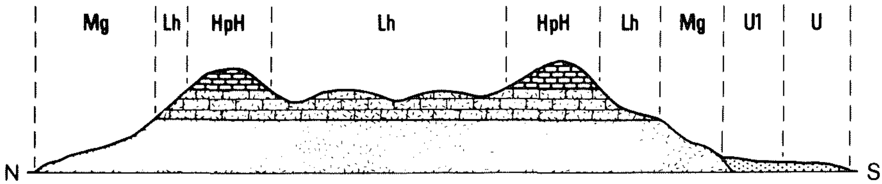


Figure 13. MANGO



Faleloa series are rated as well suited to coconut, food crops, cash crops, and pastoral use.

Again on the island of Foa, **Lotofoa soils** are mapped around the edges of swamps where about 1 metre of volcanic ash overlies **strongly decomposed** (rotten) **organic sediments** (plant remains or **peat**). Where this rotten organic matter is not covered by volcanic ash, **Ano soils** are recognised. These soils are very poorly drained and are frequently flooded during wet summer months. Their principal limitation to use is their poor drainage, and, if it was found feasible to provide adequate drainage for these soils, they would be of potential use for food crops, cash crops and pastoral use. It must be stressed that the provision of artificial drainage for these restricted areas of Foa Island to make them productive would be costly and probably uneconomic.

Ava soils are found where volcanic ash has been washed into hollows on the interior of Nomuka Island. These soils are imperfectly to poorly drained and the provision of adequate drainage for them would be very difficult. They cover relatively small areas.

Mango Island is a raised volcanic island where the major soils are derived from the underlying hard rocks with only a thin cover of volcanic ash. Three main soils are recognised on the island.

Mango soils are derived from weakly weathered **andesitic tuffs** (rock formed of fragments of volcanic rock thrown out of a volcano). These soils have shallow rooting depth for plants, poor structures and are very sticky. Generally they are poorly suited for food crops, coconut production, cash crops, and forestry. They are moderately suited for pastoral use.

Lahe soils are developed on **calcareous tuffs** (volcanic material with limestone) on rolling slopes. These again show shallow rooting depths for plants, poor structures, and are very sticky. They are subject to sheet-wash erosion and are poor soils for coconut production, food crops, cash crops, and forestry use. They are moderately suitable for pastoral use.

The **calcareous marls** (clay with limestone material) and limestone of Mango Island have given rise to **Halapula soils**. These soils have severe limitations to production because of erosion risk, shallow rooting depth and excessive drainage. They are therefore rated as poorly suited to most agricultural and forestry uses.

→

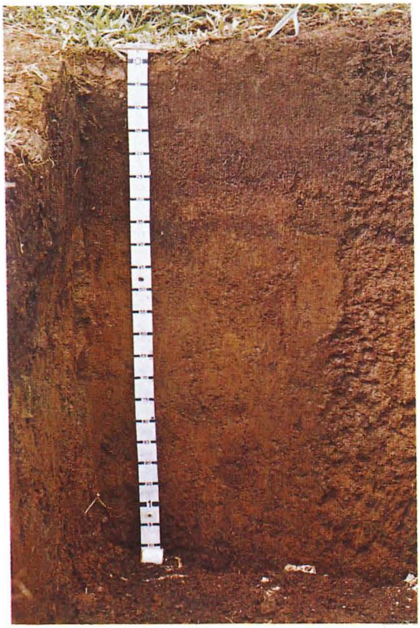
A horizon showing signs of mixing due to cultivation. Structure is good and quite fine.

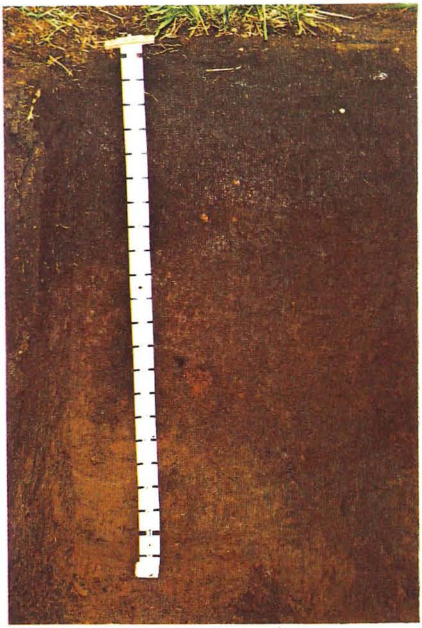
→

B horizon showing a tongue of A horizon near centre of photo where a yam pit has been dug. Structure is coarser and less well developed than in A horizon. Coral has been exposed at the bottom of the pit.

