

A STUDY OF THE LAND IN THE CATCHMENTS OF THE OTWAY RANGE AND ADJACENT PLAINS

TC – 14

By A J Pitt

Victoria, Australia, 1981

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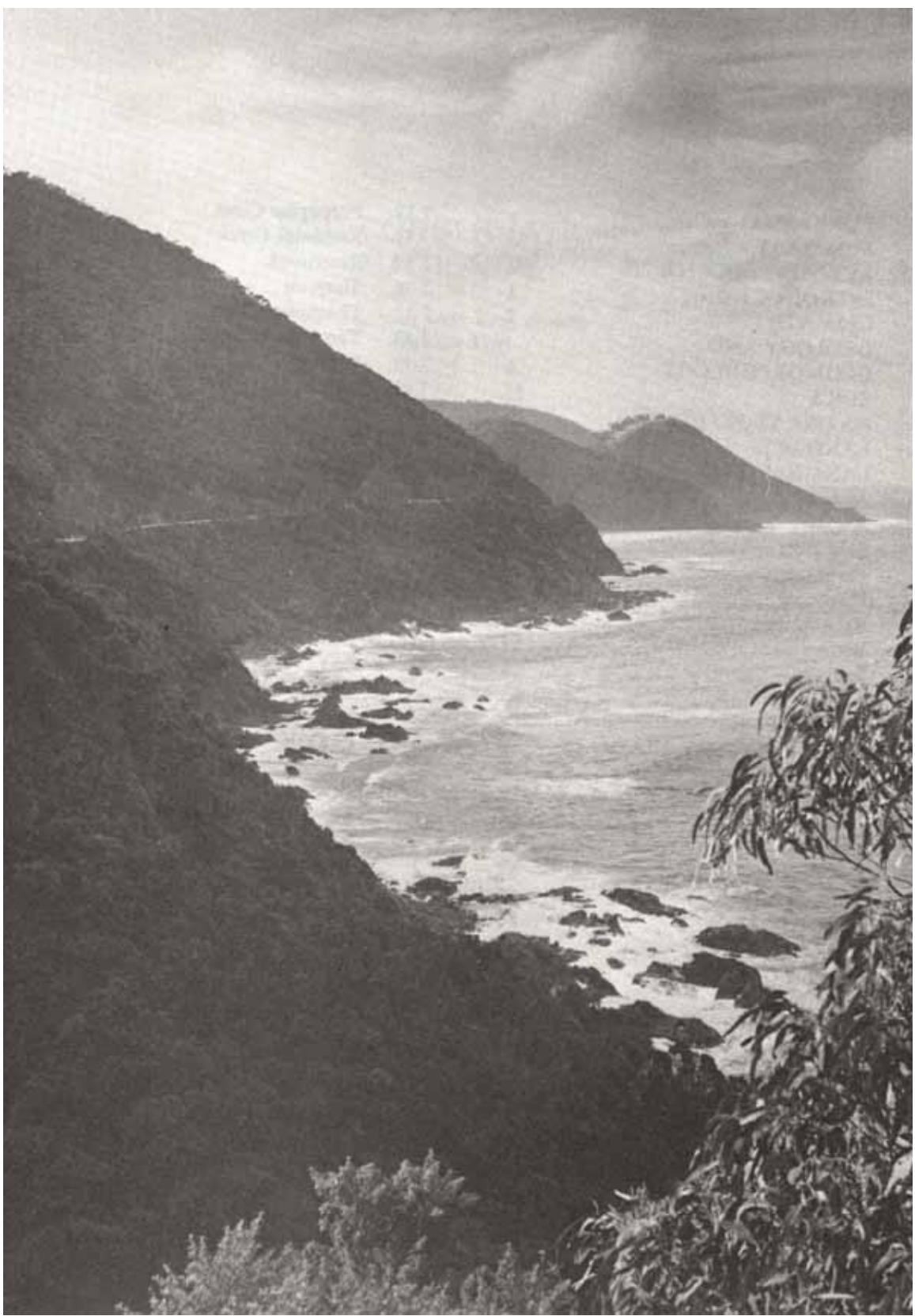
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FOREWORD

The stability of land, and hence its sustained productivity depends on its nature as well as its use and management. Some kinds of land withstand drastic modification by Man, while others degenerate under slight pressure.

Inherent feature – the climate, geology, topography, vegetation and soils – largely determine the forms of soil deterioration occurring in an area; for example, erosion by water, wind and gravity, salting, waterlogging, nutrient decline and structure decline. Such deterioration will, in turn, affect the quality and regulation of surface and underground waters.

In order to develop a systematic approach to soil conservation, we need information on the inherent features of the land, their interrelations and their interactions.

These interactions affect the nature of the land, the processes of land deterioration and the responses to land management.

Integrated surveys of land to provide such information have been carried out by the Soil Conservation Authority since 1952. They have evolved from ecological principles put forward by Downes (1949), Christian and Stewart (1953), Costin (1954), Gibbons and Downes (1964) and others. Techniques of survey have been developed over the years. A recent account of the principles and techniques is given by Gibbons and Haans (1976).

SUMMARY

This study examine the nature and interactions of the features of the natural environment. It covers the land both in and surrounding the Otway Range, a total area of 3,685 km².

The climate is generally cool and wet. Annual rainfall ranges between 500 and 2,000 mm, with a strong seasonal peak in winter. Coastal areas reflect a maritime influence – they have fewer frosts and less variation between winter and summer temperatures.

The Otway Range is a prominent feature of the landscape, rising some 500 – 700 m above sea level. It comprises Lower Cretaceous sandstones and mudstones and, except for some of the higher parts, has been deeply dissected into a rugged series of valleys and ridges. Surrounding foothills and plains to the east, west and north have been formed largely from tertiary sands and clays, with smaller areas of marl, limestone and siltstone. Flows of Quaternary basalt have formed plains in the extreme north and east.

Soils vary widely, but show certain broad trends. Deep friable profiles are found in the higher parts of the Otway Range on the relatively nutrient-rich Cretaceous sandstones. In contrast, fertile sands are common on the Tertiary sediments. Sodic duplex soils predominate in the drier areas, and most profiles on the basaltic plains have heavy-textured subsoils.

Tall open forests of *Eucalyptus regnans* and other species cover much of the Range. The surrounding foothills carry low open forests of *E. baxteri* and *E. nitida*. A great diversity of vegetation structural formations and species colonize the exposed coastal localities.

Agriculture is the predominant land use on the northern plains and in the more fertile foothills, while forestry dominates in the Range. Large parts of the Range serve as domestic water supply catchments. Coastal areas are used principally for recreation and holiday developments.

The hazard of soil deterioration is severe in certain landscapes, but the resultant damage that has occurred varies. The form and intensity of land use, together with management methods, are important in determining the damage to sensitive areas. Landslips and sheep erosion are widespread on cleared land. Gullying and soil salting are common on the drier plains to the north and east. Wind erosion occurs on coastal dunes.

ACKNOWLEDGEMENTS

Grateful acknowledgment is made of the support of the Soil Conservation authority and of the keen interest expressed by the Chairman, Mr A. Mitchell.

