CHAPTER ONE

Introduction: How Soils Are Formed

NEW Zealand is a land of almost bewildering variety in its landscapes. Within one day's journey by car, for example, we can experience the old, rounded volcanic hills of Dunedin; the cool, moist lowlands of the Southland Plains; the tussock grasslands of the rolling east Otago uplands; the semi-arid basins and craggy tor landscapes of Central Otago; the glaciated schist mountains of Mt Aspiring National Park; and the humid, densely-forested coastal lowlands of South Westland.

The continental landmasses of the world contain many different landscapes, but each is relatively uniform in itself and it may take days, or even weeks, of travel to pass from one to another. But in our rather small group of islands, a comparable degree of climatic, geological, soil and biological diversity is compressed into an area of only 270 000 square kilometres.

Although New Zealand's climate can generally be described as temperate oceanic, there are many regional climatic differences. The three main islands span 1500 km of latitude, from the subtropical Aupouri Peninsula of Northland to the subantarctic wilderness of southern Stewart Island. In addition, mountain ranges up to 3000 m in altitude stand astride the westerly wind flow, leading to pronounced moisture differences - generally wet in the west and drier in the east.

Geologically, New Zealand is very mobile. It is being torn apart along its north-east/south-west axis because it lies on the junction of the Pacific and Indian-Australian Plates - two of the great moving plates that make up the crust of the earth. Over millions of years, as these plates have tended to override and grind past each other, high mountains have been continually pushed up and subsequently eroded. Volcanic activity is another feature of this plate boundary; the landscapes and soils of half of the North Island owe their origin to the volcanic eruptions of the last two million years.

It follows that in geological terms our landforms are still very youthful. Mountain-building continues at up to 10 mm a year in many areas, a rate considered to be high. Almost 60 percent of the land is higher than 300 m, and 70 percent of the country is hilly (slopes of 12 – 28 degrees) or steep land (slopes greater than 28 degrees). Even in this respect there are major differences between the two main islands: the North Island is more hilly; the South Island is dominated by steep lands.

The plants and animals that evolved in ancient New Zealand are highly distinctive, reflecting the isolation of these islands following the breakup of the ancestral continental landmass of Gondwanaland about 80 million years ago. The climate favoured forests - not the deciduous forests of the Northern Hemisphere, but evergreen forests dominated by podocarps (rimu, miro, totara, matai and kahikatea), beech and kauri. As time passed, the soils on which these forests developed were influenced by the forest environment: rain percolating through the canopy and forest floor litter dissolved soluble elements out of the soil; a specialised soil fauna, including insects, spiders, worms and micro-organisms, developed in the decaying litter (Plate 1.1), each playing a role in transforming it into soil organic matter (humus) and nutrients available to plants.

Plate 1.1 (opposite)

Artist's impression of the teeming life in the litter and topsoil layers beneath a podocarp/hardwood forest. The circles of increasing magnification show soil animals, fungi and micro-organisms. An identification key is given in Fig. 1.7 at the end of this chapter.
This forest soil development did not always continue without interruption. Around two million years ago, at the beginning of the Quaternary Period, the climate began to fluctuate more frequently; lengthy periods of cold, dry conditions began to alternate with shorter periods of warmth, culminating in several major glacial events during the last 600,000 years. During these Ice Ages of the late Quaternary, forest vegetation retreated from most of the high country areas of the South Island and the axial ranges of the North Island. Glacial action and lower tree lines allowed vast quantities of fresh rock material to be either washed or blown onto the lowlands. As the climate fluctuated from cold to warm, or dry to wet, the land was probably subjected to many cycles of soil development, erosion, rejuvenation and revegetation. From the onset of a warmer climate at the end of the last of these glacial periods (around 10,000 to 14,000 years ago) until the arrival of Polynesians 1200 years ago, the pattern of soils and vegetation remained relatively undisturbed.

At first Polynesian settlement probably had little effect on the natural vegetation pattern. Eventually, however, fires lit by moa hunters destroyed large areas of podocarp and broadleaf forest in the drier lowlands, particularly in the eastern regions (see Chapters 7 and 12). Later, Maori agriculture developed with the cultivation of Polynesian food plants (such as kumara, gourds, yams and bracken fern), especially on the soils of the coastal lowlands of the North Island.

With European settlement, the landscape underwent major changes through the widespread replacement of forest and tussock grasslands by pastures and arable crops. Pastures were successfully established in the ashes of the former forest where the climate was suitable and the soils had sufficient stability and fertility (Plate 1.2). But the ecological damage in the drier steep lands and inland basins was severe; indiscriminate burning, overgrazing by domestic stock, and browsing by introduced herbivores (such as rabbits, possums and deer) degraded the vegetation cover on millions of hectares of soils, particularly in the South Island high country, Central Otago, and the geologically unstable hill country regions of Gisborne-East Cape, Wanganui-Rangitikei, and Hawke's Bay-Wairarapa. Whereas land use in the Old World evolved over thousands of years of trial and error, in colonial New Zealand land development was compressed into a fraction of the time by settlers largely unfamiliar with the geology, soils, climate and biota of this new land.

Modern soil science, ecological understanding, and agricultural and forestry technology have healed many of the scars and established sustainable uses of most of these soils. Notwithstanding recent emphases on manufacturing and tourism in the New Zealand economy, soils still remain our most important natural resource. They are the basis of our primary industries and we build our homes, factories and offices, schools and roads on them. They nourish our forests and other natural habitats for our native flora and fauna. We race horses and play rugby, cricket and golf on them, and many of us delight in cultivating a garden on the soil in our backyard.