→

PLATE 4 *Lapaha soil (Tongatapu) This soil is formed on older ash and has a heavy textured, compact subsoil. It is generally well drained but because of its compact subsoil it may remain fairly wet for a short time following heavy rain.*





←

A horizon is friable and well structured clay loam.

←

B horizon is clay loam to clay textured with coarse structure and is rather compact.

←

PLATE 5 *Vaini soil (Tongatapu) This soil shows evidence of more recent accumulation of volcanic material with many rounded, reddish and dark coloured weathering pieces of volcanic rock throughout the upper part of soil profile. In general this soil is well drained but can have a zone of waterlogging in the subsoil, at the junction with the older ash, immediately following heavy rain.*

←

A horizon is friable, well structured, deep (40–55 cm) and free draining.

←

B horizon is only weakly structured but is free draining and less compact. There are many inclusions of A horizon material as the result of infilling of old tree root channels.

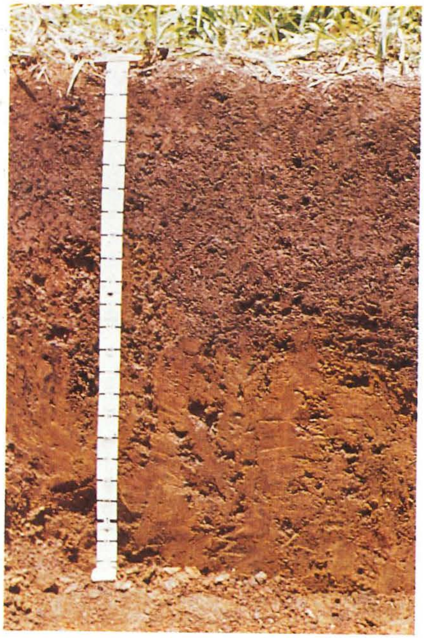
PLATE 6 *Fahefa soil (Tongatapu) Fahefa soils are formed on thick deposits of the younger ash and have fragments of young volcanic material (light coloured patches) throughout the profile. They are well drained and do not suffer from waterlogging.*

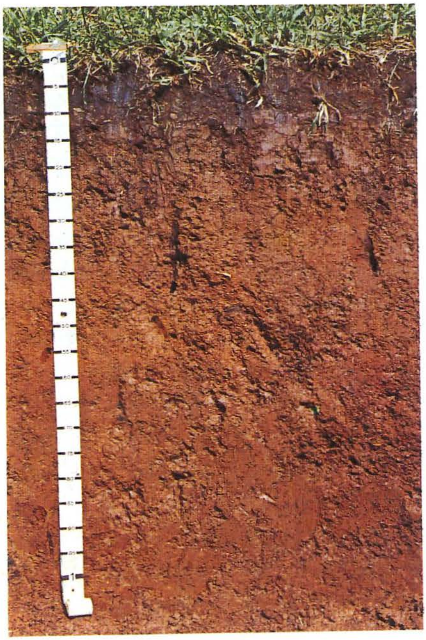
→

A horizon is deep and coarsly structured, with some evidence of restricted root distribution.

