DUPLICATE

FOREST SOILS

LECTURE NOTES OF THE
FORESTS DEPARTMENT
OF WESTERN AUSTRALIA

FOREST SOILS

A Course for Trainees of the W.A. Forests Department

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CHAPTER I - INTRODUCTION

In the study of silviculture we learnt that the two factors most powerfully influencing the growth and development of forest stands are (i) the climate of the area and (ii) the soils in which the forest grows.

Climatic factors are discussed elsewhere; our object in this course is to study forest soils, their formation and general characteristics and the manner in which they influence forest growth.

HISTORICAL BACKGROUND

For many centuries man has been aware of the influence of the soil upon his crops. Initially his interest in the soil mainly centred around its effect on the productivity of agricultural crops. However, towards the middle of the nineteenth century, foresters too became interested in the soil when studies first began to indicate that there was a connection between forest growth and silvicultural practices on the one hand and the nature of the soil on the other.

Since that time, man has come to realise that a thorough understanding of the soil is necessary for the effective production of any crop, either agricultural or forest, so that today Soil Science is a science in its own right and the study of Forest Soils is an essential part of the training of every forester.

THE IMPORTANCE OF THE FOREST SOIL

The soil is the medium which supports and nourishes the forest stand. The soil influences the composition and distribution of forest stands, their rate of growth and vigour, their degree of resistance to diseases, their stability against the wind and the quality of the timber they produce. i.e. Soil provides anchorage, moisture and nutriment to a forest.

It is true to say that an understanding of the forest lies as much below, as above ground level.

THE SCOPE OF THIS COURSE

In this course we will examine the basic principles of Soil Science and indicate how this knowledge is applicable in the practice of silviculture. We will also discuss the common forest soil types found in Western Australia and the influence of these soils upon forest practices in this State.

FURTHER READING

These notes are intended to be introductory in nature and the reader may find that he wishes to pursue some aspects of the course in greater detail. To help him in this regard, a list of publications on the subjects of Soil Science and Forest Soils is included as an appendix to this course (page 35). The publications listed are available from the Forests Department library.

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CHAPTER 2 - SOIL FORMATION

The simplest definition of the soil is that it is "that portion of the earth's surface capable of sustaining plant growth". Forest soil is described more specifically as "the portion of the earth's surface which serves as a medium for the sustenance of forest vegetation".

A discussion of the nature of soil and the manner in which soils are formed is a convenient place to commence our study of forest soils.

THE NATURE OF SOIL

Soil has six major constituents:

1. Mineral particles - These range from submicroscopic particles of clay to sand and gravel. The hard skeleton of the soil.

2. Organic matter - The decayed remains of plants and animals commonly called "Humus".

3. Living organisms - The animals, microorganisms and roots, which inhabit the soil.

4. Water.

5. Air.

6. Chemical Constituents - The chemical elements and compounds occurring either free in the soil or disolved in the soil water.

Different soils contain varying proportions of these components, the proportion depending firstly on the way in which the soil was developed and secondly on the type of vegetation which the soil supports.

THE DEVELOPMENT OF SOILS

Soils are developed from two classes of material : (i) partially decomposed plant and animal substances (organic matter) and (ii) rocks and minerals (mineral material).

The two processes involved in the development of soil from these materials are called Decomposition and Weathering, respectively.

THE DEVELOPMENT OF SOILS (continued)

We may illustrate the process of soil formation as follows:

Plants and Animals → (Decomposition) → Humus

Rocks → (Weathering) → Mineral particles

Humus - plus - Mineral particles → SOIL

The process of decomposition of organic matter will only be briefly mentioned in this chapter as it is treated in greater detail later in the course (Chapters 5 and 6). In this chapter we will be mainly concerned with the development of soil from rocks by the processes of weathering. However, before doing so it is desirable that we first examine some background geology, so that we may better understand the composition of rocks and the different types of rock materials.

BACKGROUND GEOLOGY

The Rock-Forming Minerals. The earth and its atmosphere is composed of over a hundred separate chemical elements. Of these, about fifteen are found to make up the majority of the crust of the earth's surface. These are oxygen, hydrogen, carbon, phosphorus, sulphur, chlorine, silicon, aluminium, iron, manganese, calcium, magnesium, potassium, sodium and nitrogen.

With few exceptions these elements are not found individually but are found combined together into compounds called minerals. An example of a common mineral is quartz, which is a combination of silicon and oxygen; another is pyrites ("fools gold"), which is a combination of iron and sulphur. There is a vast number of different minerals made up of different combinations of the elements listed above.

Rock minerals are the ultimate source of the essential nutrients required by plants. Eighteen of the common minerals found in local rocks are listed in Appendix II. Also fifteen essential nutrients are listed in Chapter 4.

Rock contributing to formation of a soil is known as parent rock.

This must be distinguished from parent material, which is the material from which a soil is derived - it may be wind blown sand, or ironstone, or alluvium, or rotten rock but for practical purposes, never the parent rock.

Rocks can be divided into igneous and sedimentary. Rocks which have been altered since they were originally formed are referred to as metamorphic rocks.

BACKGROUND GEOLOGY (continued)

The Rock-Forming Minerals (continued)

I. Igneous Rocks: These are formed by the solidification through cooling of molten material from below the earth's crust. Common examples are granite and basalt.

II. Sedimentary Rocks: *Metamorphic*

Sediments are materials which have been deposited after transportation, by wind, water, or volcanic eruption and cemented by various agencies such as pressure of later deposits. The materials of a sediment may be sand, mud, dead organisms, or their skeletons, gravel, eroded fragments of igneous, metamorphic or other sedimentary rocks. Examples are sandstone and limestone, shale, coal.

Sediments are classified into groups depending on the agency which transported them. Aeolian sediments were transported by wind; Alluvial sediments were transported by water; and Glacial sediments were transported by ice. e.g. Dune sand, Laterite silts, and boulder deposits near Harvey Weir, respectively.

III. Metamorphic Rocks: These are formed from igneous or sedimentary rocks through the action of intense heat and pressure which brings about great changes in the original nature of the rock. Examples of ~~sedimentary~~ metamorphic rocks are Gneiss (formed from granite) and Marble (formed from limestone.

THE WEATHERING PROCESS

Having considered the classes of rock parent material and the rock minerals, we can now examine the first process in the formation of soil. This process is called Weathering.

There are two sorts of weathering : Physical weathering in which various processes cause the mechanical breakdown of rocks without changing their chemical composition, and Chemical weathering in which certain chemical processes bring about changes in the chemical composition of the rock minerals.

1. Physical weathering. The physical weathering (or "disintegration") is brought about by the natural elements wind, rain, hail, heat and frost acting over vast periods of time. The end result of this process is the production of the skeletal material of the soil - the rock fragments, grit and sand found in soil.

2. Chemical weathering. The chemical weathering of rocks is brought about by the chemical action of water, carbon dioxide, oxygen and various organic and mineral acids on the minerals of rocks. Chemical weathering results in the production of the "colloidal fraction" of the soil.

LIVING ORGANISMS AND SOIL FORMATION

Plants, animals and microorganisms play a major role in the conversion of weathered rock into soil. Their most important effect is the introduction of organic matter to the soil - a vital soil constituent. (This subject is discussed in detail later).

Some other important influences of living organisms on soil formation are :

1. Some organisms, notably lichens and mosses, can grow on bare rock surfaces. They draw their nutrients directly from the rock and may, over a period of time, develop a thin crust of soil on the rock surface.

2. Certain bacteria are capable of extracting nitrogen from the air and "fixing" it in the soil.

3. The roots of trees and other large plants can assist in the physical weathering of rocks by growing into small cracks and joints in the rocks and splitting off small fragments.

4. Worms, ants and other burrowing insects and animals play a major part in the aeration of soils, assisting microbiological activity and the development of structure (see page 13) of soils. Soil fauna which eat raw vegetable matter (litter etc.) enrich the soil with organic matter.

5. Tree roots bring nutrient elements from deep down in the soil and deposit them (via the litter) in the surface layers of the soil.

CLIMATE AND SOIL FORMATION

1. Temperature variations influence physical weathering.

2. Heavy precipitation hastens leaching and erosion.

3. Warm moist conditions hasten plant growth and chemical weathering processes hasten the dynamics of the whole system.

4. Arid conditions reduce plant cover and encourage erosion by wind.

5. Winds transport loose, exposed materials and the deposit forms the parent material of a new soil. e.g. sand, loess.

TOPOGRAPHY AND SOIL FORMATION

Slope and aspect induce local variations of climate which in turn influence soil formation.

Thus slopes away from the sun in our climate provide better growing conditions for plants which induce development of deeper and more fertile soils.

TOPOGRAPHY AND SOIL FORMATION (continued)

Slopes exposed to the sun have a harsher local climate and hence less vegetation resulting in more erosion on steeper slopes and lateritisation on gentler slopes (discussed later).

THE PRODUCT OF THE SOIL FORMATION PROCESSES

We may summarise the preceding sections by saying that soil is the product of the combined effect of climate, living organisms and topography acting on mineral parent material over periods of time.

The type of soil formed by the process will vary, depending on the relative influence exerted by each of the "soil-forming factors" (climate, organisms, topography, parent material and time) within the process.

For example, different parent materials will give rise to different soil; the type of climatic conditions will affect the type of weathering, and thus the type of soil - and so on.

The combined effect of the soil forming factors is the production of different layers in the soil, called soil horizons.

The Soil Profile. The different layers, or horizons, formed in the soil body by the action of slowly proceeding soil-forming processes are collectively called the soil profile. Although no two soils have exactly the same profile, all soils have three characteristic horizons. These are termed the "A" Horizon, the "B" Horizon and the "C" Horizon. These are further subdivided by numbers into further recognisable strata, e.g. A_1, A_2, A_3. See Fig.1.

Typically, the A horizon loses its clay to the B horizon. The processes whereby clay moves out of the A horizon is called elluviation. When it is deposited in the B horizon, the process is called illuviation. Remember them as follows:

"e" - meaning "out of" - elluviation
and
"i" - for "into" - illuviation.

The combined processes are referred to as podsolisation.

When these processes are carried to an extreme, the soil formed is called a "podsol" (Russian word for "ashy soil"). Podsols have a powdery white A_2 and a dense clay B_1. They are common in colder, moist climates under the acid litter of pines. If the parent material is all sand, then a "sandy podsol" will form.