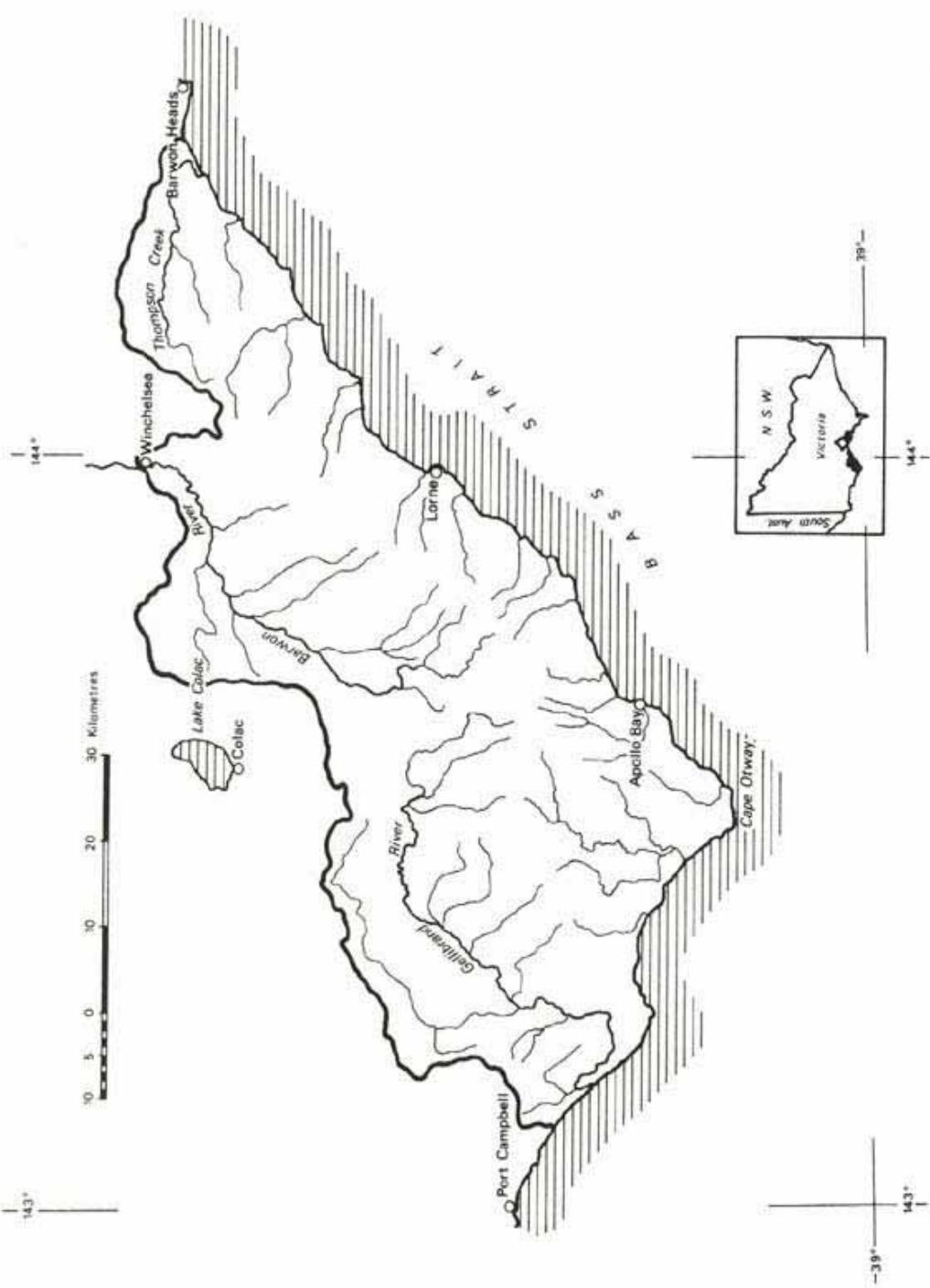
The compilation and production of this report would not have been possible without the enthusiastic assistance of many people. Within the staff of the Authority, Mr. F. R. Gibbons and Mr A. A. Thornley (now with Town & Country Planning Board) did much of the initial field work and collected many soil samples for laboratory analysis. They have both provided valuable comments for the preparation of this report. Mr J. N. Rowan has examined the technical material and provided many constructive comments. Mr T. I. Leslie directed the laboratory analyses and prepared Appendix II.

Field assistance was provided by Messrs P. Jeffrey, B. Evans, A. Jakimoff and P. Klutke. Miss L. Caruana re-drew the block diagrams for publication. Mr B. A. Young prepared the bibliography and the land system legend and co-ordinated the production of successive drafts. Mr A. R. Beasley co-ordinated the printing and publishing details. Mr R. Noonan prepared the photographs for publication.

Mrs Y. Roberts acted as technical editor. Mr J. LasGourges of the Ministry for Conservation prepared map and diagrams for publication. Mr A. Conley, Department of Agriculture, provided pasture species recommendations and Mr D. Linforth, Bureau of Meteorology, provided the average annual isohyets. Many other people, too numerous to mention, have helped in both the collection and compilation of the data presented in the report.

The assistance and encouragement of all these people is gratefully acknowledged.

Figure 1 – Study area



1.

INTRODUCTION

The Otway Range is a major feature of the landscape in south-western Victoria. Bass Strait forms its southern boundary, and inland a series of hills, dissected plateaux and alluvial plains separates it from the basaltic landscapes further north. The inland limits of the study area have been defined as the catchment boundaries of the Gellibrand River, the Barwon River upstream from Winchelsea and Thompson Creek (see Figure 1).

Methods of Study

The information presented in the following chapters has been derived from several sources. Land systems have been delineated (as shown on the map), and described according to the methods outlined in the land system chapter. Information on the native vegetation and soils, including detailed profile descriptions, has been collected in the area. Much of the geological information has been collated from a review of the literature and published maps, with some minor alterations to that of the more remote areas after field examination. Descriptions of the climatic characteristics of the area are based on records from the Bureau of Meteorology. Land use and soil conservation chapters are partly derived from field observations and partly from discussions with officers of the Soil Conservation Authority and the Department of Agriculture in Victoria.

In the following pages the environmental features are described both separately in separate chapters and together in the land system, further details of each characteristic may be obtained by referring to the relevant chapter. Conversely, the tabular descriptions outline the interactions between the characteristics.

2. CLIMATE

Rising some 500–700 m above sea level directly inland from the coast, the Otway Range exerts a major influence on this part of Victoria. Wide variations in climate are associated with the changes in topography – from the coast to the highest parts of the Range and to the flat extensive plains further inland. Accompanying changes in the dependent variables of soil and vegetation can be observed.

Rainfall

Average Annual Rainfall

The study area is well serviced by rainfall stations, and the records illustrate the marked variation in annual rainfall, as shown in Figure 2. The main ridge receives an annual average in excess of 1,800 mm, with some areas receiving close to 2,000 mm. Off the main ridge the amount drops rapidly, and in some areas the average halves within a distance of only 10 km. To the north-east lies a marked rainshadow (Linforth 1977), with Winchelsea receiving less than 600 mm. A further rainshadow is formed by the smaller ridge extending north through Barongarook to Colac. This ridge shelters Barwon Downs and Gerangamete Flats from moisture-bearing southerly and westerly air streams.

Seasonal Distribution

Rainfall varies according to the season at most stations, with the wettest month being August (sometimes July in coastal localities) and the driest being January (see Figure 3). The strongest trends occur in the wetter localities such as Weeaproinah, Forrest, Cape Otway and Simpson. The depression of seasonal trends in June at some stations is commonly found in coastal areas in Victoria.