B horizon is very coarsly structured and compact. There are many grey mottles and black stainings which indicate poor drainage. →

PLATE 7 *Fatai soil (Tongatapu) Fatai soils are somewhat more poorly drained than the majority of the soils on Tongatapu, as shown by their mottled and black-coated aggregates in the subsoil. These soils have fragments of young volcanic material throughout the profile.*

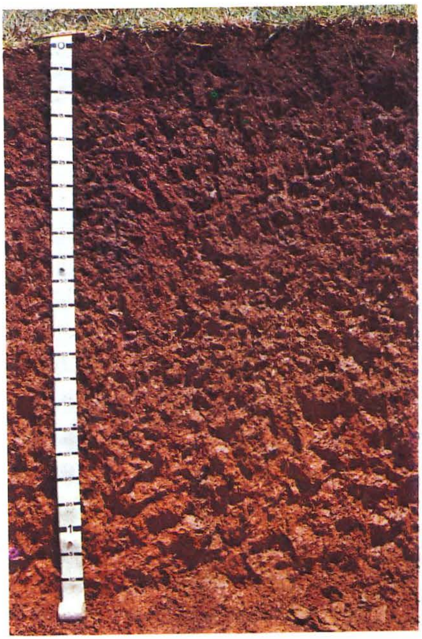




→
A horizon is thin and moderately structured.

→
B horizon is coarsely structured and compact. If wet this is sticky and plastic.

PLATE 8 *Hango soil ('Eua) This well drained soil is derived from deep older volcanic ash with a few pieces of young volcanic material in the topsoil. It has a friable topsoil and friable to firm subsoil, but shows no evidence of impeded water movement through the profile, though if wet, the lower horizons become sticky and plastic.*



←
A horizon is thin and firm with moderate structure.

←
B horizon is a firm, sticky, strongly structured red clay.

PLATE 9 *Houma soil ('Eua) Formed from older volcanic ash, this well drained soil occurs on the highest plateau of 'Eua Island and is liable to quite severe wind erosion. It has a friable topsoil overlying friable to firm subsoil. These soils have a characteristic red coloration throughout the profile.*

These three soils (Mango, Lahe, and Halapula) on Mango Island are relatively poorly suited to food crop production. However, present plant vigour is better on the Lahe and Halapula soils than on Mango soils, probably as a result of the better topsoil structure. Lahe and Halapula soils may erode if cultivated and **soil conservation** (protection against erosion) measures need to be taken if these soils are cultivated.

On Nomuka Island, **Kotomaka soils** are developed from old coral limestone with some volcanic ash mixed in; they occur on moderately steep to steep slopes around the **coral pinnacles** which form the highest part of the island. These soils are shallow, mostly excessively drained, and have severe limitations for most agricultural land uses. They are unsuited for coconut production, food crops and cash crops, and are probably best maintained in bush.

On the east coast of most of the low coral islands where a low but significant cliff occurs, the volcanic ash mantle has been eroded away by a combination of rain, wind, and salt spray, exposing hard coral limestone. **Maka soils** are recognised as developed on this limestone. These soils have severe limitations of shallow rooting depth, low available water capacity, and are open to the salt-laden south-east trade winds. These soils are therefore poorly suited to food crops, cash crops, coconut production, forestry or pastoral use and are best left in their present bush cover to act as a **buffer zone** to protect cultivated inland areas against salt and wind damage.

Around all of the islands of the Ha'apai Group are strips of low undulating coastal beach sand ridges. The soils on these coastal sands have been called **Uoleva soils** and are very similar to the Nuku'alofa soils of Tongatapu and 'Eua. These soils have limitations of droughtiness and poor soil structure. Apart from the more usual nutrient deficiencies such as nitrogen, phosphorus, and potassium, these soils may show some **trace element deficiencies** (e.g., zinc) with certain crops. Uoleva soils are moderately suited to food crop and coconut production but are only poorly to moderately suited to cash cropping, forestry and pastoral use.

Soils of the Vava'u Group

The main islands of the Vava'u Group are three-tiered, raised coral islands. The largest island, Vava'u, has an elevation above sea level of some 213 metres at its south-western end. The soils of the group are developed largely on a substantial mantle of andesitic volcanic ash beds, up to nine metres thick, overlying the coral limestone. It is mainly on the steeper sites and on the recently accumulated beach deposits that coral limestone contributes substantially as a soil-forming material. Small areas of organic soils also occur.