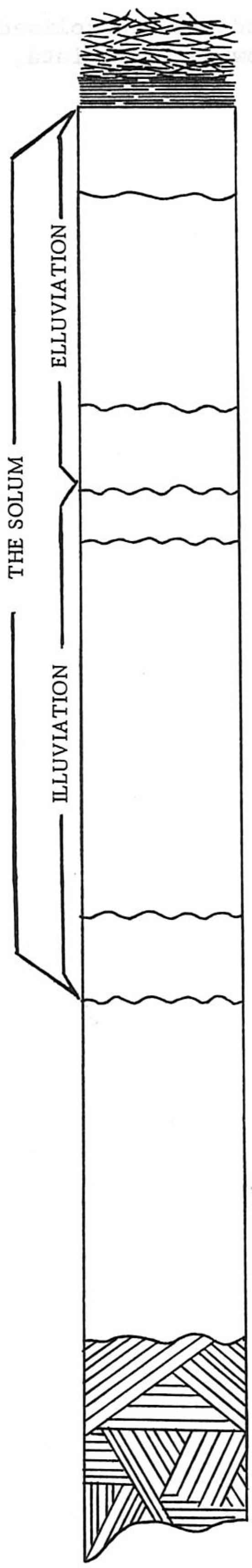
Most forest soils in W.A. show some influence of these processes and they fall in the class of "podsolic" soils.

Other soils are called Krasnozemic and Lateritic in the forest areas. Lateritic soils are discussed in Chapter 7.

The krasnozemic soil is red, showing only gradual texture changes down the profile. Under our climatic conditions it forms on parent materials high in ferromagnesian minerals.

Fig. 1.

"TYPICAL" SOIL PROFILE



THE PRODUCT OF THE SOIL FORMATION PROCESSES (continued)

The Soil Profile (continued)

It would appear that these minerals are weathered rapidly into clay and iron oxide (hence the red colour).

They are resistant to erosion and are only gradually podsolised. Under our conditions, they are fertile, and used for growing P. radiata, (see Chapter 7), figure no. 5.

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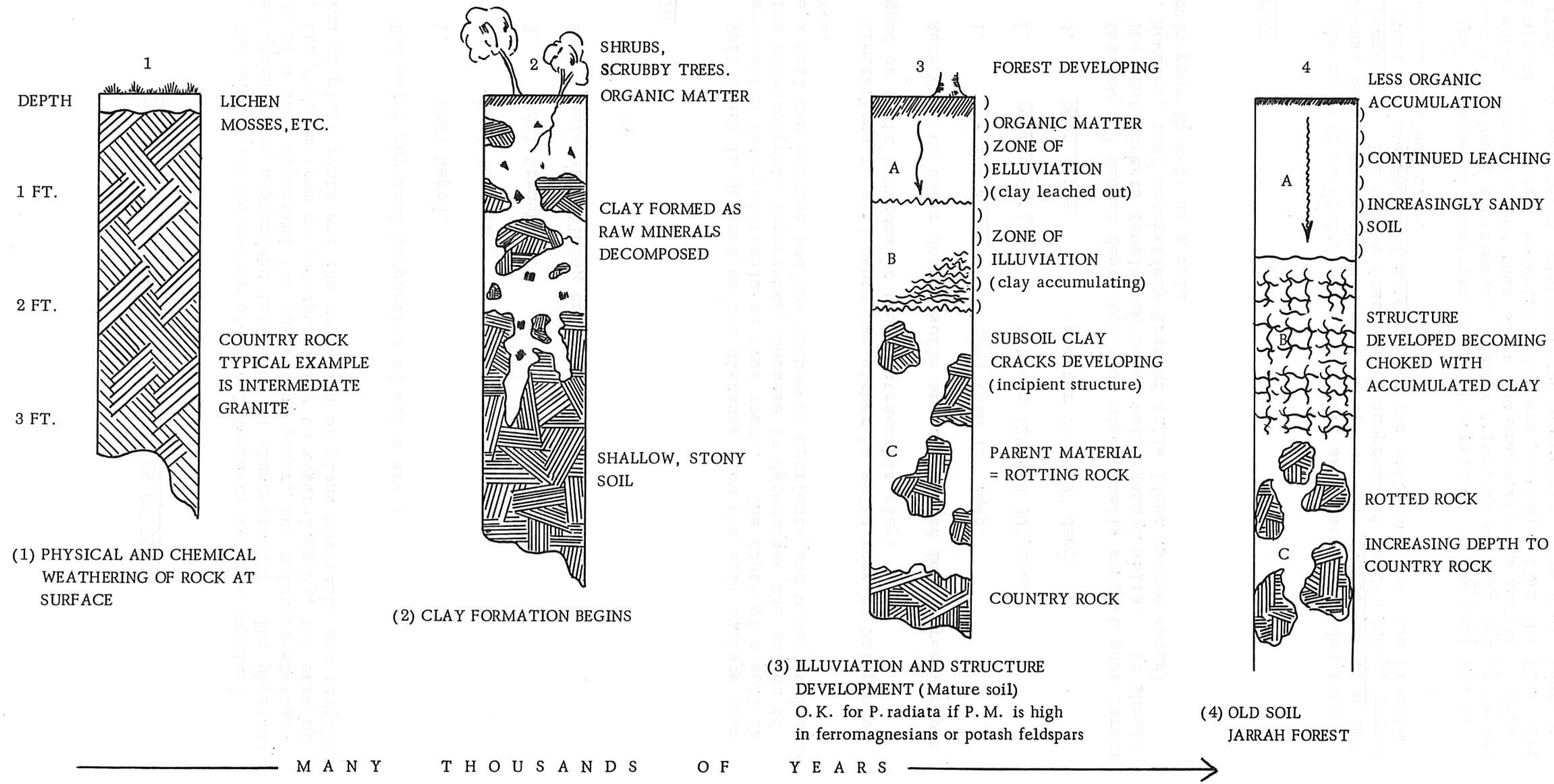
Fig.2.

PHASES IN THE DEVELOPMENT OF A PODSOLIC SOIL FROM COUNTRY ROCK



CHAPTER 3 - THE PHYSICAL PROPERTIES OF SOILS

The mechanical behaviour of a soil demonstrates its physical properties which exert a profound influence on plant growth. The physical properties of a soil determine its supporting power, its moisture-storage capacity, its freedom from or susceptibility to water-logging, the ease of penetration of plant roots and the retention of plant nutrients and fertilizers.

The major physical properties of soils are :

1. Soil Depth.
2. Soil Texture.
3. Soil Structure.
4. Moisture holding capacity.

SOIL DEPTH

Soil depth is defined as the distance from the soil surface down to any layer which is impenetrable to tree roots. The depth of a soil is of decisive silvicultural importance, because it determines the amount of anchorage a soil can provide and the volume of nutrients and water available to the tree.

Limitations to soil depth can either be solid rock or hardpan or water-logged or toxic horizons or tough intractable clay.

According to their depth, soils are classified into three groups:

1. Shallow Soils - less than 12" deep.
2. Medium Soils - between 12" and 30" deep.
3. Deep Soils - greater than 30" deep.

Shallow and medium depth soils do not normally support good forest growth. The best forests develop on deep, well drained soils. It should be noted, however, that excessively drained soils (deep coarse sands) support only poor forests as a rule.

SOIL TEXTURE

The mineral particles of the soil are arbitrarily divided into two fractions, depending on their size. These are the coarse fraction and the fine fraction. The coarse fraction is composed of small stones, gravel and sand (that is, the skeletal material of the soil) and the fine fraction is composed of silt and clay.

The presence of these two sizes of particles in the soil can be demonstrated by a simple experiment. Place a portion of soil into a vessel of water, shake thoroughly and then allow the suspension to settle. After about one minute, the coarse material will have settled whilst the fine silt and clay remain in suspension, discolouring the water. The fine fraction will not settle out for a considerable period.

SOIL TEXTURE (continued)

We describe the relative proportion of fine and coarse particles in a soil as the Texture of the soil.

Description of Soil Texture. Depending on the proportion of fine and coarse fractions in the soil, the soil texture is described as follows:

Heavy textured soils	-	have a high proportion of silts and clays.
Light textured soils	-	have a high proportion of sand and low proportion of silt and clay.e.g.70% or more.
Medium textured soils	-	have sand, silt and clay in about 60-20-10 proportion (i.e. "loamy" soil)

The texture of a soil can be determined accurately in the laboratory by Mechanical Analysis, but a field estimate of soil texture can be readily made from the "feel" of a moist sample of the soil in the hand. A guide to the field determination of soil texture is given on page 12.

Gravel Content. Another soil characteristic somewhat related to soil texture is gravel content. This feature is important in many W.A. forest soils. The gravel content of a soil is described in two ways :

(1) The quantity - whether medium, heavy light or just a trace, and

(2) The particle size - whether coarse, medium or fine. i.e. 3/4", 3/4" to 1/4", $<$ 1/4" diameter respectively.

The Importance of Soil Texture. Two important soil properties are greatly influenced by the texture of the soil; these are Water Retention and Fertility.

1. Water Retention. In the absence of soil organic matter, the ability of a soil to retain moisture in its profile depends directly upon the amount of fine fraction present - the greater the amount, the greater is the retentive capacity of the soil. In other words soils of medium to heavy texture (loams and clays) are better able to retain soil moisture than are soils of light texture (sands).

The evidence of this is readily apparent in the coastal plantation areas of W.A. The light-textured, sandy soils of these areas completely dry out each summer despite complete saturation during the winter months. Heavier textured loamy soils in the hills plantations, on the other hand, may often be still moist to the touch at the end of a long, hot summer.

TABLE 1

A GUIDE TO THE FIELD DETERMINATION OF SOIL TEXTURE

SOIL TEXTURE		CHARACTERISTIC "FEEL" OF MOIST SAMPLE
Sand	-	Gritty and coarse. Does not cohere (stick together).
Loamy - Sand	-	A cast may cohere, but easily breaks up on handling. Stains the fingers.
Sandy - Loam	-	A cast will cohere, but is friable. Small grains can be felt.
Silt Loam	-	"Fluffy" when dry. Readily forms coherent cast. Non-plastic when moist - collapses and will not ribbon.
Loam	-	As for sandy loam, but sand grains cannot be felt - will roll into a cigar shape which is very fragile. Slight ability to ribbon.
Sandy-clay-loam	-	As for clay-loam, but sand grains can be felt. Rolls readily into cigar shape but will stand only slight bending. Will form ribbons which break every inch or so.
Clay - Loam	-	Cast is plastic and will roll out into a pencil shape. Stands slight bending without breaking. Has smooth feel. Ribbons fairly well.
Sandy - Clay	-	As for clay, but sand grains can be felt. Usually sticky.
Clay	-	Tough and plastic. Can be rolled into a long pencil shape and bent into ring without breaking. Ribbons easily without breaking. Sometimes smooth, often sticky.

The Soil Texture "Triangle" (illustrated in Appendix III, page 37) shows the percentages of sand, silt and clay in these basic textural classes.

SOIL TEXTURE (continued)

The Importance of Soil Texture (continued)

2. Fertility. As we shall see later in the course, the fine fraction of the soil is one of the two major sources of nutrients for plants (the other is soil organic matter). Consequently, light-textured soils which contain a low proportion of "colloidal material" are generally less fertile than heavier textured soils.