The object of this book is to provide a better understanding of New Zealand's soil resource by explaining something of how and why particular soils occur where they do in the landscape, why they differ in their appearance, and how their properties can be recognised and used to best advantage (Chapter 14). Most of the following Chapters (2 - 13) are a journey through the distinctive soil landscape regions of the country. Any safe and satisfying journey, however, requires a minimum of preparation. Consequently, the rest of Chapter 1 is a briefing on the main factors leading to the formation of the different sorts of soils that are likely to be encountered. The simplest way to introduce these factors is to undertake our own soil survey of one small piece of New Zealand landscape. By digging a series of pits we can examine the soil in profile and then attempt to relate any variability we observe to changes in the landscape environment.

Soil Variability in the Landscape

The Taita hill landscape (Plate 1.3) of the eastern Hutt Valley is an example of old, relatively low hills, underlain by deeply weathered greywacke. As a group, the soils of this landscape are acidic and infertile, with clay-rich yellow-brown subsoils; they are difficult to maintain in pasture and have a strong tendency to revert to gorse and manuka and ultimately to the formerly dominant hard beech forest, which can still be seen as scattered remnants in Plate 1.3. Nevertheless,
Plate 1.3

Taita hill-soil landscape around Taita Research Centre, Hutt Valley, looking eastwards to Stokes Valley. The 20 ha catchment mapped in Fig. 1.1a is the area of manuka/beech forest ringed by grassed firebreaks in the centre of the photograph. The numbers refer to the profiles shown in Fig. 1.1b.

1. The Bucks soil is distributed along the rolling surface of the main ridge system. Its parent material is loess which has accumulated as pockets and resisted erosion. The topsoil is friable, colours are brown, and the presence of the clays allophane and gibbsite suggests that volcanic ash has contributed to the parent material. The light-coloured band at 1 m depth lies just below volcanic ash that was probably erupted from the Taupo Volcanic Zone around 240 000 years ago (Chapter 2).

2. The Wingate soils occur on many of the hill slopes between 12 and 28 degrees, particularly on the concave slopes of the valley heads where black beech was dominant. The parent material is a mixture of loess, gravelly colluvium and volcanic ash. The subsoil is much lighter than that of the Bucks soil and has a coarse prismatic structure (see Table 1.1) and many brown and yellowish-red mottles, indicating its more compact nature.

3. The Taita soil occurs on the main ridges and spurs where the parent material is strongly weathered greywacke and the vegetation was once hard beech forest. It has a conspicuous strongly developed nut structure and some profiles show 'red weathering' at depth, like that between 70 and 110 cm in the photograph.

4. Tawai soils occur on the steep slopes of the valley sides where the original parent material of the Taita soils has slipped off, leaving a thin layer of colluvium over yellow weathered greywacke. They are shallow, stony soils which usually carry a mixed forest of mahoe, kamahi, tree fern and occasional hard beech.

5. The Stokes soils occur at the mouth of the catchment valley and on the lower hill slopes (less than 12 degrees) where rimu and black beech were the main vegetation. The parent material is colluvium, derived mainly from loess which has slid down, or been washed down, from the higher zone of the Wingate soils. The structure of this soil is quite different from the others — large prismatic blocks with platy structure beneath a pale mottled zone (30 - 70 cm) indicating gleying when soil moisture is held up in this zone. A closer examination shows just how different some of these soils are in depth, colour, shape and feel. In just one small (20 ha) catchment in the centre of Plate 1.3, five distinct soils have been recognised and given different names — Bucks, Wingate, Taita, Tawai, and Stokes. Their distribution is mapped in Fig. 1.1a, their profiles are illustrated in Fig. 1.1b and their position on the hill slope is indicated on the cross-section. In sharp contrast, the alluvial soils of the flat industrial and residential land shown at the bottom of Plate 1.3 are quite stony and free-draining.

Four environmental factors seem to be responsible for these soil differences within the Taita hill soil landscape. They are:

- **soil parent materials** (deeply weathered greywacke rock, greywacke colluvium, loess, or volcanic ash);
- **topographic position** (ridge crest or hill slope);
- **climate** (regional, as well as local microclimatic differences, such as the aspect of the slope and consequent exposure to wind and sunlight); and
- **biological factors** (particularly vegetation; i.e. the preference of the original beech forest for the infertile Taita and Tawai soils, and podocarp/hardwood forest for the more fertile Wingate and Stokes soils).

Furthermore, each soil-forming factor has been active for a different period of time. The youngest soils are on the loess-covered ridge crests (Bucks), the eroded mid-slopes (Tawai) and the accumulated debris at the foot of the slope (Stokes); the oldest soils (Taita) occur on the deep-weathered greywacke which is not mantled with loess.

To a greater or lesser extent, time and the four environmental factors are responsible for the wide differences apparent in the ninety or so soils (and their landscapes) illustrated in this book.
Introduction: How Soils are Formed

(a) Soil map of 20 ha catchment in the Taita hill landscape of the eastern Hutt Valley (illustrated in Plate 1.3). The five soils in the legend are arranged in terms of their topographic position in the landscape.

(b) Stylised cross-section of hill slope (line A-B on map), showing topographic position and parent materials of five soils.
Time Needed for Soil Formation

Soils take time to develop. Rocks break down (weather) to smaller particles (gravels, sands, silts and clays) through the influence of climatic forces such as rain, heat, cold and wind. Plants become established, topsoils develop as organic matter is incorporated into the soil, and nutrients are released from minerals to the soil solution where they can be taken up by plant roots. Gradually, the soil matures at a rate which is very dependent upon the local climate.

It is possible to observe more clearly the progressive effect of time on soil formation — and the accompanying changes in vegetation — in a soil chronosequence where the other soil-forming factors of climate, parent material, and topography are constant. The Franz Josef Glacier soil chronosequence on the West Coast of the South Island (Fig. 1.2) has developed in a mild, humid climate where rock detritus has been deposited as a series of different-aged terraces and benches since the glaciers retreated from their maximum extent around 22 000 years ago. The freshly deposited coarse grey alluvium of the Waio River floodplain below the glacier lacks any horizon development except for a rudimentary topsoil where scattered mats of mosses and herbs have become established. Over the thousands of years this alluvial material on the older landforms has gradually weathered; yellow-brown colours started to appear beneath the topsoil as iron was released from minerals and converted to oxides. Eventually, under this high annual rainfall of 4000–5000 mm, much of the iron and aluminium was leached out of the upper part of the soil to be deposited as pans in the subsoil. In the oldest soils (Okarito soil, Plate 11.7) virtually all minerals except quartz have been leached away leaving a very prominent bleached horizon below the topsoil.