Intensity

Although summer rainfall is relatively low, heavy rain can fall during this part of the year. The warmer atmosphere in summer can hold more moisture, and heavy rain results when a rain-producing mechanism does occur (Linforth 1977). The heaviest rainfalls in any 24-hour period occur during the summer months at most recording stations, as shown in Table 1. Coastal areas appear to be particularly susceptible to these summer storms.

Table 1 – Maximum rainfall (mm) in 24 hours at selected stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Aireys Inlet	69	170	80	52	80	74	36	85	50	80	101	44
Barwon Heads	55	61	65	56	62	38	66	51	63	54	51	69
Beech Forest	102	108	117	98	152	99	82	101	80	87	72	75
Birregurra	47	70	52	36	43	32	36	56	50	58	59	59
Camperdown	88	51	57	50	41	47	34	49	51	39	30	38
Cape Otway	92	55	93	61	43	61	42	36	48	68	90	44
Colac	69	81	48	50	55	34	35	51	40	34	61	56
Forrest	51	118	72	81	93	68	51	54	52	54	95	94
Geelong	73	89	67	48	114	68	63	61	66	33	52	74
Irrewillipe East	127	46	44	43	41	82	47	52	41	81	40	40
Lorne	71	180	73	93	124	61	86	61	71	152	115	116
Pennyroyal	63	118	56	89	111	123	55	122	53	51	69	72
Port Campbell	114	50	79	74	46	47	38	51	55	46	41	70
Princetown	102	65	78	57	41	65	36	47	51	51	39	41
Winchelsea	51	76	71	29	60	44	47	74	59	43	69	70

Italicized figures are the highest values for each station.

Source: Central Planning Authority 1957, 1971.

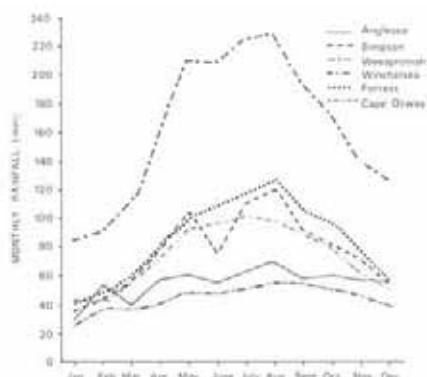
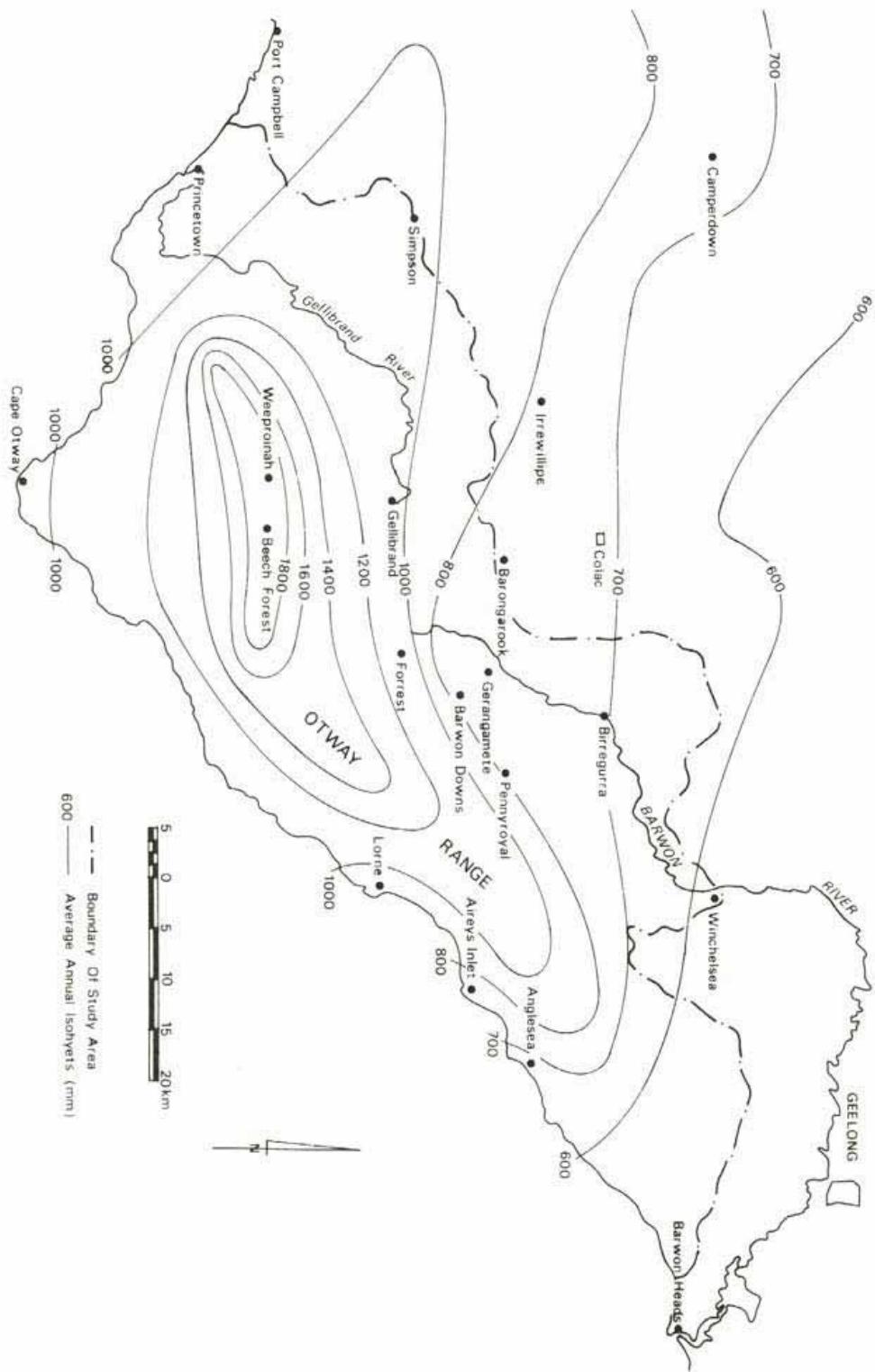


Figure 3 – Seasonal distribution of rainfall at selected sites

Figure 2 – Average Annual Rainfalls



Temperature

Climatic stations that record temperatures are to be found at Forrest, Gellibrand, Cape Otway and Lorne (Pier Head). Table 2 lists the averages from these, from several stations outside the study area and from three discontinued stations.

In summer, inland areas experience higher temperatures than coastal areas. During winter the converse applies, with inland areas being generally 2° C cooler.

Extreme maxima in excess of 40° C do occur on rare occasions in summer, when warm air spreads over the entire area and sea breezes have no effect (Linforth 1977). All stations have recorded such maxima, with the exception of Beech Forest. This station is the only site from which temperature data for the higher parts of the Otway Range have been recorded. The records show a marked lowering of the temperature with the increased elevation.