The light-textured soils of the wheatbelt country of W.A. (known locally as "light land") illustrate this point. These soils require heavy dressings of fertilizer and frequent crops of the "nitrogen-fixing" plants (such as subterranean clover, lucerne and lupins) to produce good wheat crops. Similarly, the sandy soils of the coastal plain require heavy dressings of superphosphate fertilizer before pines planted there can make productive growth.

Soil texture also influences the behaviour of the soil in other ways. For instance, soils which are heavy textured and lack pore space may be impenetrable to plant roots or may be susceptible to water-logging and stagnation, with insufficient aeration to enable plant roots to breathe.

Generally speaking, the most desirable texture for a forest soil is in the medium range of texture i.e. from sandy loam to clay loam.

SOIL STRUCTURE

Soil structure is defined as the arrangement of the individual soil particles. If the particles of the soil are in no way aggregated together the soil is said to have a simple structure; if there is some aggregation of the particles of the soil, the soil is said to have a compound structure. Most West Australian forest soils have simple structure in the A horizon and where the B horizon is clay, it has compound structure.

The structure of the soil is an important soil characteristic, for structure modifies the influence of texture on soil properties such as the availability to the plant roots of air, moisture and nutrients, and the ease with which the soil may be penetrated by roots.

Topsoil Structure is very different from Subsoil (B horizon) Structure.

Formation of Soil Structure. How do the particles comprising a soil become aggregated? Consider, first, topsoil (A horizon) structure in soils heavier than sandy loam.

Without organic matter the particles become cemented together on drying by the natural attraction of soil colloids (clays), resulting in something like sunbaked brick (massive structure). This condition collapses with the addition of water and tends to go to a slurry, (as at a churned up ~~bark~~ landing).
bush

SOIL STRUCTURE (continued)

Formation of Soil Structure.

However, the presence of organic matter changes the picture. Particles of organic matter interfere with the cementing action of clay. Instead, particles cling together in groups forming structural units or crumbs of soil which do not collapse in water. This phenomenon is complex, but is basically the combined action of a cementing agent produced by breakdown of organic matter, the fibrous nature of soil fungi, the activity of living organisms in the soil, and various properties of organic matter itself. Topsoils aggregated in this way are resistant to erosion and support active plant growth.

In the case of subsoil structure, none of the A horizon factors appear to play a part. However, its formation can be satisfactorily explained as follows:

New clay forming from the breakdown of parent material minerals forms a massively structured layer, which, during dry periods is broken by shrinkage. Water from percolation brings down elluviated clay which is deposited on the surface of cracked clay. The crumbs, swell again with the moisture and become slightly compressed. With the next drying cycle, the crumb pulls away from its neighbour, roughly along the same joint-lines. Hence the aggregates become more compacted, and eventually separate out into individual units. As this repetitive process continues the fine deposits of clay often give shiny faces to the structural units (called 'peds' by the Soil Scientists) which also develop a less irregular outline.

Roots do not penetrate these peds but form a network of fine hair-like roots on the surface of them. They penetrate down the joint-lines, deep into the subsoil where moisture can be obtained in dry periods.

This may be the secret of the survival of jarrah in the harsh soil-environment of the laterite crust.

Types of Soil Structure. The main types of soil structure occurring in forest soils are :

1. Single Grained (or Simple Structure) : no aggregation of soil particles. Found predominantly in sandy-textured soils. Commonest in our forest soils.

2. Massive Structure : Cementation of single grained soils into a hard, dense mass when dried out. If not formed by compaction, will collapse into slurry when wetted.

3. Crumb Structure : Aggregates are small (one eighth of an inch in diameter) and tend to be rounded or nut-shaped. Commonly found in the "A" horizon.

4. Blocky Structure : Aggregates are compacted, usually angled up to one inch in diameter. A B horizon feature normally.

There are other types of structure, which are not within the scope of this course.

SOIL STRUCTURE (continued)

Effect of Soil Structure on Forest Growth. The main benefit to the soil of the presence of structural aggregates is that spaces (or "pores") form in the soil between the aggregates. These pores contain the air and moisture and enable the roots to penetrate the soil.

The structure of the soil has three important influences on soil properties and thus on forest growth. It affects (i) the aeration of the soil; (ii) the moisture infiltration and retention capacity of the soil and (iii) the penetrability of the soil to plant roots.

Generally speaking soils with crumby or granular structure are the most desirable while soils with massive structure the most undesirable from the point of view of forest growth. Massive structured soils are often formed by the compaction and crushing of the soil by heavy logging equipment operating in wet weather. (Soils with massive structure are a common sight on old log landings in the Karri forest.) Such soils have few spaces for air and moisture and dry out rock hard in the summer months.

Adjustment of Soil Structure. An undesirable soil texture cannot be altered except by the addition of separate fractions (such as adding sand to clayey soils), but surface soil structure can be temporarily improved by the action of tillage and ploughing.

However, unless organic matter is replaced, repeated ploughing of heavy soils tends to destroy natural structure and renders the ground less and less workable. (See earliest note on formation of structure.)

This is particularly important in nursery practice.

The subject of ploughs and ploughing methods is beyond the scope of this course, but the interested reader can refer to pages 58 to 67 of "The Fundamentals of Soil Science" by Millar, Turk and Foth for a good coverage of this subject.

SOIL WATER

Soil moisture is one of the most important factors affecting forest growth. Apart from its direct influence on the productivity of the forest stand, the amount of moisture in the soil also influences such important soil properties as soil aeration, the availability of nutrients and the concentration of toxic substances.

Forms of Soil Water. Water can occur in the soil in two forms : (i) as a thin film surrounding each particle of soil material or as minute droplets in the pores between the soil aggregates; and (ii) as a sheet of free water lying on an impervious horizon or above the parent rock. This latter is called "ground water" or the "water table" and is not present in all soils.

The water which occurs within the soil pores and surrounding the soil particles is the moisture most commonly utilised by the fine feeding roots of plants.

SOIL WATER (continued)

Measurement of Soil Moisture. The effect of soil moisture on tree growth is so important that a measurement of the amount of water present in the soil is often required. The terms commonly used to describe the amount of water in the soil and the means by which these amounts are determined are described below.

1. Percentage Moisture Content. The amount of water present in a soil is often described as the Percentage Moisture Content (%MC) of that soil. This is found by taking a sample of the soil, weighing it and then drying it to a constant weight at 105 degrees Centigrade. The loss in weight of the sample during drying is due to the evaporation of water; the amount lost is expressed as a percentage of the "oven dry" weight of the sample - the resulting figure is the %MC of the soil.

Example.

Initial weight of sample	=	10 gramms
Oven Dry Weight (at 105° C)	=	8 gramms
Therefore, loss due to drying	=	2 gramms
Then the %MC of the sample	=	$\frac{2}{8} \times 100$
	=	25%

2. Field Capacity. There is a limit to the amount of water which a permeable, well-drained soil can hold in the field. This limit is called Field Capacity. The field capacity of a soil is generally defined as the amount of water remaining in that soil one or two days after it has been completely saturated by rain or irrigation.

Any moisture in the soil in excess of the field capacity is loosely held and will quickly drain off under the influence of gravity.

3. Wilting Coefficient, or "Permanent Wilting Point". The Wilting Coefficient of a soil is the moisture content of the soil at which the plants growing in it will permanently wilt (that is, shrivel up and die due to an inadequate supply of water). This figure varies with the type of soil and the type of plant under consideration. It is determined by careful experiments (in glass houses) with potted plants.

However, a soil at Permanent Wilting Point is not completely dry. Water is present in the soil at this point, but it is closely bound to the colloidal matter in the soil and plant roots are not able to extract it for their own use. It is "physiologically dry" - just as is a saturated soil which has become stagnant. Plants are not able to take moisture from it.

The Loss of Moisture from the Soil. There are several processes which result in the loss of moisture from the soil. These are :

1. Transpiration. - the evaporation of moisture from the soil via the leaves of plants.

SOIL WATER (continued)

The Loss of Moisture from the Soil (continued)

2. Evaporation. - the loss of water directly from the surface layers of the soil.

3. Percolation. - the seepage of soil moisture to a depth beyond the reach of plant roots.

4. Run-off. - the drainage of water across the soil surface or across the soil profile to lower lying soils.

Soil Moisture and Forest Growth. This subject has been discussed in the course on "Silviculture" and the reader should refer to that section of those notes at this point.

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CHAPTER 4 - THE CHEMICAL PROPERTIES OF SOILS

Soil Chemistry is the study of the chemical composition of the soil and of the properties of the soil which are influenced by its chemical composition.

The Chemical Properties of soils have a profound effect on forest growth and this subject is therefore an important part of our study of forest soils.

Aspects of Soil Chemistry discussed in this chapter are:

1. Soil Reaction.
2. The Plant Nutrients and Soil Fertility.
3. Soil Toxicity.

SOIL REACTION

The Reaction of a soil is its degree of acidity or alkalinity. This soil property is described in terms of an empirical scale called the "pH Scale" which ranges from one to ten. A general classification of Soil Reactions according to the pH scale is as follows:

pH value	Description of Soil Reaction
1 - 6	Soil reaction is acid.
7	Soil reaction is neutral.
8 - 10	Soil reaction is non-acid, or "alkaline".

The pH value of a soil (i.e. the soil reaction) can have a definite influence of the properties of that soil. The life of soil microorganisms, the availability of plant nutrients and the physical properties of soils can all be markedly affected by the acidity of the soil. As a general rule, as the acidity of a soil increases (pH value drops) the productivity of the soil declines. Similarly, high alkalinity induces a drop in productivity.

In forestry soil reaction is of particular importance in the nursery. Here the effect of the pH value of the soil on the development of Damping-off Fungi (the scourge of nursery seedlings) is of particular significance. A high soil pH (alkaline soil) favours the incidence of Damping-off disease and this condition must be rectified before healthy seedlings can be successfully grown. It is generally accepted that a soil reaction of between pH 5.0 and 5.5 is the most desirable for pine nursery soils. Most pine forests and our eucalypt forest have acidic soils ranging from pH 4 to 6½. Broadleaved forests of the northern hemisphere are often alkaline but do not rise above pH 8 in the upper layers.

SOIL REACTION (continued)

The Adjustment of Nursery Soil Reaction. The soil reaction may be adjusted as follows:

1. To make the soil more acid (lower the pH) : application at certain prescribed rates of either sulphur or ~~ammonium~~ aluminium sulphate.

2. To make the soil less acid (raise the pH) : application at prescribed rates of either lime or wood ash.

THE PLANT NUTRIENTS AND SOIL FERTILITY

As mentioned in Chapter 2, the earth's crust is made up predominantly of some fifteen elements combined in different ways into innumerable compounds and minerals. All but four of these elements are essential for the healthy growth and development of plants; these elements are known as essential plant nutrients.

The four non-essential elements are aluminium, sodium, silicon and chlorine.