Some associated changes in soil fertility are summarised in Fig. 1.2b. Of the essential plant nutrients, phosphorus is at a maximum in the raw glacial outwash; over 90 percent of this is lost through leaching of the soils over the 22 000 years. Much of this inorganic phosphorus is rapidly converted into the less-available organic form as the content of soil organic matter (including nitrogen) builds up to a maximum over about 12 000 years.

As the soil develops, the vegetation progressively increases in mass and stature, from scattered cushion plants, to shrubland, to a tall podocarp/hardwood forest. This stage can be considered the zenith of soil and forest development, before both soil fertility and forest structure begin to degrade.

Rocks and Other Parent Materials

Soil development in other parts of New Zealand will not necessarily follow the same pathways, or occur at similar rates, as those in the strongly leaching West Coast environment. The parent rocks in the Franz Josef soil chronosequence are greywacke and schist, rocks with a high proportion of silica-rich minerals such as quartz, feldspar and mica. These rocks have been ground up by the movement of glacial ice and the Alpine Fault, and the rock debris then transported to new locations by the forces of water, wind and gravity. In this manner the parent rock has been transformed into new soil parent materials — in this landscape alluvium, loess and colluvium. In some parts of the Franz Josef landscape the soil parent material lacks any significant mineral component at all, since peat has formed from vegetation rotting in wet hollows, leading to an organic soil.

The geology of other parts of New Zealand is very different from that of the West Coast, and the wide variety of parent rocks is responsible for many regional differences in soil chemistry. The basalt lava flows and scoria cones of Northland and Auckland (Chapter 5) and the ash from the andesite volcanoes of Taranaki (Chapter 4), have much lower silica contents than greywacke and schist because their minerals (olivine, amphiboles and pyroxenes) are rich in iron and magnesium and nutritionally important trace elements including cobalt, copper and molybdenum. In contrast, the rhyolitic pumice of the Taupo Volcanic Zone (Chapter 2) is mainly volcanic glass, rich in silica, sodium and potassium but lacking iron and magnesium and trace elements such as cobalt, selenium and copper.

The chemical influence of the parent rocks is most pronounced in weakly weathered and weakly leached soils, where the supply of such minerals has not yet been exhausted. Two such soils on very contrasting parent rocks — schist and limestone — are illustrated in Plates 1.4 and 1.5. The schist soil is grey throughout,
(a) A stylised longitudinal section of the Waiho valley and the Omoeroa Range of the West Coast, South Island, showing the soils and vegetation on landforms of different ages. The vegetation progresses from scattered mats of cushion plants and moss, to open shrubland, to a low hardwood forest of *Olearia*, *Sanecio* and *Schefflera* species, then varieties of hardwood and podocarp/hardwood forest (depending on topographic position such as moraine or alluvial flat) until the 'endpoint' of stunted yellow-silver pine and pakihi vegetation is reached in the wet heathland of the rolling summits of the Omoeroa Range. Litter builds up on the soil surface, and horizons develop in the soil profile as the minerals weather and humus, clay, iron and aluminium oxides are formed and move to lower positions in the profile. After 5000 years a podzol (Waiuta soil) has formed under rimu/rata/kamahi forest; by 22 000 years the soil is a glezy podzol (Okarito soil, Plate 11.7). The soil horizon notation is explained on p. 23.

(b) Changes in selected soil properties in the Franz Josef soil chronosequence. As phosphorus is transformed into the organic form, organic matter, nitrogen and clay levels gradually increase. After 12 000 years, overall soil fertility begins to decline, with increasing acidity and the loss of organic matter, nitrogen, and other nutrients such as calcium and magnesium.
Clays and the surface activity of soil particles

The chemical activity (reactivity) of the different particles in the soil is related to their surface area – and their shape. Sand and silt particles are of enormous size in comparison with the clays (Fig. 1.3); they are very important structurally (they can be thought of as a soil skeleton) but are rather inert chemically. It is the clays which provide most of the reactive mineral surfaces; a given weight of clay has about 30 times more surface area than the same weight of silt, and about 1000 times the area of the same weight of sand. A mere teaspoonful (5 g) of the clay mineral allophane, for instance, has the surface area of a rugby field, so finely-divided are the clay particles!

Clay minerals are mainly compounds of silicon, aluminium, hydrogen and oxygen, but minor amounts of nutrients such as potassium, sodium, calcium, magnesium, iron, manganese and phosphate can be fitted into their crystal structure. The reactivity of the clay surface is due to the presence of electrical charges arising from imperfections in its molecular structure. It is because of these electrical charges that clays such as the vermiculite group (negatively charged) can attract positively charged ions like potassium and ammonium; and other clays, such as allophane (positively charged), can attract negatively charged ions like phosphate and sulphate. These soluble ions are thereby held as plant nutrients in the soil until they can be taken up through plant roots. If they were not held by clays (or organic matter) they would be lost from the soil system through the leaching effect of water passing from the soil surface down into the groundwater.

The different clays can be conveniently arranged into eight groups according to their composition and properties (Table 1.2, p. 30); the striking differences in shape for six of the more common clay species is illustrated in Plate 1.7.

Plate 1.6

Scanning electron-micrographs of mineral grains from soils formed in different parent materials: (a) mica, in a weakly weathered dense grey soil from schist; (b) sharp-edged shards of volcanic glass in a pumice soil; (c) surface-etched cube of feldspar in a podzol from granite; (d) circular pits filled with clay, formed in situ on the weathered surface of a young basalt lava flow. (Lines represent 50μm.)