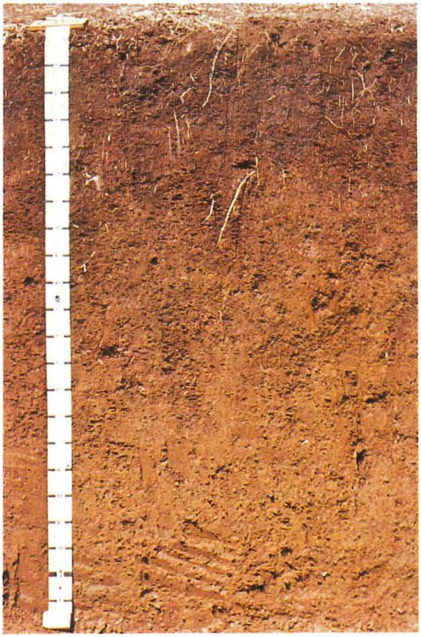
On Vava'u, in common with the rest of the Kingdom of Tonga, the volcanic ash appears to have accumulated in two phases. An older, red, strongly weathered ash is overlain by a younger, less weathered, brown ash. The soil pattern is illustrated in Figure 14, which shows all of the combinations of parent materials and topography mapped over the many islands of the Group. Note, however, that no one island shows this complete range of soils.

The **Longomapu soils** (Plate 10) have been mapped along the western side of the main island of Vava'u at an altitude of nearly 200 metres and are derived from a thick deposit of the younger, brown volcanic ash. There are verbal records that these soils received a light dusting of volcanic ash late last century from an eruption on the island of Fonualei. These soils are deep, well drained, friable and well structured, with good soil moisture properties. They are currently used for food crops under shifting cultivation. Their excellent physical properties make them suitable for growing a wide range of crops provided nitrogen, phosphorus and potassium deficiencies are corrected by fertiliser application. However, exposure on many sites may restrict the range of crops grown.

Large areas of **Pangaimotu soils** (Plate 11) have been mapped on the islands of Vava'u, Pangaimotu, Utungake, Ovaka, Nuapapu, and Lape. These well-drained soils are derived from deep, younger, brown volcanic ash at altitudes ranging from 3 to 150 metres. They differ from the Longomapu soils in being more clayey and having stronger, coarser structures. Pangaimotu soils are currently used for the production of food crops under shifting cultivation. Their excellent physical properties mean that, with adequate fertilisers, they are suited for sustained production of a wide range of crops.

Hunga soils are found on the islands of Hunga, Fofoa, Vaka'eitu, and Nuapapa. These are very similar to Pangaimotu soils but are slightly redder in colour and the thickness of the volcanic ash mantle tends to be less than 1 metre. Land use and soil limitations for agriculture are similar to the Pangaimotu soils

Where the younger brown ash is either very thin or virtually missing, the older, strongly weathered, red volcanic ash is the soil-forming parent



←
A horizon is thin, friable and weakly structured. When wet it feels slippery.

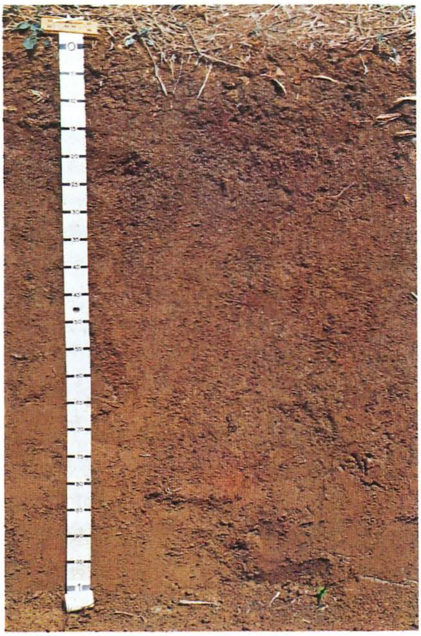
←
B horizon is friable to firm with weak structure and many inclusions of A horizon down old tree root channels.

PLATE 10 *Longomapu soil (Vava'u) Formed from deep deposits of younger volcanic ash, this well drained soil tends to dry out during periods of low rainfall. It is generally friable throughout the profile.*

→
A horizon is moderately thick, moderately structured, friable clay loam.

→
B horizon is moderately structured friable clay loam with some black patches.