Although manganese is a major element in rocks, it occurs only in traces in soils. There are four other essential elements which occur in traces in soils (and they are only required in small amounts). They are boron, zinc, copper, molybdenum.

TABLE 2

THE ESSENTIAL PLANT NUTRIENTS

Name	Chemical symbol	Name	Chemical symbol
Major Elements			
Carbon	C	Magnesium	Mg
Hydrogen	H	Iron	Fe
Oxygen	O	Trace Elements	
Potassium	K	Boron	Bo
Nitrogen	N	Manganese	Mn
Sulphur	S	Zinc	Zn
Phosphorus	P	Copper	Cu
Calcium	Ca	Molybdenum	Mo

THE PLANT NUTRIENTS AND SOIL FERTILITY (continued)

Soil Fertility. With the exception of hydrogen (which comes from water) and oxygen, carbon and nitrogen (which comes from the air) all the other essential plant nutrients have their origin in the soil. Here they are derived from two sources: (i) from decomposed organic matter and (ii) from the rocks and soil minerals.

A soil is termed a fertile soil if it is able to supply all the necessary nutrients to plants and an infertile soil if it cannot.

Factors Determining Soil Fertility. Many factors determine whether a soil is fertile or not. Some of the more important of these are:

1. The type of soil-forming minerals in the soil parent material. If these originally contained few of the essential nutrients, there is little chance that the soil derived from them will be a fertile one.

2. The age of the soil, or the degree of weathering which has taken place. This determines the volume of nutrients released to the soil from the rock minerals. Very young (skeletal) and very old soils are often unfertile.

3. The microfara and microfama of the soil. The presence of the mircroorganisms responsible for the breakdown of organic matter is essential for the return of nutrients to the soil.

4. The degree of leaching to which the soil has been subjected. Leaching washes available nutrients down and out of the profile.

As a general rule, an idea of the fertility of a particular soil can be obtained from the following clues.

1. Soils high in organic matter are likely to be more fertile than soils with a low organic matter content, except of course the highly organic but strangely acid peaty soil.

2. Dark coloured soils are generally more fertile than pale coloured soils (organic matter has a darkening effect).

3. Soils containing enough silt or clay to put them in the loam class, are generally more fertile than soils of a sandy texture.

4. Lush growth of vegetation.

Nutrient Deficiencies. It is important to realise that each of the fifteen nutrient elements listed above is essential for healthy plant growth. Even ideal amounts of the other fourteen will not make up for a deficiency of any one. If a particular element is in such short supply that it must be added to the soil before plants can make healthy growth, such an element is called a limiting factor, because it limits plant growth.

Common limiting factors in W.A. forest soils are Phosphorus, Nitrogen and Zinc. A critical deficiency of nearly all nutrients is found on the sandy soils of the coastal plain.

THE PLANT NUTRIENTS AND SOIL FERTILITY (continued)

Nutrient Deficiencies (continued)

Nutrient deficiencies can occasionally be artificially produced through bad management of the soil. Examples are:

1. Overcropping (e.g., of a nursery) without fertilization. Nutrients are lost through the constant growing and removal of whole plants (in other words, the Nutrient Cycle is broken).

2. Repeated hot burning. Organic matter and soil organisms are destroyed and once again the nutrient cycle is broken.

3. Any practices which lead to increased soil erosion. Soil erosion nearly always involves loss of topsoil where nutrients are concentrated.

Functions of the Essential Nutrients in the Plant. Our understanding of the importance of the nutrients in the soil may be increased by an understanding of the role which these nutrients play in the nutrition of the plant. The following notes briefly describe the major functions of the plant nutrients and the effect of their deficiency on the plant.

1. Carbon, Hydrogen, Oxygen. The building blocks of plant tissue. Used in photosynthesis to produce sugars and ultimately, wood. Deficiency of any one causes stoppage of the process.

2. Nitrogen. Nitrogen is an essential constituent of the cell proteins which are at the very hub of all plant life processes. The symptoms of N-deficiency in trees are stunted growth, yellowish or redish foliage, premature death of leaves or buds and under-developed root systems.

3. Phosphorus. Phosphorus is a constituent of the cell nucleus and plays an essential part in cell division, the development of meristematic tissue and respiration. P-deficiency symptoms in trees are restricted branching, bronzing of the foliage and poorly developed roots. In P.radiata - short needles and fusion of needles.

4. Potassium. Plays an important role in hardening of soft tissues, and root growth. K-deficiency symptoms are the abnormal development of foliage and the "scorching" of leaves.

5. Calcium. Calcium is important in the development of the roots and particularly the development of the fine root hairs. Ca-deficiency results in stunted, discoloured roots.

6. Magnesium and Iron. Magnesium and iron are both constituents of chlorophyll, the important "trigger" of photosynthesis. Deficiency of either of these elements leads to chlorosis (yellowing of the foliage) followed by defoliation.

7. Sulphur. Sulphur is another constituent of cell proteins and is also important in respiration and root development. S-deficiency symptoms are similar to the symptoms of nitrogen-deficiency.

THE PLANT NUTRIENTS AND SOIL FERTILITY (continued)

Functions of the Essential Nutrients in the Plant (continued)

8. The Trace Elements. The trace elements are largely required in the making of chlorophyll and in the utilization of carbohydrates (respiration). Deficiencies of these elements leads to chlorosis, stunted growth and poor development of branches and roots. In P.radiata, multiple leaders, poor leaf colour.

9. Non Functional Elements. Aluminium, Chlorine and silica are often present but do not enter into the physiology of the plant.

SOIL TOXICITY

The productivity of a soil may be limited not only by a deficiency of nutrients but also by the presence of certain elements or compounds in toxic (or "poisonous") concentrations. This condition generally develops in areas of low rainfall where, in the absence of leaching and dense vegetation, mineral compounds can gradually accumulate to high concentration in the soil.

Soil toxicity causes either the immediate death of plants or a gradual deterioration leading to their eventual death.

An example of a compound which occasionally reaches toxic concentrations in W.A. soils is Salt (sodium chloride). Few trees can survive in a "salty" soil. This is a problem in the wheat belt where there is insufficient rainfall to remove salt accumulations. Salt is not a problem in the forest areas. The only field of forestry practice where it is likely to become an important problem is in the nursery. Here, the use of saline irrigation water has led to problems in the past. Also the over application of fertilizers may sometimes result in the concentration of an element to toxic levels. Fertilizer dressings in the nursery must be carefully calculated if this development is to be avoided.

Soil toxicity can also result from the over-zealous application of various fungicides, herbicides and insecticides, or from the careless disposal of garbage, cinders or soapy water. Nurserymen must be alert to the dangers of such practices.

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CHAPTER 5 - SOIL ORGANISMS

The soil is the home for innumerable forms of plant and animal life, ranging in size from microscopically small organisms such as bacteria, to organisms large enough to be seen with the naked eye, such as worms and ants.

We have already seen how living organisms contribute to the processes of soil formation and development. They also contribute in many ways to the overall productivity of the soil.

In this chapter we will examine the following aspects of soil organisms:

1. The nature and activities of the soil population.
2. The influence of soil conditions on the soil population.

THE NATURE AND ACTIVITIES OF THE SOIL POPULATION.

The soil teems with a vast variety of different types and shapes of living organism. To simplify our study of them we will classify them into eight groups. These are: Plant Roots, Bacteria, Fungi, Actinomycetes, Algae, Worms, Insects and Small Animals.

1. Plant Roots. Plant roots are the most important of the living constituents of the forest soil; they represent the centre of soil microbiological activity. Three of the important influences exerted by tree roots on the soil are as follows:

(a) Growing roots play an important part in soil formation. They help in physical weathering by prising open small cracks in the parent rock and in chemical weathering by the release of certain organic acids.

(b) Upon decay, roots leave channels of humus in the soil which can serve as passages for water, air and young roots as well as adding to the soil organic matter.

(c) Well developed tree root systems help to bind the soil together, thus enabling it to resist erosion by wind and water.

2. Bacteria. In all soils, bacteria far out-number all other types of soil organisms. (They can amount to several million per gramm of soil.) Bacteria live on roots, on soil particles and in the soil water. Bacteria take part in two vital soil processes (i) the decomposition of soil organic matter and (ii) the "fixing" of atmospheric nitrogen into the soil.

Nitrogen "fixing" by bacteria is generally accomplished as follows: (i) the bacteria form nodules on the roots of certain leguminous plants (such as Subterranean clover, lucerne or lupins); (ii) they absorb air from the soil pores and extract the nitrogen from it; (iii) they supply this nitrogen to the plant, in return for simple carbohydrates manufactured in the plant leaves. When these plants decay, nitrogen is returned to the soil and becomes available for other plants.

THE NATURE AND ACTIVITIES OF THE SOIL POPULATION

3. Fungi. Fungi are chlorophyll-free plants which derive their food from the living parts or dead remains of other organisms. There are three types of soil fungi, saprophytic, parasitic and mycorrhizal fungi.

(a) Saprophytic fungi obtain their food requirements from dead organic matter. They are extremely important soil inhabitants, for they are the organisms mainly responsible for the breakdown of soil organic matter and the release of plant nutrients.

(b) Parasitic fungi obtain their food requirements from other living organisms. Most parasitic fungi are also known as pathogenic fungi because they are responsible for many plant diseases (for example the fungi Phythium and Phytophthora which cause Damping-off disease, are parasitic fungi).

(c) Mycorrhizal Fungi live "in partnership" with the roots of certain trees and higher plants. They live in close association with the living roots and a mutually beneficial exchange takes place: the fungi supply the tree with nitrogen, potassium and phosphorus (which they extract from raw organic material) and the trees supply the fungi with the carbohydrates manufactured in their leaves.

The fungi are vitally important soil organisms from the forester's point of view. Mycorrhizal fungi are very important. Their absence so severely inhibits the growth of the pine seedlings that all local pine nurseries must be innoculated with mycorrhizal fungi before satisfactory seedlings can be grown.

4. Actinomycetes. These are minute organisms which are classified as falling between the Bacteria and the Fungi. They are very numerous in some soils. Their function is to assist in the breakdown of soil organic matter to release nitrogen and other plant nutrients.

5. Algae. Algae are tiny, filamentous, chlorophyll-bearing plants. Within the soil their major function is to assist in the process of rock weathering : as lichens, they develop colonies on bare rock and in this way initiate the soil formation process.

6. Worms. Earthworms perform several important functions in the soil. Some of these are : (i) they assist in the breakdown of soil organic matter; (ii) they improve the structure of the soil by burrowing through it; and (iii) they improve the aeration and drainage of the soil.

7. Insects. These tiny animals abound in the litter and the "A" horizon of the forest soil. They help in the decomposition of organic matter, and in the redistribution of the litter layer.

8. Small animals. The small animals which inhabit the forest floor also influence the forest soil in numerous ways. The digging for food, burrowing for protection and the dropping of excreta all have their effect on the soil of the forest.