Plate 1.7 (opposite)

Scanning electron-micrographs of some of the main clay species in soils: (a) flakes of mica; (b) plates of kaolinite stacked together like pages of a book; (c) spheres of halloysite; (d) allophane, teased out like threads of cotton-wool; (e) grains of quartz bound together by a lattice of iron oxide (probably ferrhydrite), in the iron pan of a podzol; (f) needles of goethite, wrapped together like skeins of wool. (Lines represent 5μm.)
Soil particles and textures

Texture is the feel of the soil, reflecting the proportion of sand, silt and clay-sized particles (Fig. 1.3), as well as the amount of organic matter mixed with them. Sandy soils feel gritty, silts smooth, and most clays are sticky and plastic (i.e. they can easily be moulded into shapes when moist). The textural differences among the soils of New Zealand reflect both the age of the soil (i.e. duration of weathering) and the parent material. Since most of our landforms are youthful, and our climate is far from tropical, most soils are relatively young, with sand and silt dominating their textures.

The proportion of different-sized particles in four New Zealand soils of contrasting textures – sandy, silty, clayey and loamy – from very different parent rocks or materials, is illustrated in Fig. 1.4.

Fig. 1.3
The relative sizes of sand, silt and clay particles. Sands range in diameter from 2 - 0.02 mm; silts, 0.02 - 0.002 mm; and clays are less than 0.002 mm. Gravels are rock particles from 2 - 20 mm in diameter.

Fig. 1.4
Contrasting proportions of sand, silt and clay in four New Zealand soils. The sandy Foxton soil (Plate 6.15) has developed in sands rich in quartz, feldspar, and volcanic glass, washed down to the Manawatu coastal lands from the greywacke ranges and volcanic uplands. The Waimatenui soil (Plate 5.11) is a clay which has developed through the deep weathering (over a long time in a subtropical climate) of basalt rocks in Northland. The silt-textured Wharekohe soil (Plate 5.17) also occurs in Northland but here the parent material is a range of sandstones, siltstones and mudstones. The Egmont soil (Plate 4.9), in contrast to the other three, has a loamy texture because it has a balance of sand, silt and clay.
Whereas sands and silts are generally primary fragments of parent rock, clays are usually true secondary minerals formed through chemical changes to the parent material as the soil develops. Because of their enormous surface area, and hence their reactivity, they are of fundamental importance in determining the properties of the soil (see description of clays, p. 20).

Both clays and soil organic matter are very important in promoting soil structure, by helping bind individual particles of sand and silt together into larger particles called 'aggregates' (see description of soil structure, below). Soil structure controls the movement of both water and air, each essential for plant growth, through the profile. A well-structured soil will have ample space (pores) between the macroaggregates, thereby allowing free drainage of water, and easy penetration by plant roots. Good aeration of the soil is important because oxygen is necessary for the growth of plants and of beneficial soil micro-organisms involved in nutrient cycling.

**Soil structure – the role of clays and organic matter**

Both clays and soil organic matter bind the soil particles together to form soil aggregates, the building blocks of soil structure. In the smallest aggregates, non-crystalline clays with very high surface area (such as allophane or ferrihydrite) are the most effective. A good example of this type of binding is illustrated in Plate 1.7(e) where a honeycomb lattice of iron oxide (probably ferrihydrite) is holding the particles of silt together; these microaggregates are very stable when wetted. Aggregates which are bound together only by crystalline aluminosilicate clays tend to fall apart when wet.

Organic components can act as both 'glue' and 'binding twine' in holding soil particles together. In the smallest microaggregates (0.2–20 μm) the clay particles are held together by organic cementing agents (humic substances) and microbial remains, such as the hypha of an actinomycete (a micro-organism) shown snaking its way between the flakes of clay and organic glue in Plate 1.8(a). Polysaccharides can be exuded by plant roots and micro-organisms and their sticky strands are important in 'ropeing together' these small microaggregates; Plate 1.8(b) shows some soil polysaccharide strands with colonies of bacteria growing on them. Other organic materials, such as the clay-plastered spores in Plate 1.8(c), can also contribute to microaggregation. These microaggregates are more loosely bound together by other organic materials – fungal hyphae and plant roots – to form macroaggregates (200–2000 μm) which can be seen with the naked eye.

The larger aggregates (macroaggregates) vary widely in their size and shape and fit together like a three-dimensional jigsaw to confer different structures on soils (Table 1.1).

### TABLE 1.1

**Shape and properties of soil macroaggregates**

<table>
<thead>
<tr>
<th>Shape</th>
<th>Structure</th>
<th>Properties</th>
<th>Typical soil illustrating structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>crumb</td>
<td>like breadcrumbs; up to 5 mm across</td>
<td>do not fit neatly together in place; soak up water easily; roots penetrate easily and wrap around aggregates</td>
<td>Egmont black (Plate 4.9)</td>
</tr>
<tr>
<td>granular</td>
<td>like breadcrumbs but more rounded; up to 10 mm across</td>
<td></td>
<td>Naite (Plate 3.19)</td>
</tr>
<tr>
<td>nut</td>
<td>like small nuts – blocklike but rounded edges; up to 50 mm across</td>
<td></td>
<td>Belmont (Plate 8.4)</td>
</tr>
<tr>
<td>blocky</td>
<td>like blocks – with sharpish edges; can be any size</td>
<td></td>
<td>Warepa (Plate 13.2)</td>
</tr>
<tr>
<td>columnar</td>
<td>standing like columns flattened at top; can be any size</td>
<td>fit neatly together in place within the soil; water and roots penetrate more slowly down cracks between aggregates</td>
<td>Tokomaru (Plate 6.4)</td>
</tr>
<tr>
<td>prismatic</td>
<td>standing like columns flattened at top; can be any size</td>
<td></td>
<td>Manorburn (Plate 10.16)</td>
</tr>
<tr>
<td>platy</td>
<td>layered like plates; can be any size</td>
<td>impedes water and root penetration; can be induced by bad management</td>
<td>Matapao (Plate 7.10)</td>
</tr>
</tbody>
</table>