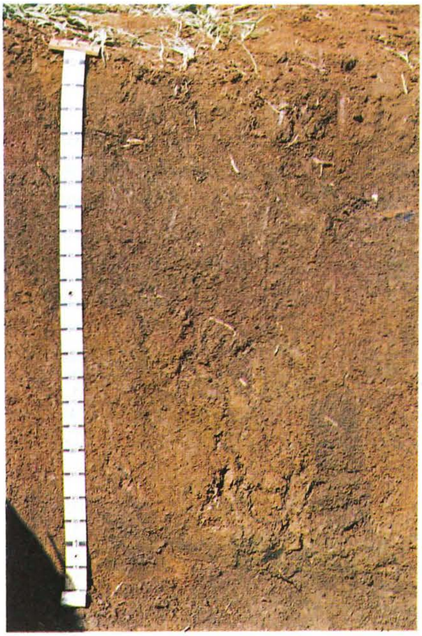
→
PLATE 11 *Pangaimotu soil (Vava'u) Derived from deep deposits of older volcanic ash over coral limestone, this generally well drained soil may become a little wet after heavy rain. There is some tendency to sheet erosion on sloping land.*



→
A horizon is a friable clay with strong structure.

→
B horizon is a reddish, firm, strongly structured clay.

PLATE 12 *Tu'anekevale soil (Vava'u) This soil is derived from older volcanic ash with little evidence of accumulation of younger ash. The soil has a heavy textured compact subsoil and though generally well drained, the compact subsoil may remain wet for a period following heavy rain. Profiles usually exhibit a characteristic red colour.*



←
A horizon is a deep, dark, friable clay with weak structure.

B horizon is a firm clay with weak structure and some young volcanic material.
←

PLATE 13 *Neiafu soil (Vava'u) This well drained soil is derived from deep volcanic ash and shows evidence of a long period of cultivation in the deep topsoil, with many traces of yam pits (dark inclusion in lower middle of photo). The deep topsoil is friable, the subsoil rather compact.*

material. This occurs somewhere on almost all of the islands, especially towards the east and results in the formation of the **Tu'anekevale soils** (Plate 12). These are well-drained, strongly structured, friable, clayey soils showing strong red colours right through to the surface. These soils have only moderately good physical properties which restrict their range of uses, and in natural conditions they are grossly limited by low nitrogen and phosphorus, but with adequate fertilisers should be capable of supporting a wide range of crops. Because of their clayey nature these soils tend to be poor suppliers of plant-available moisture.

The **Fulivai soil** found only on the north eastern part of Hunga Island is very similar to the well drained Hunga soils, except that it has many coarse black manganese concretions in the subsoil, which probably indicate a slight impediment to drainage in the lower part of the soil profile.

Throughout the group there are many large and small areas where **Neiafu soils** (Plate 13) are found. These are the soils which have been overdeepened either by receiving eroded material from upslope or by having extra organic material added during yam pit preparation. These soils are mainly recognised by having topsoils more than 50 centimetres thick. Except for this very deep topsoil, the profiles generally closely resemble those of the Pangaimotu soils. These are versatile soils with minimal limitations, showing good physical properties and are suited to sustained production of a wide range of crops.

The **Matamaka soils** are generally found in close association with Pangaimotu soils. They are derived from shallow, andesitic volcanic ash overlying coral limestone, frequently within 25 centimetres of the surface. Their shallowness, restricting both rooting depth and amount of plant-available moisture, is a limitation to intensive cropping and most other land uses. They have probably been subject to severe erosion in the past.

At various localities throughout the islands of the Vava'u Group small areas of swamp occur. Where these are large enough to show on the soil map they have been mapped as **Okoa soils**, but many small unmapped areas of these soils are to be found in association with all of the other soils found throughout the Group. Okoa soils consist of black or brown peaty loam overlying volcanic ash or coral limestone.