THE INFLUENCE OF SOIL CONDITIONS OF THE SOIL POPULATION

The microbial population of the soil is not constant, but fluctuates widely; both the numbers and the types of organisms in the soils varies greatly with any change in the soil environment.

The major factors which influence the soil population are :

1. Moisture. Soil organisms are extremely sensitive to changes in the moisture content of the soil. Soil populations develop to their maximum in numbers and variety in moist well drained soils, they are severely affected by waterlogging or prolonged drought.

2. Soil Reaction. The degree of acidity or alkalinity of the soil also influences the soil population. While most soil organisms exist only within a narrow range of pH there are organisms adapted to every level of soil pH found in nature.

3. Aeration. Well aerated soils, provided they are not devoid of moisture, favour the development of high soil organism populations.

4. Fertility. Microorganisms require roughly the same nutrients as higher plants and will develop the greatest populations in fertile soils.

5. Organic Matter. Organic matter is the source of food and energy for most soil organisms and those soils most abundantly supplied with organic matter develop the largest microorganism population.

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CHAPTER 6 - SOIL ORGANIC MATTER AND HUMUS

All soils which sustain plant life contain some organic matter. The amount of organic matter in the soil can vary from up to 100% in the case of peat-bog soils to practically nil on sandy coastal soils carrying sparse vegetation. Good P.radiata soils contain 10-15% in the A_1 horizon, while laterite Jarrah soils, only 2 to 7%.

Organic matter is one of the most vital constituents of forest soils, for it represents the pathway for the return of plant nutrients to the soil.

In this chapter we shall examine the following aspects of this subject:

1. The Decomposition of Organic Matter and the Formation of Humus.
2. The Influence of Soil Organic Matter on Soil Properties.

THE DECOMPOSITION OF ORGANIC MATTER AND THE FORMATION OF HUMUS.

If the plant and animal remains accumulating in soil did not decompose they would do little to improve the soil. Decomposition of organic matter is a vital step in the plant nutrient cycle.

The decomposition of organic matter is carried out by soil micro-organisms, as discussed in Chapter 5. Although all the soil microfauna play some part in this process, the most active workers are the bacteria and the fungi (microflora).

The decomposing action of the soil micro-organisms does not result in the direct release of individual nutrient elements to the soil; it results in the formation of a substance called Humus, or Soil Organic Matter.

Raw Organic Matter ⟶ Decomposition by microorganisms ⟶ Humus (Soil organic matter)

Humus. Humus is organic matter which has undergone complex processes of decomposition. It may be defined as dark coloured material in the soil consisting of plant and animal remains which have been broken down by soil fauna, bacteria and fungi together with the remains of these organisms, when the whole will rot no further, or only very slowly.

Plant nutrients are released as soluble by-products of decomposition. Large quantities of raw organic matter are required to produce small quantities of humus. Loss by fire and erosion plus slow decomposition of humus keep the proportion of it in the soil fairly constant, i.e. on a given site it will not fluctuate appreciably from year to year.

THE INFLUENCE OF SOIL ORGANIC MATTER ON SOIL PROPERTIES

Organic matter has an appreciable effect on the physical and chemical properties of both sandy and heavy soils. Most effects are beneficial.

Physical Effects of Organic Matter. Organic matter improves the physical properties of all soils, but particularly those of sandy soils which have a low silt and clay content. The main beneficial effects are:

1. The water-holding capacity of sandy soils is increased. Humus is very similar to silt and clay in its ability to retain water. It increases available moisture in heavy soils due to structure improvement.

2. Soil structure is improved, so that the aeration of heavy soils is increased, and the drainage improved.

3. Organic matter in the surface layers of the soil helps to protect the topsoil from erosion by wind and water, particularly heavy soils.

4. Organic matter darkens the colour of the soil, thus allowing the soil to absorb more heat energy from the sun. The temperature of the soil is therefore increased and this leads to better conditions for the germination of seeds in the winter months.

5. In sands nutrient storing "coffee rock" sometimes develops at depth from leached-out organic cementing agents. This can be detrimental if close to the surface.

The Chemical Effects of Soil Organic Matter. Organic matter has a very significant effect on the chemical properties of the soil. It serves as a storehouse and source of supply of the essential nutrients required by plants.

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CHAPTER 7 - FOREST SOILS OF W.A.

INTRODUCTION

In many respects, West Australian forest soils are unique. Mostly, they are poor which is the main reason why the jarrah forest did not go under the plough in the early days of settlement.

Failure of a number of P.radiata plantings in the early years of this century, lead to more critical examination of our forest soils. In the 1930's all existing plantations and plantation proposals were subjected to detailed soil surveys, from which our present technique for P.radiata plantations has evolved.

Pinus pinaster is tolerant of poorer soils, but a broader type of survey is carried out to define its plantation limits, which depend mainly upon depth to an impervious layer.

The aim of this chapter is to describe the important characteristics of W.A. forest soils.

Jarrah forest soils
Karri forest soils
Suitable soils for P.radiata
Suitable soils for P.pinaster.

To understand the pattern of soils in the forest area, something must be known of the parent materials, past geological history and the soil forming processes of the past and present.

The four forest soils listed above have developed on various parent materials under present climatic conditions.

The source of all the soil parent materials is the igneous and metamorphic rocks of the Darling Ranges which extend almost to the south coast, and an area of similar rocks between the Capes Naturaliste and Leeuwin.

Ancient climatic regimes resulted in weathering of these rocks and the formation of Laterite (to be described shortly). A change in climate stopped this process, destroyed vegetation, and blew topsoil (mostly sand) off the ironstone, westward into the sea forming the coastal plain (where the bulk of P.pinaster is now grown).

Improvement in the climate saw the development of gravelling soils on the laterite and the evolution of the Jarrah forest.

At the same time, the western edge of the continent was uplifted, forming an escarpment. This encouraged downcutting by streams and led to the exposure once more, of the underlying country rock and to further soil forming processes.

In sheltered situations, these processes, working on the more mineral-rich rocks produced fertile, heavy-textured soils suitable for growing Pinus radiata - such as are found in pockets from Mundaring to Barlee Brook (south of Nannup). These patches were occupied by Jarrah, Marri and Blackbutt in the north, and pure Karri in the south.

The higher rainfall in the south caused deeper downcutting and earlier removal of ancient ironstone. Deeper soils also developed through active leaching and illuviation, which favoured the development of big trees.

INTRODUCTION (continued)

The low-lying area between Margaret River town and Nannup is known as the Donnybrook Sunkland and is very old. Little is known of it except that it is based on old sediments and has a laterite surface roughly the same age as the laterites of the Darling Ranges. This area is part of the Jarrah forest.

These areas are shown on a map in Appendix V.

JARRAH FOREST SOILS

Let us consider the Jarrah forest soils in more detail. While Jarrah grows on a range of soils, its main occurrence is on "Laterite". That is, the gravelly ironstone soils of the country east of the Darling Scarp. How did the old laterite form?

It appears that a warm, moist climate, combined with fairly stable surface conditions are essential. Thus the land was a gently undulating peneplain with a gradual fall toward the sea - no mountain ranges, no deep river valleys. Erosion was very slight and the underlying rock weathered to great depths.

The warm, moist climate led to illuviation of clays, and their breakdown into iron and aluminium oxides, leaving colloidal silica in solution - this was lost to drainage and all the mineral that remains at the surface is the hard skeleton of sand (insoluble silica (SiO_2)). The profile which results is shown in Fig. (3).

This process, which requires stable slopes of less than 8^o is continuing in modified form under the present climate and is producing gravelly soils as sites often not even influenced by ancient laterite residues.

KARRI FOREST SOILS

In the case of Karri forest soils, we have already seen that large trees require deep soil and abundant moisture. Soils supplying this need are found in the Karri forest belt. Karri forest soils range from red clay loams forming on basic schists to sandy, gravelly, brown loamy sands over clay. The latter are podsolised, partly lateritised soils derived from acid gneiss, which is common east of Pemberton. It appears that the moist climate while hastening erosion, hastens the soil forming processes also, so that a deep mantle of A horizon materials are found in practically all Karri soils. (Fig.4.) They have a deep structured subsoil which serves as an important moisture reservoir.

In the heavier textured soils, weak crumb structure is a common feature. Although having the appearance of fertility they are often poor - as evidenced by slow progress of the Group Settlement Schemes of the 1920's and '30's.

For agriculture, phosphorus, zinc, potassium and molybendum are the main elements which are deficient.

For P.radiata, the needs vary but are mainly phosphorus and zinc. Spectacular results have been achieved with zinc on ailing P.radiata at Pimelea plantation.