Scanning electron-micrographs of some soil organisms: (a) hypha of an actinomycete amid flakes of clay and 'glue' of humic substances; (b) soil polysaccharide strands and colonies of bacteria; (c) spores partly covered with clay and humic substances. (Lines represent 2μm.)
The Soil Profile and its Description

Using the concepts of soil texture and structure discussed in the previous paragraphs, it is now possible to begin to describe a soil profile in more technical detail. For instance, a simple profile description of the Mawhera soil (Plate 1.9) would focus on three distinguishing features – 20 cm of dark-coloured litter and humus, overlying 50 cm of pale silty material, overlying an unknown depth of stony gravels which become progressively darker with depth. By making a series of additional detailed observations (such as colour, texture, structure, presence or absence of mottles, humus, or clay coatings) throughout the profile it is possible to identify a number of discrete layers (horizons) and give each a distinct notation, using the letters and numbers defined below.

The soil profile and its horizons

The soil profiles illustrated throughout this book have a minimum of technical description – usually a depth scale and sometimes the notation of individual soil horizons.

The horizon notation is expressed by a master horizon (capital letters) qualified by a series of lower case suffixes to express other properties. These are:

**MASTER HORIZONS**

**Organic**
- L = partly decomposed litter accumulated under moist conditions
- H = well-decomposed litter
- O = peat, accumulated under wet conditions

**Mineral**
- A = mineral horizon formed at the surface (topsoil) and characterised by incorporation of humified organic matter
- AB = a transitional horizon between the topsoil and the subsoil B horizon; common in soils under grassland where a worm-mixed layer occurs below the topsoil
- E = an eluviated horizon below the H, O, or A horizon; clay, iron or aluminium have been lost, leaving behind a relatively pale, structureless horizon richer in quartz and lower in humus and nutrients than the underlying B horizon and overlying A horizon
- B = mineral horizon without rock structure that has one or more of the following characteristics:
  - (i) accumulation of clay, iron and/or aluminium, or humus (Bt, Bs, Bh horizons), or
  - (ii) alteration of the original material involving formation of oxides to give brighter colours than the horizons above and below, and the formation of granular, nut, blocky, or prismatic structure (Bw horizon)

**Qualifying suffixes to indicate properties within the master horizon**
- g = gleyed horizon, caused by periodic saturation with water; reduction of oxygen causes segregation of iron as red/brown mottles
- h = accumulation of humus in a mineral horizon; (the notation Ah indicates an A horizon which has not been disturbed by ploughing or other human interference)
- m = strongly cemented horizon which resists root penetration
- r = a strongly reduced horizon in a gley soil, usually blue-grey in colour and lacking structure
- s = accumulation of oxides of iron, aluminium or manganese (e.g. Bms is used to designate an iron pan in the B horizon)
- t = accumulation of clay, usually washed down from upper horizons (e.g. Bt)
- w = weathering in situ as reflected in changes in colour, clay content or structure (e.g. Bw)
- x = a compact but uncemented horizon (a fragipan) caused by dense packing of mineral particles

Where there is a very sharp contrast in the content of sand or stones between layers in the profile it is convenient to indicate this with a numerical prefix. For example, the horizon sequence A, B, 2C indicates that the C horizon is different from the material in which the overlying soil has formed. This is common when volcanic ash covers non-volcanic rocks, or loess covers glacial outwash gravels.

Plate 1.9

The Mawhera soil is a gleyed and podzolised forest soil of the intermediate-level glacial outwash terraces of the West Coast of the South Island. This profile occurs under beech/podocarp forest near Ikamatua in the Grey Valley. Morphologically, the profile has 3 major components — an organic-rich top (0–20 cm), over a thick, dense silty layer (20–73 cm) which is probably loessial in origin and has become gleyed, resting on glacial outwash gravels and stones below 73 cm which are gleyed at their surface and stained with organic matter lower down.

In terms of the horizon notation outlined on this page, the profile has the form: L, F, H, Ahg, Bg, 2Bh, 2BC, 2C.
Topography and Climate in Soil Formation

The significant topographic and climatic diversity within the New Zealand environment is responsible for much of the variation in the soil pattern of the country. The slope of the land influences the nature of the soil parent material. Soils on the gently rolling ridge crests are usually quite deep because these sites are more stable, allowing the underlying rock to weather without eroding and allowing any airborne volcanic ash or loess to accumulate. Where rock and soil debris (colluvium) is eroded from hilly slopes, it tends to accumulate as deposits at the foot of the slope, often leaving shallow soils (such as the Tawai soil in Fig. 1.1) in the eroded steep mid-slope area. Consequently, the soil pattern in hilly country can be complex, depending on its erosion history.

The other important soil factor affected by topography is soil water. On gentle slopes rainfall tends to infiltrate and pass vertically through the soil; on steep slopes much of the rain runs off over the surface and some of the water that does pass into the soil profile tends to move downslope under the influence of gravity. This lateral movement can concentrate nutrients in the soils at the foot of the slope. If these soils become saturated with water they are said to be waterlogged. Such poorly drained soils (gley soils, Chapter 3) often contain plenty of plant nutrients but, during the wet season, they lack the soil structure and aeration required for good plant growth.

Climate affects soil formation through local differences in precipitation (snowfall and rainfall) and temperature. Temperature controls the rate of chemical reactions. For instance, the chemical weathering of rocks is much more rapid in warmer places like Northland, than it is in Southland or in the high country of the South Island. The biological activity in soils (and the decomposition of plant litter) is much higher, and the growth of vegetation is more rapid, in warmer climates. Soils also tend to lose moisture to the atmosphere more rapidly in warmer (and windier) climates.