Effects on Plant Growth

Each species has its own minimum, maximum and optimum temperature requirements, and thus it is difficult to specify generalized values for these. Some temperate grass species show signs of growth when the temperature is below 0° C, while some tropical plants practically cease growth at temperatures below 16° C. However, a generally accepted value below which active growth of cool temperate pasture and crop species ceases is 6° C (Martin and Leonard 1967). The value of 10° C has been accepted in southern Australia as the borderline between moderate and slow growth (Trumble 1939).

Most of the survey area experiences slow growth in the three winter months, as sown on the land system tables in Chapter 7. At coastal localities the period below 10° C is restricted to July. Only the most elevated parts of the Otway Range have average monthly temperatures below 6° C.

Frost

Frost is likely to have little effect on the native vegetation, which is usually well adapted to it (Foley 1945). However it may result in death or severe damage to the introduced pastures and crops.

Estimating the occurrence of frost from measured screen temperatures is not simple. The relation between ground temperatures and screen temperatures varies widely between different climatic stations. Caution is required in interpreting regional temperatures figures for predicting local frost damage. Other factors, such as the drainage of cold air to local depressions and the placement of windbreaks that may disrupt and 'pond' the movement of cold air, have a major influence. Aspect is also important, as fast thawing on north- and east-facing slopes is more dangerous to the plant tissues than slow thawing.

Despite these variations, screen temperatures of 2° C provide a fair general basis for prediction of light to moderate frosts at ground level, while a screen temperature of 0° C may be adopted to indicate a heavy frost on the ground. Figure 4 indicates the occurrence of light and heavy frosts for each month of the year for several stations. Coastal areas such as Cape Otway and Lorne are almost frost-free. Frost frequency increases with distance from the coast. A similar trend would be likely with increasing altitude, but no minimum temperature figures are available for the higher parts of the Range.

Table 2 – Average February, July and Annual Temperature (0° C)

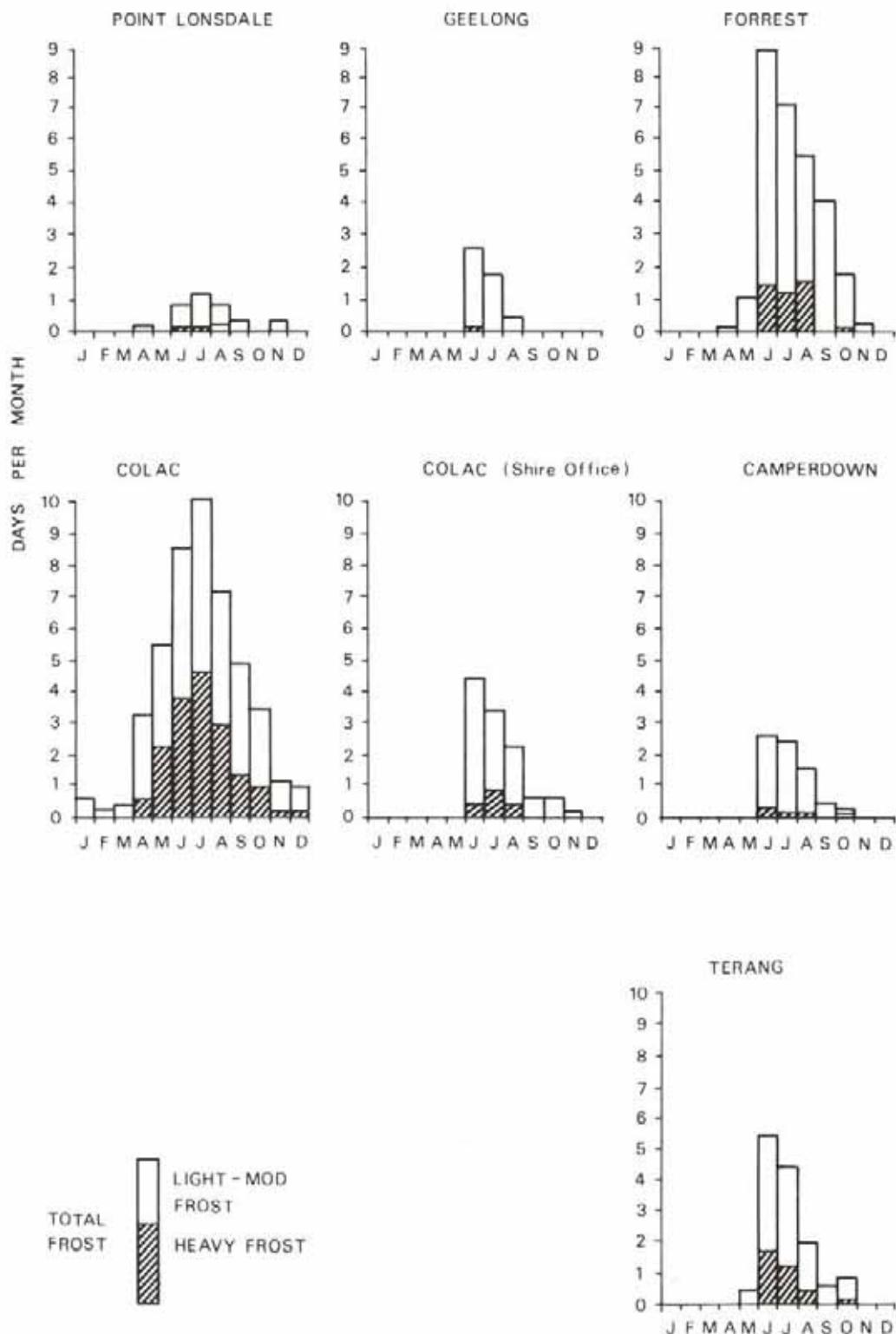
Station	Monthly Averages		Annual average
	Feb	Jul	
†Apollo Bay	18.2	10.2	14.1
†Beech Forest (Forestry camp)		(Jan)	
*Camperdown	20.0	8.5	13.7
Cape Otway	17.6	9.9	13.6
*Colac	17.5	7.6	12.6
Forrest	18.3	7.2	12.4
*Geelong (Cheetham Salt Works)	18.9	8.7	13.8
Gellibrand	18.2	7.8	12.6
Lorne (Pier Head)	19.5	10.9	14.8
†Lorne	17.6	9.7	13.7
*Point Lonsdale	18.8	9.7	14.1
*Terang	19.3	8.4	13.4