All of the sandy soils (tu'one) found in the Vava'u Group have been mapped as **Nga'unoho soils**. These occupy the low beach land almost at sea level and large areas occur on Ofu and Ovaka Islands. Although these

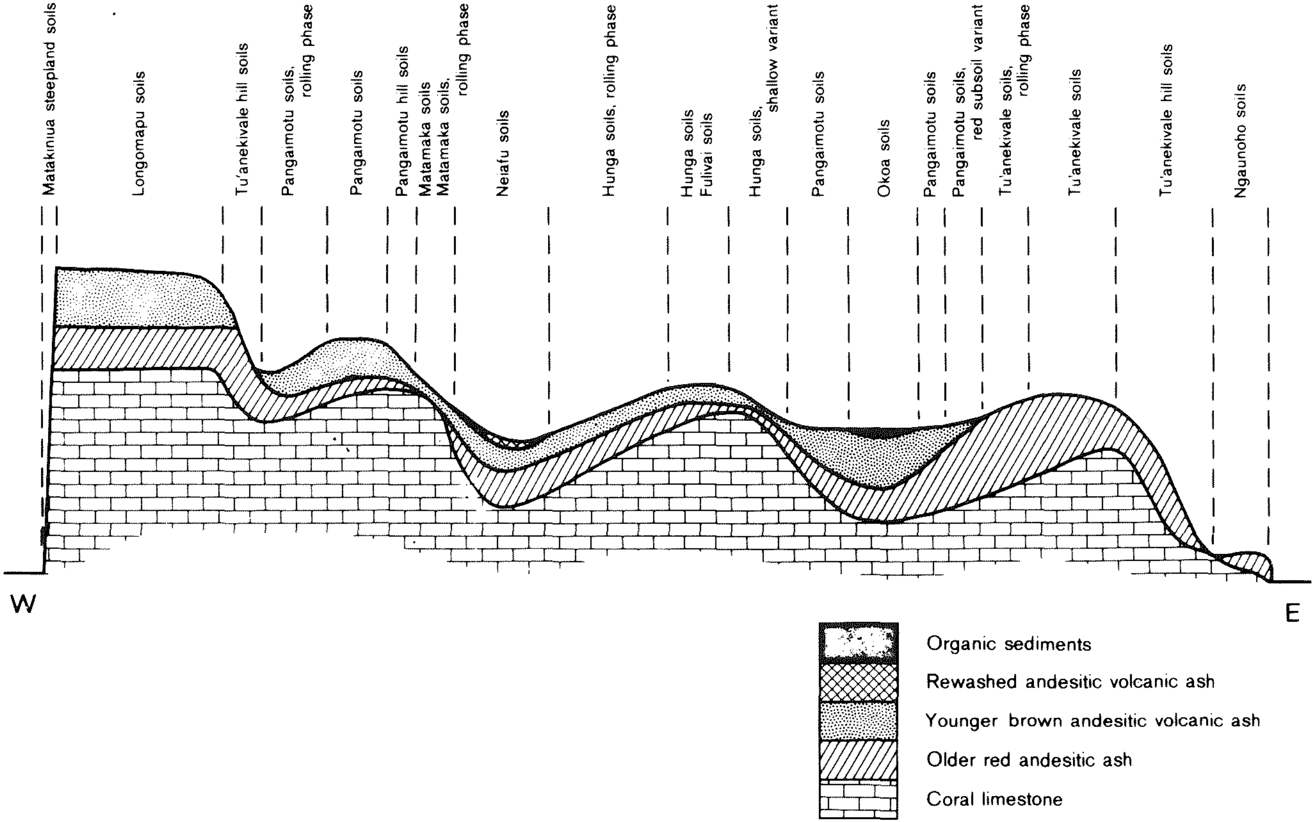


Figure 14 *Hypothetical cross-section of Vava'u Group.*

soils are generally free draining there are some small areas of poorly drained soils included with this mapping unit. Occasionally there is quite an amount of volcanic ash mixed in with these sands. Poor soil structure and excessive drainage are major limiting factors for intensive use of these soils.