The influence of climatic differences on soil formation is illustrated by a sequence of soils on the Old Man Range near Alexandra (Fig. 1.5) in the basin and range landscape of Central Otago (see Chapter 10). The soils form a climosequence, as the influence of the other soil-forming factors is minimal. In other words, all the soils have:

- similar age (8000–10 000 years);
- parent materials derived entirely from schist;
- free-draining sites on rolling to hilly slopes;
- tussock grassland or herbfield vegetation; no forest.

Soil development and plant growth is limited by climatic extremes at either end of the slope sequence – cold, windy conditions at the top; dry summer/cold winter (i.e. continental) conditions at the bottom.

Biological Factors in Soil Formation

Perhaps the most complex soil-forming factors are biological. The soils already illustrated in the Franz Josef chronosequence (Fig. 1.2) and the Old Man Range climosequence (Fig. 1.5) have biological as well as physical origins. As sun, wind and water weathered the mineral surfaces, organisms also played a critical role. Lichens secreted organic acids that dissolved rock surfaces, successions of plants added nitrogen from the atmosphere to the soil, nutrients were taken up by plants and recycled. Dead roots, stems and leaves decomposed and the products were absorbed back into the soil, mainly as soil organic matter (see p. 26). Some of the main classes of organisms involved in this decomposition segment of the organic cycle are illustrated in Plate 1.1 for a soil under indigenous forest, and in Plate 1.2 for a pasture soil.

Once established, a vegetation community has a marked effect on soil development. The microclimate of a forest interior is very different in terms of humidity, windrun and sunlight from that of a grassland or open shrubland. Tree roots usually penetrate much deeper into the subsoil than grass roots and are therefore able to bring up minerals from greater depths and incorporate them in the organic cycle. On the other hand, a grassland turf has a dense network of roots in the topsoil and much more intensive nutrient cycling and biological activity (especially earthworms) in the rooting zone.
Furrowed landscape ('soil polygons') on broad summits of block mountains: alpine cushion plants and Obelisk soils.

Mean soil temperature
Jan/Feb

Mean soil temperature
July

Introduction: How Soils are Formed

Annual rainfall

Annual soil moisture deficit

Looking north from the dry foothill tor landscape at the foot of the Old Man Range towards the Dunstan Range on the skyline.
Soil organisms and soil organic matter

Soil organisms (or the 'soil biomass') are the animals and plants that live almost entirely within the soil. Macro-organisms are visible to the naked eye and are mainly soil animals and the roots of plants. Micro-organisms are minute animals and plants which can be seen only under a microscope. Most topsoils and litter are teeming with these soil organisms – the weight of earthworms in the top 30 cm of soil under a highly producing Waikato dairy pasture is equivalent to several times the weight of the cows grazing on it. The number of micro-organisms is mind-boggling – a teaspoon of soil would have around 100 billion bacteria and fungal threads of around 15 km in length.

The deep litter layer under a typical indigenous forest (Plate 1.1) is full of the larger soil animals (wetas, slaters, springtails and cockroaches) which chew the plant litter into smaller pieces more suitable for micro-organisms to feed on. Other soil animals (spiders, harvestmen and centipedes) prey on these plant-feeding animals; yet others (such as ants, beetles and mites) feed on both decaying vegetation and other animals – dead or alive. Another group (various larvae and nematodes) specialise in sucking juices from, or eating, plant roots. Under pastures the organic cycle is much more rapid but there is a much narrower range of soil animals (Plate 1.2). The mat of fine roots is attractive to pasture pests like nematodes and insect larvae (such as grass grub and porina moth). Earthworms are the dominant group in pastures and they play an extremely important role in aerating the soil and intimately mixing the organic topsoil with the mineral layers in the subsoil. Worm-mixing is clearly shown in Plate 13.12, the Waikiwi soil.

Soil micro-organisms play a vital role in the organic cycle, for they can decompose most plant and animal wastes, releasing many nutrients which are then taken up by plant roots. Most are very small, often single-celled, plants such as algae which can make sugars by photosynthesis like green plants; fungi (including yeasts) which are very effective at rotting damp fragments of wood, leaf or root; and bacteria which can decompose most organic (and many inorganic) compounds and, in some cases, synthesise natural nitrogen fertilisers from atmospheric nitrogen. Actinomyces bacteria cause the distinctive earthy smell of soils. Other micro-organisms such as protozoa (including amoebae and soil nematodes) are small animals (see the 'armour-plated' protozoan in Plate 1.10). This latter group generally prey upon bacteria.

All these micro-organisms (the microbial biomass) make up about 5 percent of the organic matter in an average topsoil, yet they are very important because of the nutrients they contain which are released after their short lifetimes (1–2 years). The remaining 95 percent of the soil organic matter is inanimate humus – the dark-coloured, relatively stable product of the many microbial transformations of plant litter fragments and soil animal bodies and waste products. Both the micro-organisms and the humus play an important role in stabilising soil aggregates (see p. 22). Humus also has moisture-holding and nutrient-exchanging properties similar to the clay.

The types of humus accumulating in our soils fall into two broad categories. The native conifers (kauri, kaikawaka and podocarps such as rimu, miro, totara and matai), beeches, and exotic conifers tend to build up layers of raw, fibrous, poorly decomposed and acidic humus (mor). The litter of broadleaved trees (tawa, puriri, kohekohe) and grasses tends to decompose more readily to a mull humus which is crumbly, less acidic, and more intimately mixed with mineral material (particularly through the action of earthworms). The podzolised Wharekohe soil (Plate 5.17) under kauri is a good example of mor humus formation, and the Egmont black soil (Plate 4.9) an example of mull humus formed under coastal broadleaf forest and bracken fern.