† Discontinued stations

* Stations adjacent to surveyed area

Source: Bureau of Meteorology 1977

Figure 4 – Occurrence of Frosts



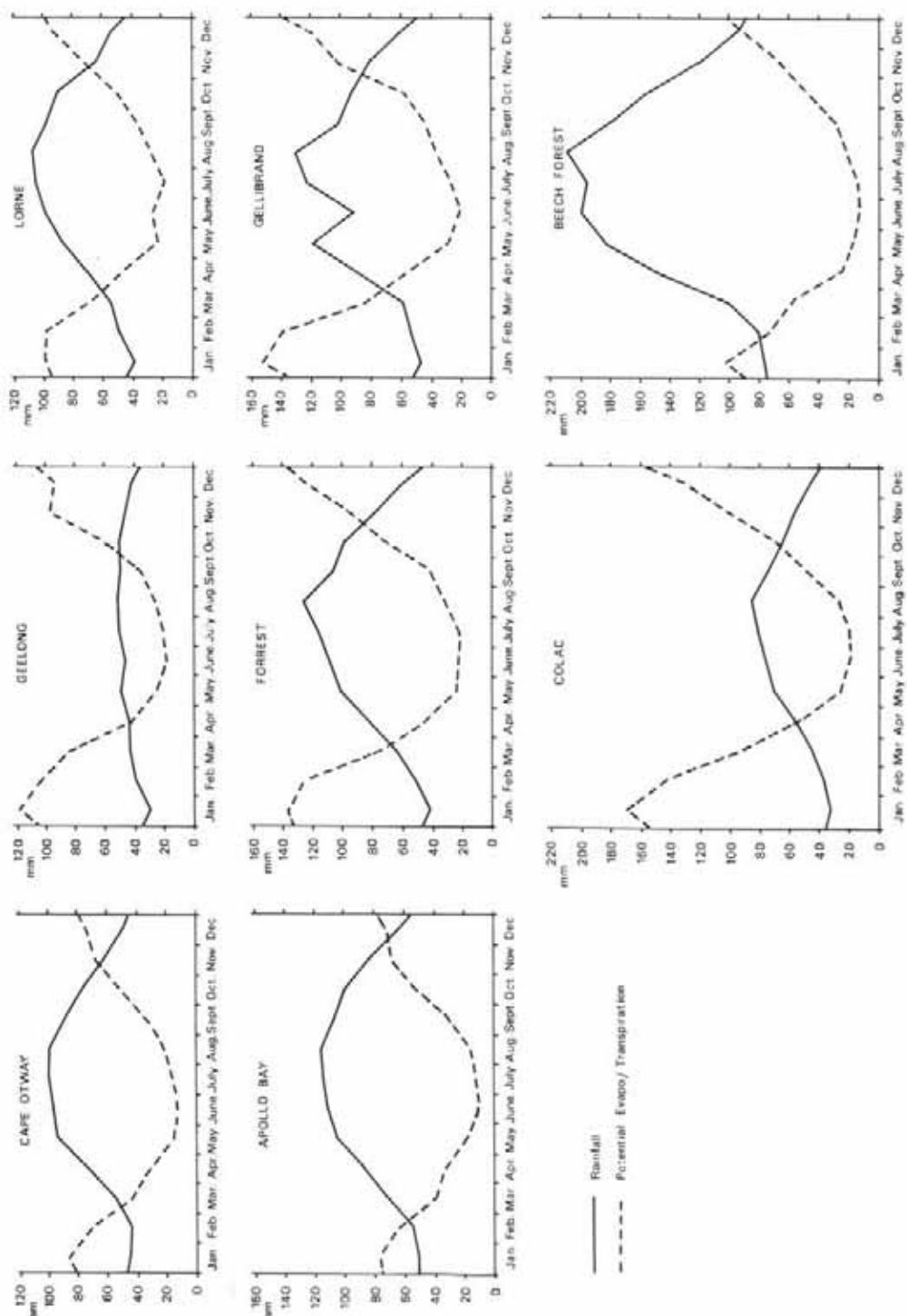
Seasonal Moisture Availability

Estimates of the availability of soil moisture for plant growth can be made from the rainfall, the potential rate of evapotranspiration and the capacity of the soil to store water within the root zone. A number of empirical methods exist for the calculation of evapotranspiration from meteorological data (Thornthwaite 1948, Leeper 1950, Fitzpatrick, 1963). Fitzpatrick's method uses constants derived from comparison with measured evaporation rates from class 'A' pans. This method, together with evaporation data from Wurdiboluc, has been used to derive the potential monthly evapotranspiration for climatic stations at Apollo Bay, Beech Forest, Colac, Cape Otway, Gellibrand, Forrest, Geelong and Lorne, as shown in Figure 5. These monthly rates are compared with the monthly rainfall to derive estimates of seasonal moisture availability.

Rainfall generally exceeds evapotranspiration in the autumn. At first this excess recharges soil moisture storage, but during the winter months it either enters drainage lines as run-off or replenishes groundwater reserves. Its magnitude is a measure of the potential of an area to supply run-off for water supply catchments. During spring, the potential evapotranspiration again rises and exceeds precipitation. Moisture remains available for plant growth for some time after this happens, as the soil moisture stored above wilting point is used up.

At moister sites with deep soils likely to store more than 200 mm of water, for example around Beech Forest, deep-rooted species do not normally suffer moisture stress. By contrast, the shallow soils, or sands with low water-holding capacities, will not support plant growth into the summer. In the drier north around Colac the soils have adequate water-holding capacities, but pastures, being shallower-rooted than native perennials, tend to dry off in November or December.

Figure 5 – Comparisons of precipitation and potential evapotranspiration



3. GEOLOGY AND GEOMORPHOLOGY

The geology and geomorphology of the Otway Range and adjacent plains form the basis of many of the land system separations. This chapter gives a chronology of the area in terms of sedimentation, tectonic movements, major climatic changes and igneous activity, all of which have an important influence on the present nature of the landscape.

Mesozoic Sedimentation

In the Lower Cretaceous epoch some 100 – 140 million years ago, the southern parts of south-eastern Australia are thought to have been a vast depositional plain, with rapid sedimentation keeping pace with subsidence and resulting in several thousand metres of interbedded sandstones and mudstones (Edwards and Baker 1943). Douglas (1969) suggested that these sediments were ‘largely deposited on extensive flood plains with braided streams contributing homogeneous sands and clays, possibly supplemented by volcanism’. The environment of sedimentation probably resembled that existing today on the riverine plain north of the Great Divide in south-eastern Australia.

These Lower Cretaceous sediments outcrop in various parts of Victoria, the most notable areas being the South Gippsland Highlands, the Merino Tablelands, the Barrabool Hills and the Otway Range. The sediments of the study area were laid down in the eastern part of the Otway Basin and these have been described and analysed by Edwards and Baker (1943), and reviewed by Douglas *et al.* (1976). They are composed mainly of fine- to medium-grained feldspathic sandstones interbedded with dark, dense mudstones and minor associated sediments. Quartz content is low in comparison with the older Palaeozoic rocks in Victoria, and the matrix cement is mainly chlorite with small amounts of calcite. Chemical analyses show that these sediments are moderately well endowed with most cations required for plant nutrition and even contain detectable levels of phosphates (Edwards and Baker 1943).

Towards the end of the period, a slight but significant change in the nature of the sediments occurred. Defined by Baker (1950) as the Moonlight Head beds, these sediments are exposed on the northern and western margins of the Otway Range. Douglas (1969) considers that they were laid down in large swamplands. The beds are characterized by fine-grained highly feldspathic sandstone inter-bedded with light-coloured mudstones. Their major mineralogical differences from the older beds are higher levels of feldspar and possibly of phosphates. They tend to weather more rapidly than the older beds and are usually present as friable, light-coloured, weathered sandstones and mudstones in surface exposures and have high clay contents.

Tertiary Developments

Marginal marine conditions at the close of the Mesozoic era signalled the commencement of successive transgressions and regressions of the sea, resulting several depositional cycles (Abele *et al.* 1976, Bock and Glenie 1966).

The Wangarri Group Equivalents

The oldest series of these marine transgressions and regressions has been associated with deposition of unconsolidated sands, silts, clays and gravels of the Wangarri Group and equivalents. The most widespread deposits are those of the Dilwyn Formation and the Eastern View Formation, which occupy much of the western and eastern margins of the Range respectively. Deposition ranged from Upper Cretaceous to Lower Eocene times in a variety of marine and continental environments. Some coal deposits were laid down in the continental phase of the Eastern View Formation. Grain size is variable in these sediments, and the outcrops of fine or coarse material have influenced the location of land system boundaries (see the map).