FIG. 3. - LATERITE

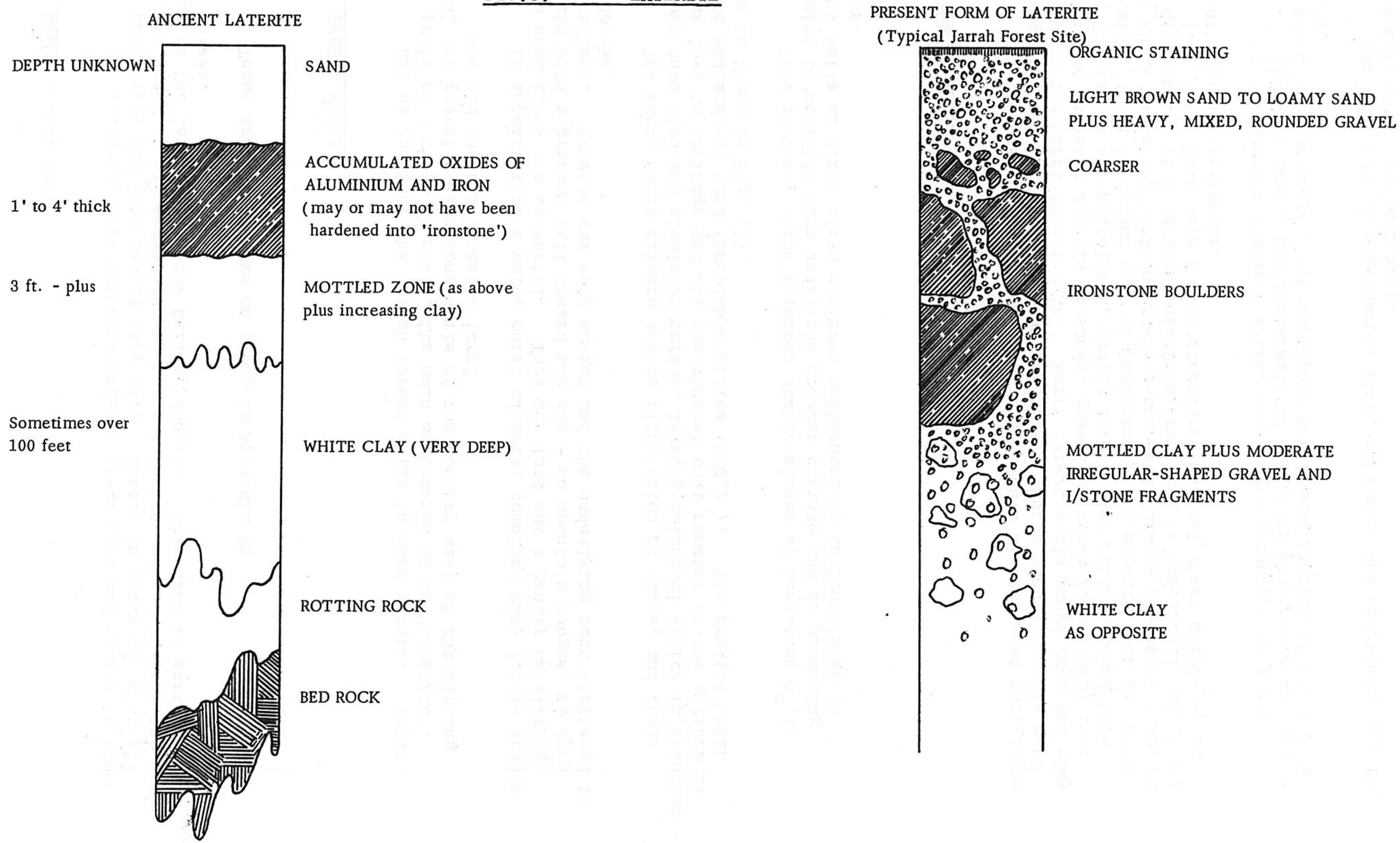
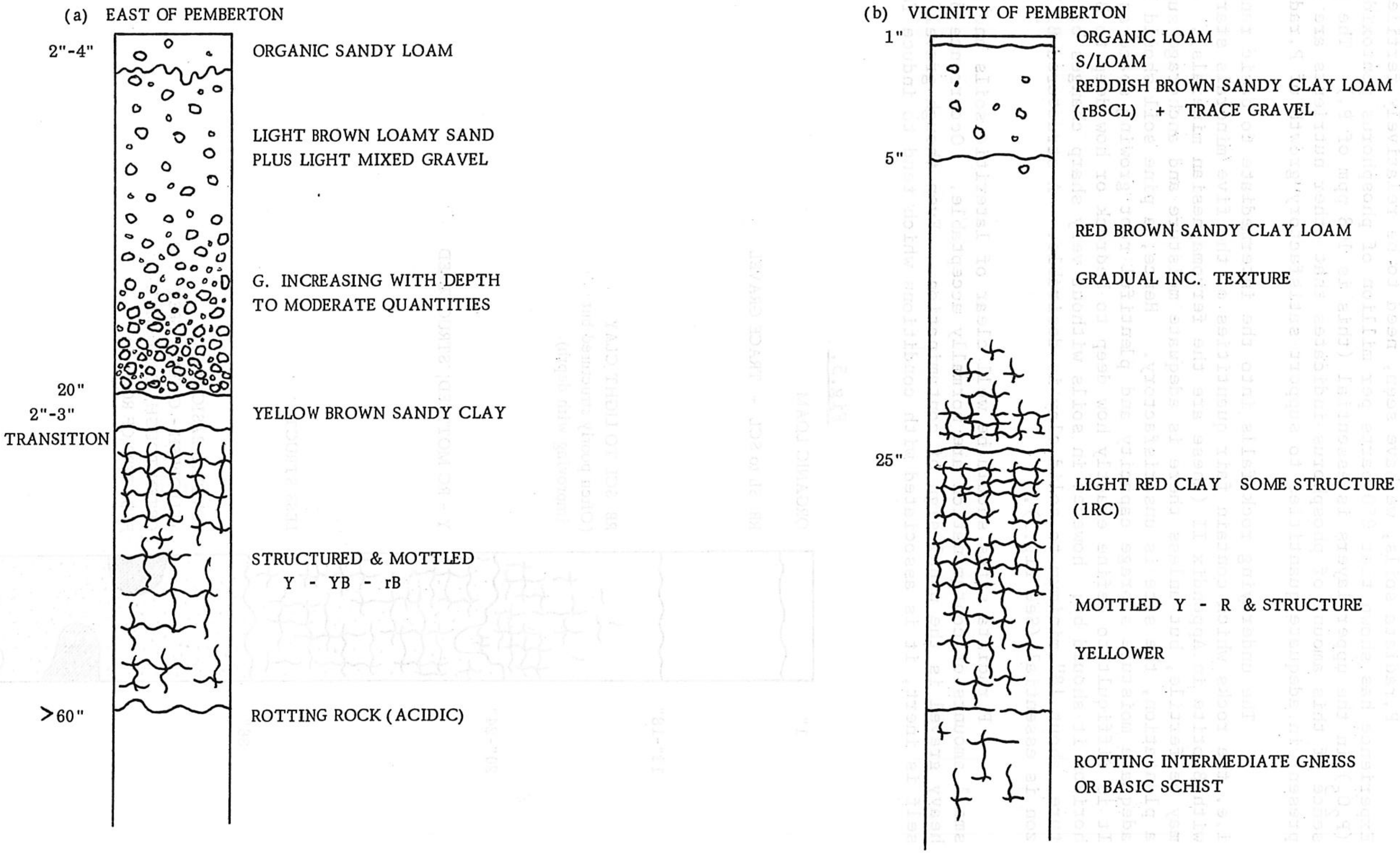


FIG.4. - TYPICAL KARRI SOILS



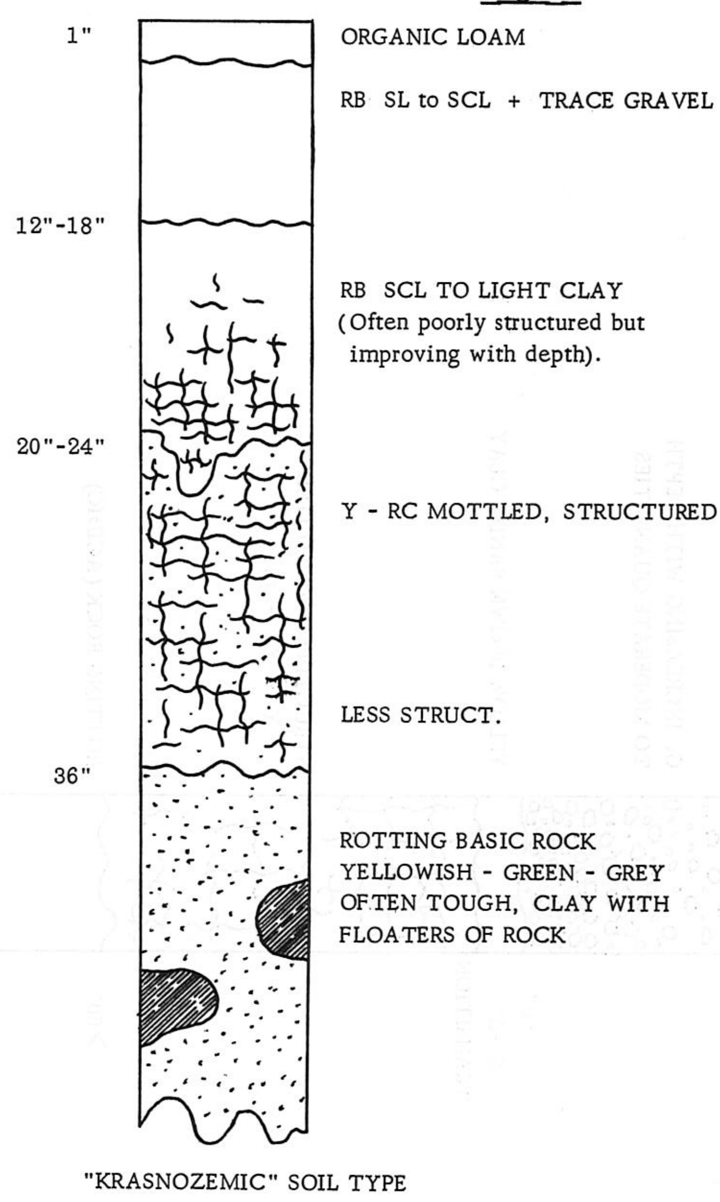
PINUS RADIATA SOILS

P.radiata soils, we have seen, need to be relatively fertile. Experience has shown that 250 parts per million of phosphorus pentoxide (P_2O_5) in the upper layers is essential (this is 108 ppm of P.) The presence of this amount of phosphorus indicates that other nutrients are also present in adequate quantities to support satisfactory growth of P.radiata.

The underlying rock falls into the intermediate to basic range. i.e. the rocks which contain fair quantities of the five minerals starting with Biotite in Appendix II (these are the ferromagnesian minerals). Soils may be fertile, but unless there is adequate moisture and anchorage support for a plantation, the site is unsatisfactory. Hence, a pine soil should have adequate moisture storage capacity and plentiful root growing space as well. It is difficult to define exactly how deep to bedrock or how deep to B horizon it should be; however in soils without very sharp changes of texture, about 18" minimum to solid clay is desirable. A structured B_2 horizon is essential (See Fig.5).

P.radiata sites should be well clear of lateritic soils and only small amounts of contamination are normally acceptable. Occurrence of heavy gravel is the usual sign of contamination. Even though gravel itself is inert, it is associated with conditions which tend to induce fertility.

Fig.5.



"KRASNOZEMIC" SOIL TYPE

PINUS RADIATA SOILS (continued)

Vegetation of the native forest responds to these good conditions. For instance the crowns grow densely and crowd one another. Dead wood and malformation is not common (except from fire damage). The undergrowth becomes dominated by soft-leaved plants of a healthy green colour (mesophytic types) e.g. netic or waterbush, soft-leaved "buttercups", hazel, tall bracken, Acacia urophylla often indicates good pine soils in the northern regions.

In the south netic occurs on marginal sites, while the better sites are dominated by hazel thickets or Acacia urophylla, and a few other mesophytic plants.

"Negative indicators" from the undergrowth and understorey are useful too e.g. Banksia grandis indicates gravel deposits, xerophytic vegetation generally indicates poor moisture relations, while swamp plants indicate an excess of moisture. There are other indicators and the bush tells a story which can be read, but it requires experience and skill in observation to be able to draw reliable conclusions.

More details are available in ref.No. 14.

Most Pinus pinaster planting is on the Coastal Plain. Here two main soil systems are involved.

The sands closest to the sea are yellowish to brownish in colour and overlie limestone. See Figure 6(a). These sands form the Spearwood Dunes System and have been subjected to less leaching than the older, deep grey sands of the Bassendean Dunes Systems which range between the limestone sands and the Darling Scarp.

The younger, yellow sands have the highest fertility. Naturally they carry Tuart and often can be established satisfactorily with Pinus pinaster without the addition of superphosphate. Zinc deficiencies may be common on these sands.