The relationship between vegetation and soils is so strong that the major soil groups of the world are often differentiated in terms of their natural vegetation. In New Zealand it is harder to recognise this relationship because introduced pasture and trees have replaced most indigenous vegetation. Nevertheless some remnant indigenous vegetation communities do occur on certain kinds of soil. Examples are:

- kauri forest on the deeply weathered, clay-rich soils north of the Waikato-Bay of Plenty;
- individual species of beech (mountain, red, hard and silver) on different soils in the wetter, steeper parts of the country;
- kahikatea forest on the fertile wet soils of floodplains; totara/matai forest on free-draining stony terraces;
- red tussock on the colder, wetter sites, and other species of snow tussock according to differences in soil drainage and fertility.

Such relationships pose the old chicken and egg question – which came first, the soils or the vegetation? The answer is often neither, but a little bit of each, in stages. Consider, for instance, the influence of vegetation on the formation of podzols (described in Chapter 5), such as the kauri podzols of Northland. The egg-cup shaped podzols under the kauri trees of the subtropical north of New Zealand (Plate 5.1) are often quoted in soil science textbooks as one of the world's
Introduction: How Soils are Formed

outstanding examples of podzolisation. At the base of its huge trunk, a cone of fallen leaves, bark and twigs builds up over hundreds of years. As this litter decomposes to a deep, raw humus, percolating rainwater dissolves organic acids and other decomposition products which are capable of forming soluble organic complexes with oxides of iron and aluminium, clay, and important nutrients like calcium, magnesium and trace elements. The upper part of the soil is very acidic and leached of nutrients, many of which have been redeposited deep in the soil profile as conspicuous iron pans or humus pans.

Very often there is evidence that soils have already been strongly weathered or leached before low-fertility tolerant trees became dominant in the vegetation succession; in these cases, the vegetation may simply have accelerated the rate of soil development otherwise due to climatic influences. The pakihi soils of the West Coast of the South Island, such as the Okarito soil (Fig. 1.2a and Plate 11.7), are extreme examples of soil degradation and the present depleted vegetation may be the consequence, not the cause, of soil deterioration. There is no real evidence that this wet heathland, fernland and shrubland (pakihi vegetation) causes podzolisation, but it is certainly well adapted for survival on such impoverished soils.

The total amount of soil organic material depends not only upon vegetation, but also upon topographic and climatic influences. Peat formation can occur in basin situations where the water table is high; these are organic soils (described in Chapter 3). High levels of organic matter are also found in soils in cool, wet climates such as the uplands of east Otago and Stewart Island and the mountains of Fiordland. Generally, the drier the climate, the less prolific the vegetation, and hence the lower the content of organic matter in the soil.

Soil Groups and Landscape Regions of New Zealand

The soil-forming factors of parent materials, topography, climate, and biota, all acting throughout time, have combined to give New Zealand its pattern of soils and landscapes. The distribution of the soils is shown in map form (Fig 1.6) by grouping them into 18 main classes whose names have been simplified to convey something of the colour, texture, parent material, climate or topography of the soil.

It would have been more conventional to structure the remaining chapters of this book in terms of major soil groups mapped in Fig. 1.6. However, this approach can become rather repetitive. Instead, the following chapters describe soils and landscapes of 12 distinctive regions of New Zealand. The journey begins high on the pumice lands of the central North Island. Here, among youthful volcanic landscapes, it is easier to appreciate the weathering of the raw, mineral parent materials (in this case the tephras from the volcanoes) and their transformation into a variety of soils. By comparison the old, deeply weathered clay-rich soils of Northland are much more complex and are therefore considered later (in Chapter 5), after the soils fringing the pumice lands – the superb volcanic loams of the loam lands of the Bay of Plenty, Waikato, and the western Taranaki ringplain – have become familiar.

From there the journey is more or less southwards, through regions which may not make much geographical sense at first glance but which have, nevertheless, a considerable degree of soil landscape unity:

- the marine and alluvial terraces and coastal dunes of the Manawatu;
- the shattered, eroded hills of the seasonally dry East Coast of the North Island and central Marlborough;
- the rugged, windswept hills of Wellington, Nelson, and the Marlborough Sounds;
- the steepland soils of the high mountain barrier to the wet west wind, stretching from the Tasman Mountains to Fiordland;
- the dry basins and low ranges that lie to the east of the mountain chain, with their climatic extremes of cold winters and hot summers;
- the lowlands of Canterbury, Otago and Southland, where more simple patterns of silty and stony soils can be found on vast terraces, fans, and downlands formed by the deposition of erosion debris from the mountainous hinterland.

Some soil and landscape changes are abrupt between the regions; others are more subtle, changing imperceptibly under the influence of gradual differences in climate, topography or parent material. These, and many other observations, can help us to interpret why our soils appear where they do in the landscape.
Fig. 1.6

Map of New Zealand's soils: (a) North Island; (b) South Island.

The 18 soil groups shown occur on flat, rolling and hilly slopes (0 - 28 degrees). Soil groups have not been shown in the large area of steep-land because of the small scale of the maps and the complexity of the steepland topography (see Chapter 4).

Soil-group names used in the legend are simplified from those used in usual New Zealand soil science publications. Their equivalent names in the New Zealand Soil Classification are listed in the appendix, which summarises the influence of the soil-forming factors on each soil group.
### TABLE 1.2
General properties of main clay groups