Reserves of coal in the Eastern View Formation to the east of the Range are actively mined at Anglesea.

Fringing the western margin of the Lower Cretaceous surface exposures, sediments with moderate levels of clay and silt size particles with copious rounded quartz pebbles are found. Adjacent to these sediments, unconsolidated quartz sand and occasional gravel predominate in a wide belt stretching from Chapple Creek to Lardner Creek, with many outcrops in other localities. Slightly further west again and to the south, from Mount Mackenzie to the lower reaches of the Gellibrand River, the sediments have moderate to high levels of clay and silt size particles, moderate amounts of sand, and little gravel. These finer deposits also dominate the outcrops at Ferguson Hill and along the top of the ridge separating Tomahawk Creek and the Gellibrand River.

To the north of the Lower Cretaceous surface exposures, outcropping unconsolidated sediments of the Wangarrup group contain intermixed beds of finer and coarser material. No areas exist where sand or finer material dominates.

Immediately adjacent to exposures of Lower Cretaceous sediments on the eastern margin of the Range, clays, silts and silica-cemented siltstones predominate around Moggs Creek. Further east and apparently overlying these finer beds are the coarse quartz sands of the Bald Hills. In the central section of the Range, flat-topped hills in the Redwater Creek area are capped with deposits of coarse quartz sand and gravel. They shallowly overlie the Lower Cretaceous sandstones at a relatively even depth of about 6 m.

Continental deposits

During the early Eocene epoch, the sea retreated and some continental deposition with associated erosion and dissection became widespread. Basaltic extrusions occurred in restricted areas around Gellibrand during this continental phase.

Heytesbury Group and equivalents

The second major Tertiary depositional cycle began in the late Eocene epoch and, with minor oscillations, the sea reached its maximum advancement in the early Miocene. By the end of late Miocene the sea had regressed. Sediments laid down during this cycle are referred to as the Heytesbury Group in the western part of the study area and as the Demons Bluff Formation and the Torquay Group in the east.

Sediments from this second cycle are found further from the main body of the Range. In the west, widespread unconsolidated clays, silts and sands are found in the catchment of Kennedys Creek and further south towards Princetown. Around Princetown itself are found calcareous clays, marls and limestone belonging to the Gellibrand Marl. This formation is exposed on in the south-western corner of the study area, but is widespread in the neighbouring catchments of Scotts and Cooriemungle Creek (Pitt, Jakimoff & Evans, internal report).

On the eastern side of the Range a similar pattern emerges. The Anglesea Member of the Demons Bluff Formation contains carbonaceous clay, silt and very fine sand, with thin coarse quartz sand and gravel beds that were apparently deposited in a marine-marginal environment. Further from the Range lie sediments of the Torquay Group including calcareous clays, marls and limestone, these being exposed along the valleys of Spring Creek and Jan Juc Creek. The Angahook Member of the Demons Bluff Formation contains basalt, tuffs and volcanic breccias together with clays and sand (Abele *et al.* 1976).

West and east of Cape Otway, a similar pattern again occurs, with unconsolidated clays, silts and sands dominating the exposures of Tertiary sediments. Some remnants of Tertiary sediments have been uplifted to moderately high elevations. A complex pattern of marls and limestones is found in the lower part of the former depositional basin at Hordern Vale.

Pliocene Lateritization

During the Lower Pliocene epoch, climatic conditions promoted widespread lateritization over western Victoria (Gill 1964). The Timboon Surface is well preserved in plateau remnants near Simpson, where deeply weathered profiles comprise an indurated ironstone layer up to a metre thick overlying kaolinitic mottled zones. A layer of siliceous sand is often present below the lateritic profile, possibly representing the initial stages of a minor marine transgression. The upper fine sediments have been altered by the lateritic weathering.

To the north and east of the Range, other lateritic remnants may belong to this same Timboon Surface. They are common to the south and east of Birregurra, and to the north of Anglesea. Flat or gently undulating lateritic landscapes were probably continuous over most of the study area. Rejuvenation of these landscapes with subsequent dissection has left only minor lateritic plateau remnants.

Some areas apparently related to the Timboon Surface exhibit deep weathering, but do not possess indurated ironstone layers. Examples can be found near Irrewillipe, Barwon downs, Birregurra and Paraparap.



Coarse quartz sand and gravel from distinctive road cuttings along the Gellibrand River valley. This one shows wind scalding, scree slopes and original bedding.

Tectonic Movements

Uplift of the Otway Range has continued since the Cretaceous period. However, it is likely that the largest period of uplift occurred during the major tectonic movements in south-eastern Australia in Upper Pliocene times, referred to as the Kosciusko Uplift. Major movements occurred along the Chapple Vale, Bambra, Johanna and many other Faults, given rise to the main structure of the Otways. These movements resulted in rejuvenation of the landscape. Rapid downcutting removed many hundreds of metres of Tertiary unconsolidated sediments and Lower Cretaceous sandstones and mudstones, to form deep, steep-sided valleys with rapidly flowing creeks and numerous waterfalls. Some pockets of Tertiary sediments remain high up on the Range, in localities such as Lorne, Cape Patton, Benwerrin and Lavers Hill.

In some central parts of the Otways, down-cutting and deep dissection have not yet advanced back to the old surface developed before uplift. Undulating landscapes with rounded rolling hills remain, similar to the high plains of the Alps in eastern Victoria and southern New South Wales. These rolling hills are well preserved between Lavers Hill and Beech Forest, and they continue as isolated patches north-east to Gentle Annie Hill and south towards Cape Otway,

Movement along the Love Creek and Bunker Hill Faults has exposed Lower Cretaceous sediments to the north of the Gellibrand River. Landscape with unconsolidated sands and clays on the higher parts and interbedded sandstones and mudstones in the lower positions occur intermittently along the northern margin of the Range from west of Bunker Hill to east of Wormbete Creek. Further from the Range, less dramatic faulting has occurred in the Tertiary sediments. The Paaratté Fault west of Princetown has exposed areas of fresh limestone. The Bambra Fault forms the northern edge of the lateritic plateau inland from Anglesea and marks the edge of an old elongate alluvial plain (Currey 1964).

Quaternary Developments

Basaltic Extrusions

Volcanic activity increased towards the close of Tertiary times. Soil weathering properties indicate that three major periods of activity occurred.

The most weathered and thus probably the oldest flow is that in the northern parts of the Thompson Creek catchment. Only occasional outcrops of weathering basalt remain, although east of Mount Duneed some retreating scarps are found.

Apparently younger flows extend from near Mount Gellibrand to Winchelsea. Here the soils are deep but not highly weathered (see Chapter 4). Occasional retreating scarps are present in a gently undulating landscape.

The youngest flows are those found south of Mount Gellibrand. They are characterized by numerous stony rises, with basaltic wash filling depressions between these. The soils are often shallow and are not deeply weathered (Leeper, Nicholls and Wadham 1936).



The Otway Range contains many steep and narrow valleys, often with picturesque waterfalls.