Successful pine growth on Tuart sands is dependent on the depth to limestone. Only the deepest soils can support satisfactory pine growth.

The grey sands of the Bassendean Dunes System have a very low nutrient content. In general the System consists of rolling dunes with interspersed flats. Water table depth is shallowest on the flats where it may occur at depths of 0 (swamps) to 10 feet. Depth to water table increases progressively up the dune slopes. The heaviest development of natural vegetation occurs on the flats. Here Jarrah, Marri and the Banksias are found and their presence is accompanied by the formation of a deposition, or B horizon, of yellow to brownish sand or coffee rock. See Figures 6 (b) and 6 (c). These are the best sites for pine planting. Soil water is adequate and the deposition horizon concentrates nutrients to support tree growth.

Proceeding up the dune slopes the depths to the deposition horizon increases and the extent of development of the horizon decreases. Natural vegetation changes from Jarrah and Marri to smaller Coastal Blackbutt trees. Near the dune tops no eucalypts, only small Banksias are found. Pine quality also falls off as the extent of natural tree development declines up the dune slopes.

It is hence the deepest of the limestone sands and the soils of the flats in the grey sands which are suitable for pine growth.

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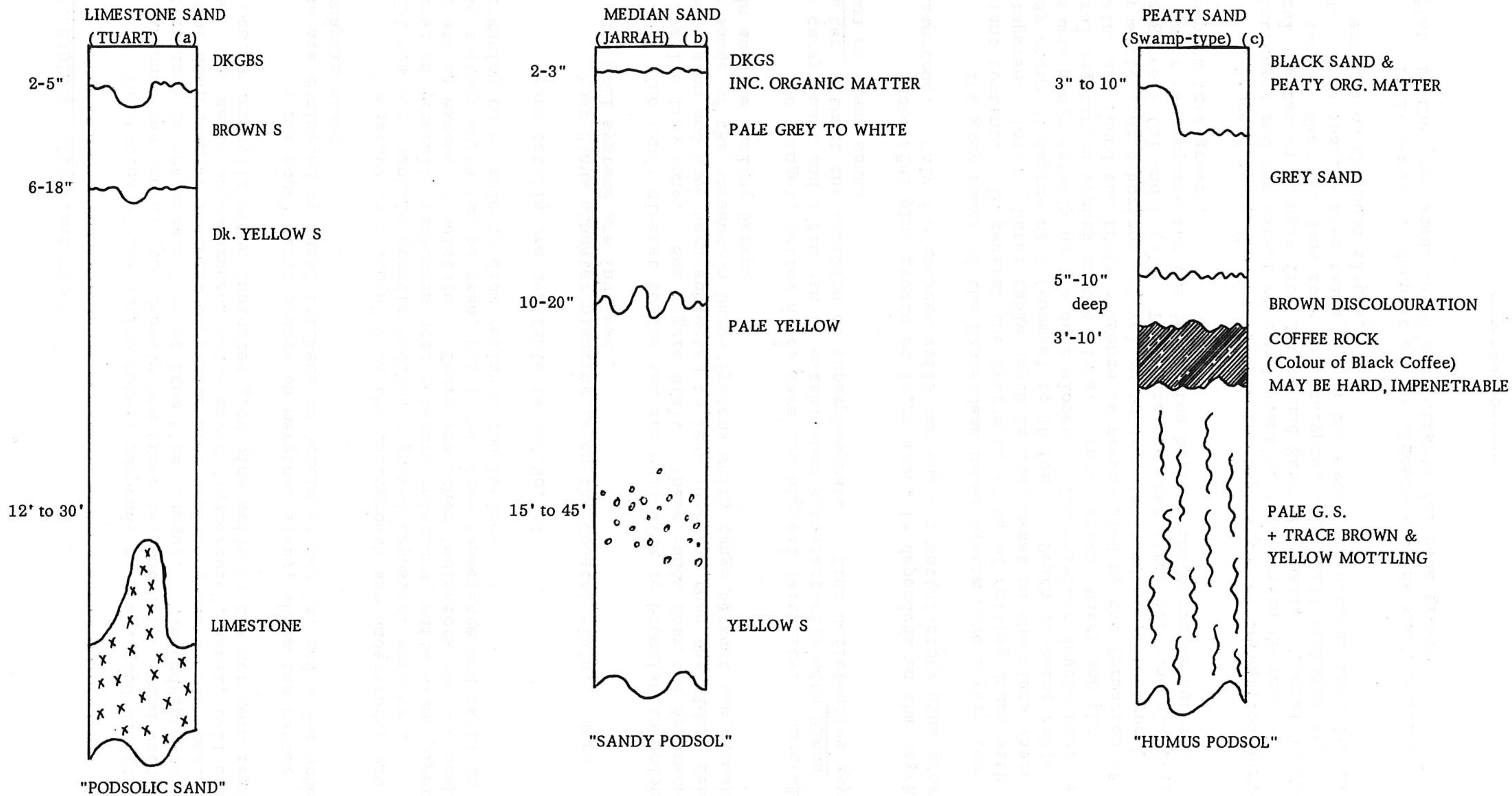
FIG.6. - PINUS PINASTER SOILS



APPENDIX I - SUGGESTED FURTHER READING

The student is recommended to the following publications for further reading on the subjects of Soil Science and Forest Soils.

1. "Forest Soils" by S.A.Wilde (1958).
2. "The Scientific Study of the Soil" by N.M.Comber, (1927) - (a very good introductory text).
3. "The Fundamentals of Soil Science" by Millar, Turk and Foth (1958) - (See particularly the section on ploughs and ploughing).
4. "Soil" by G.V.Jacks (1954)-(an English text, but Chapter IX deals with forest soils and would be useful general reading).
5. "Fertilizers for the Farm & Garden" by Teakle & Boyle (1958)- (should be read by every soils student).
6. "Introduction to Soil Science" by G.W.Leeper (1957) - (deals with Australian soils).
7. "Soil Conditions and Plant Growth" by E.J.Russell (1952) - (a more advanced coverage).
8. "Laterite and Lateritic Soils" by Prescott and Pendleton (1952).
9. "Micro-organisms in the Soil" by A.Burges (1958) - (see particularly Chapters I and II).
10. "Ash Bed Effects in West Australian Forest Soils" by A.B.Hatch. F.D.Bull. 64 (1960).
11. "The Fertilizer Factor in <u>Pinus Pinaster</u> Ait. Plantations on the sandy soils of the Swan Coastal Plain, W.A." by E.R.Hopkins. F.D.Bull. 68 (1960).
12. "Nursery Soil Fertility Studies with Pinus Radiata - D.Don, Hamel Nursery, W.A." by A.B.Hatch. F.D.Bull 70 (1961).
13. "Ashbeds and Nutrients in the Growth of Seedlings of Karri (E.diversicolor)" by J.Loneragan and O.Loneragan Jour.Roy.Soc.W.A. 47(3) 1964.
14. "Soil Surveying for Pinus Radiata in Western Australia: A brief outline of the occurence of P.radiata soils and the procedure used for surveying them by the Forests Dept. of W.A." by A.L.Clifton (1964).
15. "Soil Survey Method" N.Z.D.S.I.R. Soil Bureau 1962.
16. "Soil Survey Manual" U.S.D.A.

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APPENDIX II - THE IMPORTANT SOIL-FORMING MINERALS

The following are the minerals commonly found in the parent rocks under forest soils.

	Name of Mineral		Nutrient Elements Contained
Found in igneous rocks	1.	Orthoclase	K, Cu
	2.	Plagioclase	Ca
	3.	Muscovite	K
	4.	Biotite	K, Mg, Fe, Cu, Zn
	5.	Amphibole (hornblende)	Mg, Ca, Fe, K
	6.	Augite	Mg, Ca, Fe, Mn, Cu, Zn
	7.	Olivine	Mg, Fe, Zn, Cu, Mo
	8.	Garnet	Ca, Mg, Fe
	9.	Apatite	P, Ca
	10.	Magnetite	Fe, Zn, Co
	11.	Limonite	Fe
	12.	Hematite	Fe
	13.	Siderite	Fe
Frequently associated with coastal sands	14.	Quartz	None
	15.	Ilmenite	Fe, Co
	16.	Calcite	Ca
	17.	Dolomite	Ca, Mg
	18.	Gypsum	Ca, S

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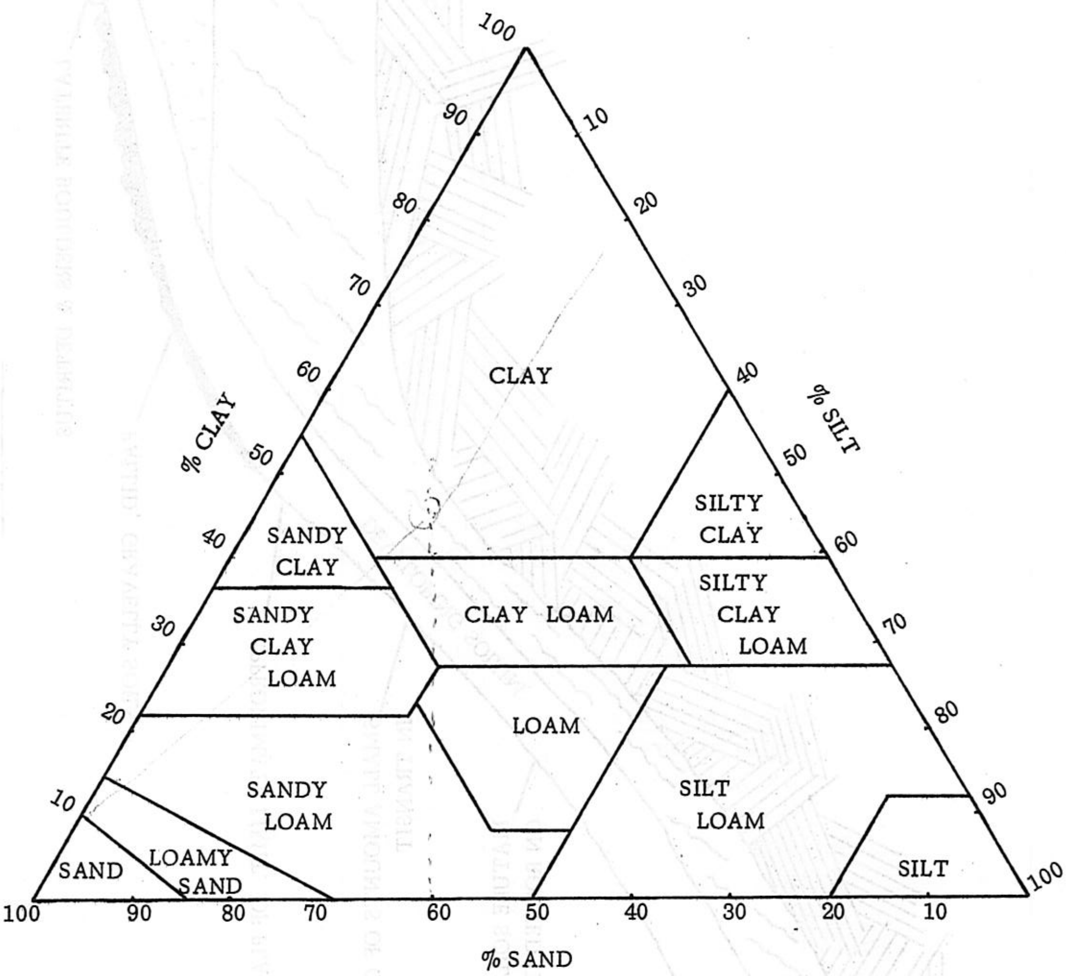
APPENDIX III - THE SOIL TEXTURE "TRIANGLE"