<table>
<thead>
<tr>
<th>Clay group (species)</th>
<th>Shape</th>
<th>Occurrence</th>
<th>Surface area</th>
<th>Water retention</th>
<th>Cation exchange capacity</th>
<th>Anion retention</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALUMINO-SILICATES</strong></td>
<td></td>
<td></td>
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<tr>
<td>Micas (muscovite, illite, biotite)</td>
<td>irregular crystalline flakes</td>
<td>primary minerals arising from breakdown of rocks like schist</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
<td>low</td>
<td>important source of soil potassium; appear as shiny flakes in soils (muscovite-silver; biotite-brown)</td>
</tr>
<tr>
<td>Vermiculites</td>
<td>irregular crystalline flakes</td>
<td>alteration products from weathering of micas and chlorites; widespread in moderately weathered soils (dense grey soils, brown earths)</td>
<td>high</td>
<td>medium</td>
<td>very</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Smectites (montmorillonite, beidellite) flakes</td>
<td>irregular</td>
<td>montmorillonite forms in soils with high base status, high pH, especially with poor drainage; predominant in black swelling clays from weathered limestone or basalt; beidellite forms in strongly leached soils (upland brown earths)</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
<td>can hold organic matter strongly; shrink and swell with varying water content — used in cricket wickets; very hard when dry; very plastic; lose strength on wetting — responsible for many landslides, e.g., Abbotsford</td>
</tr>
<tr>
<td>Chlorites (primary and secondary)</td>
<td>irregular crystalline flakes</td>
<td>primary chlorite occurs in less weathered soils (recent alluvial, semi-arid and dense grey soils); secondary chlorite ubiquitous in temperate soils from non-volcanic parent materials</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>medium (in secondary chlorites)</td>
<td>primary chlorite a source of magnesium</td>
</tr>
<tr>
<td>Kaolins (kaolinite, halloysite)</td>
<td>hexagonal plates (K); tubes and spheres (H) (both crystalline)</td>
<td>kaolinite abundant in soils in sub-tropical climates and in older soils (volcanic clays, brown clays); halloysite common in weakly leached soils from volcanic ash (some volcanic loams, volcanic loamy clays)</td>
<td>very low</td>
<td>very low</td>
<td>very low</td>
<td>low</td>
<td>chemically among the most inert of clays; both white; pure kaolinite important in porcelain-making; halloysite more important in N.Z. — a useful pottery clay; low expansion on wetting; low shrinkage on drying of kaolinite</td>
</tr>
<tr>
<td>Allophane</td>
<td>non-crystalline hollow spheres</td>
<td>common in strongly leached soils from volcanic ash (pumice soils, volcanic loams); can form in non-volcanic parent materials in high-leaching climates (high country brown earths)</td>
<td>very high</td>
<td>very high</td>
<td>variable (very low at low pH medium at pH&gt;7)</td>
<td>very high</td>
<td>variable for other anions</td>
</tr>
<tr>
<td><strong>OXIDES</strong></td>
<td></td>
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<tr>
<td>Iron oxides</td>
<td></td>
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<tr>
<td>Ferrhydrite</td>
<td>non-crystalline spheres</td>
<td>all formed by oxidation of iron released by weathering of iron-containing minerals; ferrhydrite and goethite widespread in NZ soils</td>
<td>very high</td>
<td>similar to allophane</td>
<td>similar to allophane</td>
<td>high pigmenting power: —haematite (shades of red)</td>
<td></td>
</tr>
<tr>
<td>Goethite</td>
<td>usually long needles, sometimes twisted into balls</td>
<td>—haematite in red soils, common in northern N.Z.</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>—ferrhydrite shades —goethite of —lepidocrocite brown</td>
<td></td>
</tr>
<tr>
<td>Haematite</td>
<td>usually hexagonal plates</td>
<td>—lepidocrocite often in gleys soils</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>—lepidocrocite brown</td>
<td></td>
</tr>
<tr>
<td>Lepidocrocite</td>
<td>usually elongated plates</td>
<td>—lepidocrocite often in gleys soils</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>medium-high (depending on particle size)</td>
<td>— promote soil aggregation —strong attraction for phosphate</td>
<td></td>
</tr>
<tr>
<td><strong>ALUMINIUM OXIDE</strong></td>
<td>crystalline hexagonal plates</td>
<td>common in acidic, very strongly weathered soils with very low levels of silicon (friable volcanic clays); often occurs with iron oxides</td>
<td>low</td>
<td>low</td>
<td>low (at soil pH levels)</td>
<td>medium-high (depending on particle size)</td>
<td>forms only very slowly in soils; may indicate an earlier, warmer, weathering period; main constituent of aluminium ore, bauxite</td>
</tr>
</tbody>
</table>
Introduction: How Soils are Formed

Key to identification of soil organisms illustrated in Plates 1.1 and 1.2.

FOREST (top) [Plate 1.1]

Live root feeders
1 scarab beetle grub
2 weevil grub
3 nematodes
4 cicada nymph

Symbiotic organisms
5 nodules formed by nitrogen-fixing micro-organisms

Live plant-leaf feeders
6 bush weta

Organic matter feeders — dead leaves, roots, wood, and micro-organisms
7 amphipod
8 isopod
9 weevils
10 beetle grub larva
11 osorine rove beetles
12 leaf-case caterpillar
13 native earthworm
14 millipede
15 springtails
16 striped ant nest
17 fungi
18 bacteria and actinomycetes

Predators, feeding on other animals
19 back crab spider
20 centipede
21 carabid beetle
22 peripatus
23 mites
24 false scorpion
25 japygid symphylan (eating a campodeform symphylan)
26 native snail
27 Cordiceps fungus parasite on a puriri caterpillar

PASTURE (bottom) [Plate 1.2]

Live root feeders
1 grass grub adult
2 grass grub
3 black beetle
4 white-fringed weevil grub
5 wire worm (also eats other larvae)
6 mealy bugs
7 nematodes
8 nematode cysts on clover roots

Live plant-leaf feeders
9 porina caterpillar
10 lucerne flea
11 lucerne aphid

Symbiotic organisms
12 Rhizobium nodules (nitrogen-fixing bacteria)

Feeders on organic matter — dead leaves, roots, dung, bacteria, algae and fungi
13 common topsoil-mixing earthworm
14 common topsoil-mixing earthworm aestivating
15 dung worm
16 yellow-tailed worm
17 maggots
18 small dung beetle
19 springtails
20 ptillid beetle
21 fungi
22 bacteria and actinomycetes

Predators, feeding on other animals
23 mites
24 rove beetle