Soils of the Volcanic Islands

Along the western margin of the Kingdom lies a chain of active and recently active volcanoes. Tofua, Kao and Late are examples of these high volcanic islands. Of these, both Tofua and Late have erupted within historic times and Tofua has a currently active crater, Lofia. Kao has not erupted in historic times, but its general appearance and youthfulness of its soils indicate that it is still to be considered an active volcano. The last violent eruptions on these islands were in Tofua in 1906 and Late in 1854. Other volcanic centres in the western chain have erupted more recently. On all three of these representative islands the soils are of recent origin. Profiles are not well developed and the soils are sandy or stony. The major soil-forming materials are deposits of ash or lapilli (stones). The numerous **lava flows** present on these islands are so little weathered that they do not appear to contribute to soil formation.

Poor soil structure, lack of moisture-holding capacity (droughtiness) and shallow rooting depth (thin ash and lapilli over hard rock) severely limit the agricultural potential of these soils. Because many of the volcanic islands have quite steep slopes most of the soils would be subject to severe erosion if their vegetative cover were to be removed and any form of intensive land use started.

MAIN PROPERTIES OF THE MOST IMPORTANT SOILS

Tongatapu

Fahefa soils : These well drained soils are developed on the western side of the islands on deep deposits of younger volcanic ash. They have a deep, dark-coloured, friable clay topsoil with a few lapilli (volcanic stones) over a more compact brownish clay subsoil (Plate 6). These are versatile soils which are suitable for most land uses, but nitrogen fertiliser is required for good crop yields. Generally phosphorus and potash are adequate for crop growth, but there may be some requirement for sulphur on these soils.

Vaini soils : Found mainly in the middle and eastern parts of the island, these well drained soils are developed from a slightly thinner layer of younger ash overlying older ash at from 60 to 100 centimetres from the surface. This soil again has a deep, dark, friable clay topsoil overlying a dark, reddish brown compact subsoil (Plate 5). In general they lack any noticeable content of lapilli (volcanic stones), though a very few weathered ones may be found. For good crop growth, nitrogen fertiliser and sometimes phosphorus and sulphur are needed. These are extremely versatile soils with good physical properties and are suited to sustained production of a wide range of crops.

Lapaha soils : Confined mainly to the eastern side of Tongatapu these well drained soils are developed on older volcanic ash with a thin surface layer of younger volcanic ash. Weathering of this older ash is more advanced than in the Vaini or Fahefa soils and textures are even heavier than in those two soils. Lapaha soils have a dark, friable clay topsoil, about 30 centimetres thick, overlying a brown, firm, sticky clay with coral limestone occurring at from 1 to 2 metres from the surface. These are versatile soils with good physical properties and are suitable for sustained growth of a wide range of crops. However, they need fertilising with nitrogen, phosphorus, potash and sulphur to produce well. There is some tendency to early drying out (droughtiness) in dry seasons when compared with the Vaini and Fahefa soils.

'Eua Island

Hango soils : These well drained soils occur mainly on flat to gently undulating and rolling slopes on raised coral terraces mantled with volcanic ash. They have dark-coloured, clay loam and silty clay loam friable topsoils over brown or reddish brown, friable to firm clay (Plate 8). Again these are versatile soils with few limitations to most uses and suited to sustained production of a wide range of crops, although they need nitrogen, phosphorus and sulphur.

Houma soils : These are formed from volcanic ash on undulating and rolling slopes of the highest plateau on 'Eua Island. They have a thin, friable to firm, reddish clay loam topsoil over reddish brown and red, friable to firm, clay subsoil (Plate 9). Houma soil is well drained but because of its altitude and exposure to wind has quite severe limitations for most agricultural uses. In places it has lost up to 90% of its topsoil by erosion and there is strong evidence of wind deflation (blowing away) near the eastern cliffs (liku) on top of the plateau. Susceptibility to erosion is the major limiting factor of the Houma soils and they should be used for food crop production only if adequate precautions are taken to eliminate the erosion hazard. Erosion of these areas could have a devastating effect on lower-lying areas by covering productive soils with this lesser quality soil material and, if the erosion products (clay and silt) were to enter the waterways, irreparable siltation of the harbour at O'honua could occur. For these reasons these soils are more suited to forestry and pastoral use. For pasture growth, fertiliser phosphorus and molybdenum are needed.