The retreating scarp of the Paaratte Fault, west of Princetown

Lake Deposits

Currey (1964) postulated that basalt flows east of Winchelsea were instrumental in the formation of a vast inland lake during the Pleistocene by blocking the path of the Barwon River. He suggests that the river formerly flowed along the fluvial plain to the north of the eastern part of the Bambra Fault, and was responsible for deposition of the lateritic alluvium referred to above. Basalt valley flows have since obliterated most remnants of its former course.

The almost flat plain to the north-east and north-west of Birregurra comprises the remnants of the sediments laid down in this lake. Eventually the lake overflowed and cut a new path to the north of the Barrabool Hills, and the alluvium left behind has been mainly derived from basalt with some influence from surrounding Tertiary sediments. Slight rejuvenation and mild dissection have occurred. These high-level calcareous lake deposits are in sharp contrast to surrounding siliceous deposits of Tertiary marine or Recent alluvial origin.

Alluvial Terraces

Alluvial terraces are common in the upper reaches of the Barwon River system, and along the Gellibrand River, particularly at Carlisle River and Gellibrand. Here terraces at different levels can be found. Weathering patterns in soils on the highest terraces indicate considerable age. In addition, some apparently alluvial material is found occasionally perched as terrace remnants on sides of hills, suggesting deposition before the last major tectonic movements.

Coastal Land Forms

At Cape Otway and to the west, including Johanna Beach and the Princetown coastline, elevated areas of aeolian dune sand have been variably lifted by internal deposition of calcium carbonate. The degree of cementation of this calcarenite depends on the proportion of calcareous material in the parent sand (Bird 1976). A basement of calcarenite also exists in the dune system between Torquay and Breamlea, but elsewhere it is rare.

To the west of Cape Otway, the calcarenite often forms cliffs almost 100 m high, or overlies buried soils developed on older Tertiary deposits. The weathering pattern of the palaeosols supports the theory that this coastline emerged during Pleistocene times (Abele *et al.* 1976). Cliff erosion has left the coastal dune deposits high above the present sea level.

Most of the seaward slopes of the Lower Cretaceous sediments have been steepened by wave undercutting and are thus prone to landslides (Joyce and Evans 1976). Emerged shore platforms with overlying boulder beds and colluvium found at intervals along the coasts are also inherently unstable.

Coastal erosion of unconsolidated Tertiary sediments has often been even more active, producing vertical cliffs, massive landslides and earth flows at various localities along the coastline, particularly near Anglesea. The development of a dune system in front of some of these landslides indicates temporary stability.

Further modifications of land forms in the coastal vicinity have been initiated by minor fluctuations in sea level (Bird 1976, Gill 1977). Recent rises in sea level have drowned the river mouths of the Gellibrand, Aire, Barham and Anglesea Rivers and Thompson Creek, creating extensive estuaries.



The Otway Range has been formed on Cretaceous sandstones and mudstones, which have been uplifted and deeply dissected to form a steep and rugged terrain.

Calcareous cliffs are common along the coast to the west of Cape Otway; here, a layer of buried soil or palaeosol lies between the calcarenous and underlying Tertiary sediments.



The most notable is at Thompson Creek, where tidal salt marches have developed on the lee side of the coastal dune system. Occasional higher surfaces in this salt marsh are thought to be due to deposition under previous higher sea levels, some 1-2 m above the present level.

Surface Sediments

Widespread redistribution of coarse surface material by both wind and water is commonly observed. In the eastern parts, deep sand sheets overlie older soils, particularly north and west of Torquay. In the west, deposits are usually thinner and overlie an older deeply weathered profile. A hardpan often develops between the two layers (see Chapter 4).

4. SOILS

The nature of the soils reflects the interactions of the various soil-forming factors, such as climate, parent material, position in the landscape, age of formation and vegetation. Variations in these factors have led to a wide range of soils in and adjacent to the Otway Range.

In the wetter areas of the Range, strongly acid, well-drained gradational profiles with high levels of organic matter are found. Textures on Cretaceous sandstones and mudstones are moderately heavy, while soils on Tertiary sediments range from sands to clay loams.

On the surrounding plains, soils may be acid, alkaline or close to neutral, but their organic matter contents are low. Most of them possess duplex properties and have heavy or medium clay subsoils. Those developed on basalt, or alluvium derived from basalt, have the heaviest textures and the lowest permeabilities.

The soils developed on Cretaceous sediments have moderate levels of most plant nutrients, although calcium is often low and high acidities decrease the availability of these nutrients for plant growth. Deficiencies of phosphorus, potassium and nitrogen are widespread on Tertiary sediments, with occasional exceptions. Minor and trace elements such as copper, molybdenum, zinc, cobalt and selenium are also often required for active plant growth. Phosphate fertilizers are required on the basaltic plain in the north.

Soils recognized as entities in the field have been given descriptive names based on subsoil colour and the nature of textural change with depth. Other features may also be used, as described in Appendix III. When linked with parent material, these grouping serve to differentiate soils at the series level (U.S.D.A. 1951). The soils are listed in Table 3, together with their place in the classifications of Northcote (1974) and Stace *et al.* (1968).

Altogether, 48 soils have been recognized, some widespread and other localized. They are described below in terms of their occurrence, organic content, soil reaction trend (Northcote 1974), drainage characteristics and other aspects relevant to land use.

Soils of Uniform Texture

1. **Yellow calcareous sandsoils.** Inherently unstable coastal dunes formed for aeolian sand and shell grit posses soils with little or no profile development. Most areas regularly receive or lose sand through the action of strong onshore winds. Apart from occasional darkening by organic matter, yellow coarse sands and grit of high alkalinity are found throughout. Permeabilities are high and water-holding capacities low, presenting a generally unfavourable medium for plant growth. On exposed sites, coastal winds also severely restrict plant growth.

2. **Brown calcareous sand soils.** On stable coastal dunes, organic matter has accumulated and some weathering has occurred. Dark-brown loamy sand A horizons overlie brown or yellowish brown calcareous sands at about 30 cm depth. Moderate levels of organic matter in the A horizons improve the moisture-holding capacity and fertility of these alkaline sands, but conditions are still unfavourable for plant growth.

3. **Red-yellow calcareous sand soils.** Older coastal dunes with well-differentiated soil profiles are found at Cape Otway and to the west of the Aire River mouth. Black loamy sand A horizons about 30 cm deep overlie B horizons of reddish yellow or light-red sands. At about 1 m, deeply weathered yellow sands are encountered. In some areas, calcarenite replaces the yellow sand C horizons. Profiles usually have alkaline trends and are again excessively drained, with low water-holding capacity and low fertility.

4. **Stony black calcareous sand soils.** Old coastal dunes to the east of Torquay overlie calcarenite. Where it is exposed on some of the steeper slopes, shallow stony soils have developed. They are known to occur elsewhere along Victoria's coastline (Gibbons and Downes 1964). Surface horizons are black loamy sands interspersed with calcarenite stones and gravel. At about 20 cm there is a gradual change to brown sands with carbonate deposition around root channels. Infiltration is restricted by the stone layers near the surface, and rapid surface run-off with resulting severe sheet erosion occurs in areas without protective vegetation.

5. **Grey sand soils.** Freely drained slopes of Tertiary sand with these soils are widespread throughout the study area, and are particularly common along the western edge of the Range. Profiles are well differentiated and consist of black loamy sands some 30 cm thick overlying bleached grey sand A₂ horizons. In drier areas, particularly where the sand appears to be partly aeolian in origin, the B horizons are weakly developed and non-columnar.