SHOWS THE PERCENTAGES OF SAND, SILT AND CLAY IN THE BASIC SOIL TEXTURAL CLASSES



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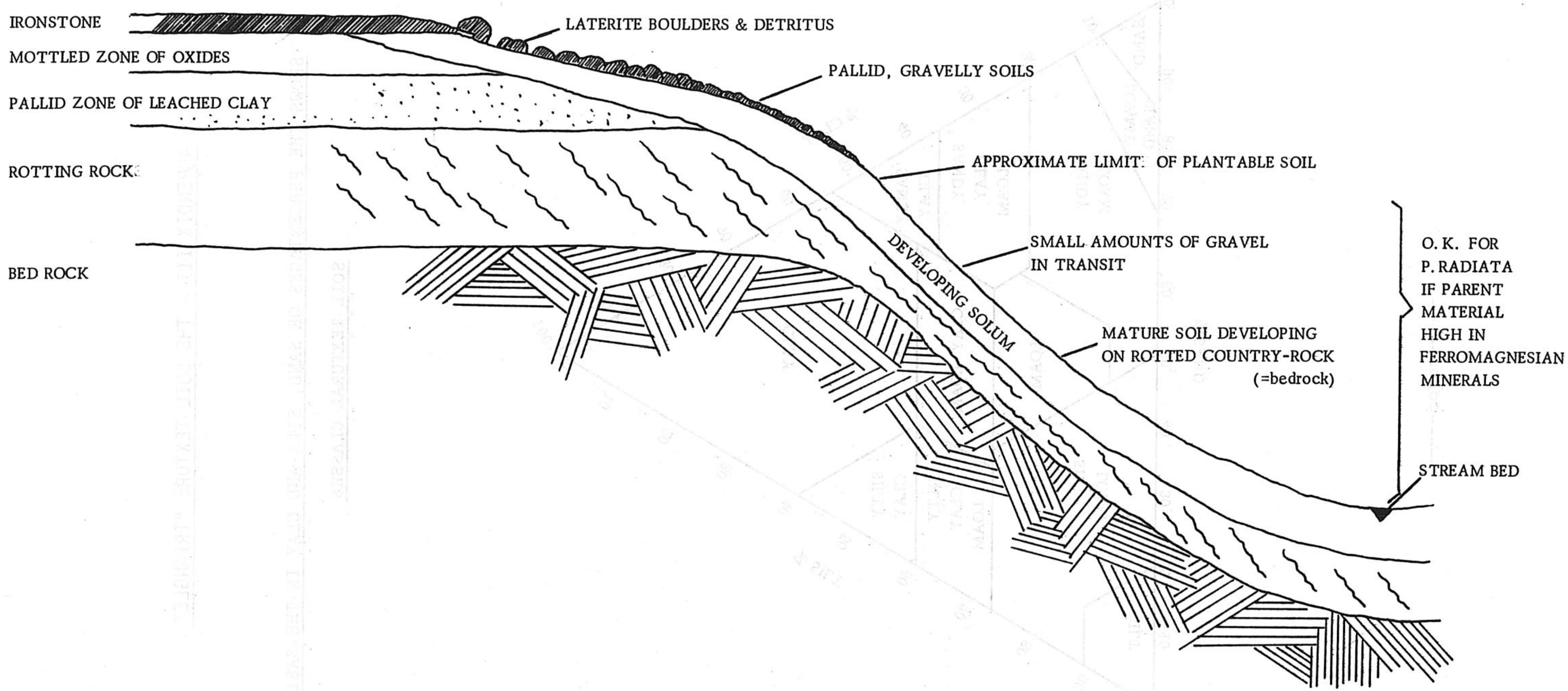
APPENDIX IV



Section showing effect of downcutting by watercourses through Laterite crust into underlying rocks. Definite pattern of soils is produced. P.radiata sites created.

APPENDIX V

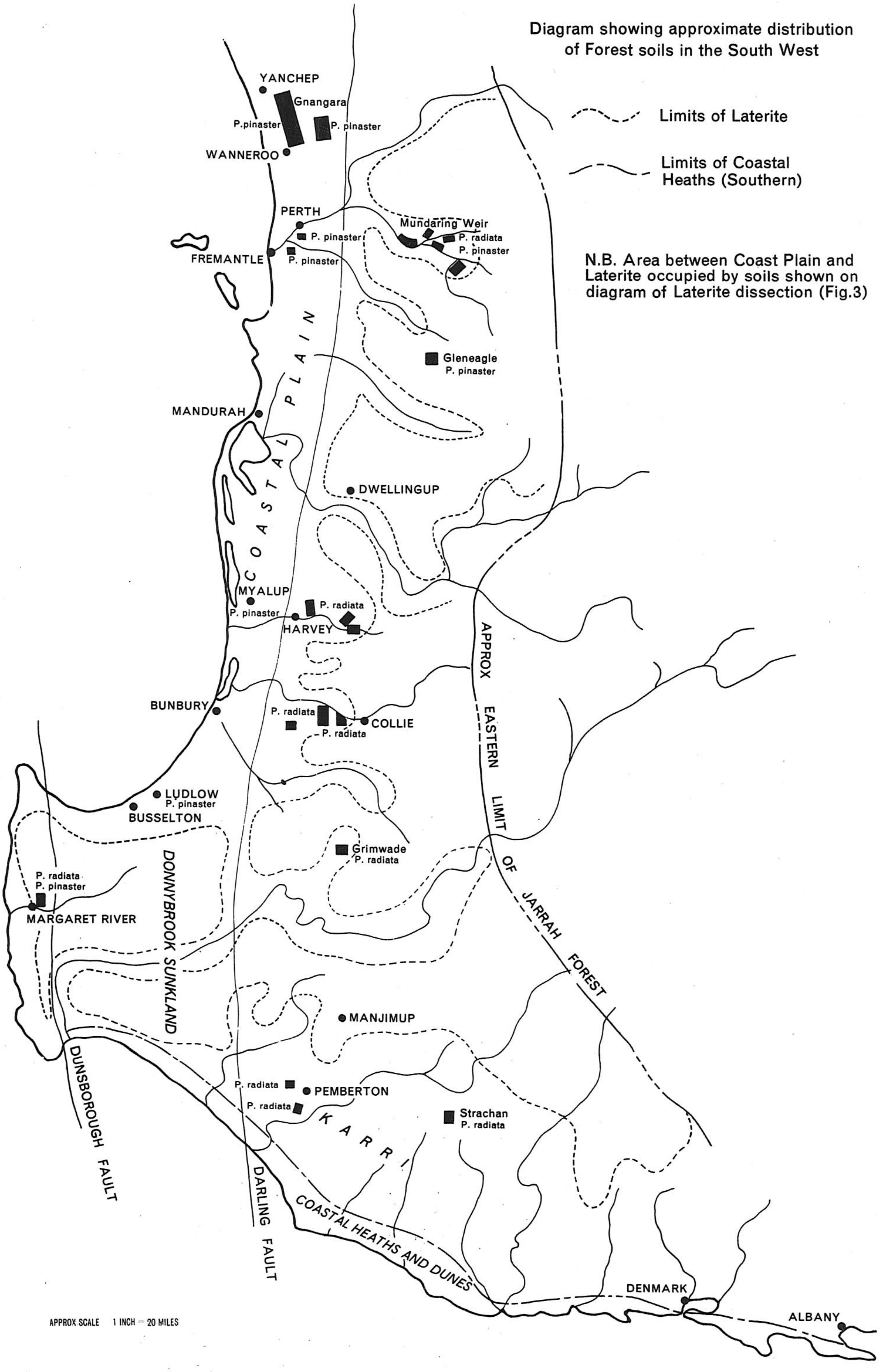


Diagram showing approximate distribution
of Forest soils in the South West
Limits of Laterite
Limits of Coastal
Heaths (Southern)
N.B. Area between Coast Plain and
Laterite occupied by soils shown on
diagram of Laterite dissection (Fig.3)
YANCHEP
Gnangara
P.pinaster
P. pinaster
WANNEROO
PERTH
P. pinaster
FREMANTLE
P. pinaster
Mundaring Weir
P. radiata
P. pinaster
Gleneagle
P. pinaster
COASTAL PLAIN
MANDURAH
DWELLINGUP
MYALUP
P. pinaster
P. radiata
HARVEY
APPROX EASTERN LIMIT OF JARRAH FOREST
BUNBURY
P. radiata
COLLIE
P. radiata
LUDLOW
P. pinaster
BUSSELTON
DONNYBROOK SUNKLAND
Grimwade
P. radiata
P. radiata
P. pinaster
MARGARET RIVER
MANJIMUP
P. radiata
PEMBERTON
P. radiata
KARRI
Strachan
P. radiata
DUNSBOROUGH FAULT
DARLING FAULT
COASTAL HEATHS AND DUNES
DENMARK
ALBANY
APPROX SCALE 1 INCH = 20 MILES

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FOREST SOILS BOOKLET.

Errata Slip.

Please amend your copy of the "Forest Soils" booklet as follows :-

Page 4.	Under "Metamorphic Rocks." 6th line "sedimentary" should read "metamorphic."
Page 13.	Last line "bark landing" should read "bush landing."
Page 14.	Heading "Blocky Structure". After the word "angled" insert word "and"; also hyphenate "B-horizon" in next sentence.
Page 19.	"Adjustment of Nursery Soil Reaction," sub-para. 1, delete "ammonium" and insert "aluminium."
Page 20.	No. 3 under "Factors Determining Soil Fertility." "microfara" and "microfama" should read "microflora" and "microfauna." Also, "mircroorganisms" should read "micro-organisms." Second No. 1 "strangely acid" should read "strongly acid."
Page 28.	9th paragraph delete "gravelling" and insert "gravelly"
Page 29.	Last sentence under "JARRAH FOREST SOILS" delete "as" and insert "on".
Page 32.	Last word in text should be "infertility." Fig. 5 - Add: "or 'BASIC' SOIL TYPE" at foot of diagram.
Page 33.	Insert the heading "PINUS PINASTER SOILS" before "Most Pinus pinaster..."