Ha'apai Group

The **Ha'apai, Ha'afeva, Uiha, Tungua, Nomuka, Lifuka, Foa** and **Koulo** soils are the most important food producing soils of the Ha'apai Group. These are all similar in their main characteristics, but have been separated as different soils, mainly on the basis of minor differences in soil texture, consistence and colour, all of which are probably a reflection of differences in the nature of the original volcanic ash from which they are derived. These are all well drained soils with dark, deep, friable clay or clay loam topsoil overlying reddish brown, firm to friable clay subsoils. Depending on the soil series involved there are variable amounts of weathered volcanic lapilli (stones) throughout the profiles. These soils show varying requirements for additions of nitrogen, phosphorus, potash and sulphur, and if these requirements are met they are suited to sustained production of a wide range of crops. The Koulo soils, however, are distributed along the eastern side of the main islands and this often dictates that they must be left in a bush protection zone to give a buffering effect against the salt-laden south-east trade winds. These Koulo soils also have a slight addition of coral sand, blown in from the coast, mixed in with the volcanic ash.

Vava'u Group

Longomapu soils : These are well drained soils developed from deep, younger volcanic ash on the gently undulating highest terrace on the western side of Vava'u (Plate 10). There are historic records of ash accumulating on these soils late last century. This soil is phosphorus deficient and needs adequate phosphatic fertiliser to reach its full potential. It is also marginal for soil nitrogen and will probably need nitrogenous fertiliser for sustained production. There is a tendency for this soil to dry out quite markedly in the dry season and this lack of soil moisture may seriously affect plant growth. This is a versatile soil which, if the moisture and phosphate requirements are satisfied, is capable of sustained production for a wide range of crops. It is, however, vulnerable to hurricanes, which approach from the west and cause crop damage. The climatic environment limits the land use on these soils rather than soil properties.

Pangaimotu soils : The greater part of Vava'u is covered with these soils, which are well drained soils developed from deep, younger ash overlying older, volcanic ash. These soils have a deep, dark, friable clay loam topsoil overlying dark brown and brown, friable clay loam which frequently has prominent black patches and smears throughout it (Plate 11). In a few cases a reddish clay may be found within 1 metre of the ground surface, but usually this red clay is much deeper. These soils are strongly deficient in phosphorus, moderately deficient in nitrogen and slightly deficient in sulphur. Potash is generally adequate but needs to be considered in any fertiliser programme for these soils. These are versatile soils with good physical properties, and with adequate fertiliser application they are capable of sustained production of a wide range of crops. Under clear cultivation there is some risk of sheet erosion on quite gentle slopes, the risk becoming marked on higher slopes.

Tu'anekevale soils : Along the eastern side of Vava'u, and on many of the smaller islands on the eastern side of the Group, a distinctive red-coloured soil is developed. This soil has been called Tu'anekevale and is developed on older, deeply weathered, volcanic ash with a very thin surface layer of younger ash. It is well drained but is extremely clayey in texture so suffers from many of the disadvantages of heavy clay soils. It has a rather shallow, dark reddish brown, friable clay loam to silty clay loam topsoil over a reddish brown to yellowish red firm clay (Plate 12). Trials indicate that these soils are strongly deficient in phosphorus, moderately deficient in nitrogen and slightly deficient in potash. Overall these soils have moderate physical properties and in the natural condition are grossly limited by a low phosphorus and nitrogen status. With adequate fertiliser application they should be capable of supporting a wide range of crops.

Neiafu soils : Neiafu soils are not extensive throughout the group but provide a very valuable resource. These soils are recognised where profiles have been overdeepened, either as a result of downslope movement of soil material or by man's influence, especially during yam pit preparation. They occur on flat to gently undulating and easy rolling foot slopes, valley floors and depressions. They have a deep (greater than 50 centimetres), dark brown, friable clay loam to silty clay loam topsoil overlying a firm, brown, silty clay loam subsoil (Plate 13). It shows slight to moderate phosphorus deficiency and a moderate nitrogen deficiency. This is a versatile soil with excellent physical properties and is capable of sustained production of a wide range of crops.

MORE INFORMATION ABOUT SOILS IN THE KINGDOM OF TONGA

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