Permeabilities are high, with soil water draining through the grey sand channels separating the B horizon columns. The reaction is acidic, with particularly low pH values at the surface. Low nutrient levels in the parent material and intense leaching of the permeable profiles have led to severe nutrient deficiencies. Limitations to plant growth also come from low water-holding capacities.

6. **White sand soils.** On the coarser Tertiary deposits in high-rainfall areas, practically all traces of iron and organic compounds have been leached from the subsoils. Black or dark-grey coarse loamy sands, rich in organic matter, overlie light-grey or white bleached coarse sands at about 20 cm. These A₂ horizons continue for several metres, occasionally with weak silica cementation at about 1.5 m depth.

The reaction is acidic throughout and severe nutrient deficiencies occur. Water-holding capacity below the A₁ horizon is very low and drainage is excessive.

7. **Grey sand soils with hardpans.** Hardpans, rich in iron and organic compounds, have been formed in outcrops of coarse Tertiary deposits. Dissection has brought many of them close to the surface. They are usually covered by a wash of sand approximately 60 cm deep. The surface horizon comprises black loamy sand, which overlies mildly bleached dark-grey sands at about 25 cm. An organic-rich loamy sand about 15 cm thick is encountered just above the hardpan. Cemented sand and gravel varies in thickness from 30 cm to several metres, and below this are yellow sand and gravel layers.

8. **Yellow sand soils.** Steep slopes on coarse Tertiary deposits have yellow sand with only weak surface darkening due to organic matter accumulation. They appear to be formed on B horizons exposed by erosion of adjacent uniformly textured grey sand soils. Brownish yellow loamy sands at the surface merge to yellow or yellowish red sands at about 1 m. Organic matter levels and water-holding capacities are low. Despite high permeabilities, the reaction trend is neutral with a mildly acidic surface reaction and this appears to be reflected in the nutrient supply. The native vegetation is noticeably taller with a dense crown cover than in surrounding areas of uniformly textured grey sand soils.

9. **Black sand soils.** Where water accumulates in landscape on Tertiary sand deposits, a permanent anaerobic environment causes organic matter to accumulate. These conditions exist in many drainage lines around the borders of the Otway Range, and on flat hilltops in higher-rainfall areas where weakly developed hardpans impede the profile drainage. Silty loam O horizons with up to 30% organic matter overlie black loamy sand A₁ horizons at about 20 cm. In drainage lines, layers of sand a peat alternate at depths greater than 60 cm. Elsewhere the black sands continue to a depth of 1 m or so, underlain by a weakly cemented hardpan developed in yellow sand. These hardpans do not appear to significantly impede root penetration or permeability. Plant nutrient levels are sometimes high, but the strong acidity (pH values are frequently below 4) decreases their availability.

High levels of sulphide are found in the most acidic horizons of these soils. They can have corrosive effects on concrete or metal structures.

10. **Red sandy loam soils.** Iron-rich Tertiary sediments outcrop in the southern and western part of the study area. Some of these outcrops have soils with black sandy loam surface horizons overlying dark-red sandy loam or sandy clay loam B horizons. These merge into permeable yellow sands, frequently with ferruginous gravel or stones, at about 1 m. The reaction trend is usually acidic, and the relatively vigorous growth of native vegetation indicates a better supply of plant nutrients than is usually found in light-textured highly permeable soils.

11. **Grey calcareous sodic clay soils.** The basaltic plains in the north possess many complicated patterns of microrelief. Solution of calcium carbonate in the lower parts of the landscape is the most probable reason for the development of 'sink holes' some 5 – 12 m across south of Mount Gellibrand and north-east of Birregurra. Water tends to pond in these depressions for long periods after rain.

The soils are weakly structured gleyed clays with prominent oxidation along root channels. Textures range from silty clays at the surface to heavy clays at about 50 cm. Levelling of paddocks in many areas had led to a layer of lighter-textured material from surrounding duplex soils being deposited over the surface. Soil reaction trends are usually alkaline. Restricted permeability and the low position in landscape result in poor drainage and waterlogging severely restricting plant growth.

12. **Black calcareous clay soils** are found on the basaltic plains in the north, often demarcated by the presence of thistles. They occur on gentle scarps and crests of ancient lava flows and around the periphery of 'stony rises'. Surface horizons are dark brownish grey self-mulching clays. Black heavy clays are found below 15 cm and these merge to greyish yellow clays with soft accumulations of free lime. Gilgai microrelief is common, with a vertical variation of about 40 cm. Textures are slightly lighter in the shelf position. Apart from phosphorus, nutrient levels are moderate, but permeability is low. Soil depth, although variable, is usually about 120 cm, with basalt floaters throughout the profile. Leeper, Nicholls and Wadham (1936) termed these soils 'mooleric clay'.

Soils with Gradational Profile Forms

14. **Brown gradational soils** with weak structure are the more common soils on the alluvial plains, particularly in areas where much of the alluvium is derived from Cretaceous sediments. Surface textures range from fine sandy loams to clay loams, which merge into dark-brown silty clay loams or light clay at about 50 cm depth. Structure in the subsoil is weak or absent, but the surface has a moderate to strong crumb structure. Nutrient levels are relatively high, as the parent

material is mainly derived from Cretaceous sediments. However, soil reaction is acidic, calcium levels are low and carbon-nitrogen ratios are unfavourable high.

15. **Grey gradational soils.** On flood plains throughout the study area, and extending back up many river valleys to narrow drainage lines, alluvial deposits derived from Tertiary sediments have poorly drained heavy-textured soils. Very dark-brown sandy clay loams at the surface grade into slowly permeable medium or heavy clays, which are usually grey with yellow mottles. Seasonally high water tables lead to weak coarse structural development. Nutrient levels are moderately low.

16. **Mottled yellow and grey gradational soils.** High alluvial terraces and lower slope positions in the west have profiles that are relatively well structured and well drained when compared with the adjacent soils of the above-mentioned grey gradational soils. Dark greyish brown sandy loams overlie mildly bleached A₂ horizons. Yellow and grey mottled clays occur from 50 to 120 cm, below which are alluvial deposits of sandy clays and silts. The reaction is usually acidic. Permeability is moderate, but the subsoils tend to be dispersible and some gully erosion occurs under agricultural use.

17. **Yellow gradational soils with weak structure.** On steep outcrops of Tertiary clays, silts and sands, profiles with weak differentiation and minimal structure development are encountered. They occur around the margins of the Range and are particularly common near Mount Mackenzie and Bunker Hill in the west, and the Bald Hills in the east. The A₁ horizons are grey sandy loams of variable depth. Loamy sand A₂ horizons are sometimes present. Yellow or yellowish brown sandy loam B horizons occur at 5 – 50 cm depth, and these grade into sandy clay loams of high permeability at about 1 m. Floaters of ironstone are common throughout the profile. Sandy loam C horizons are found below approximately 150 cm.

Profiles are acidic and water-holding capacities are low, particularly in the A horizons. Soil nutrient levels are moderate in the western areas with notably high available phosphorus values, frequently concentrated into the surface 10 cm. In the Bald Hills area, nutrient levels are extremely low, with particularly low values for potassium and calcium and a high carbon-nitrogen ratio.

18. **Stony yellow gradational soils.** Where outcropping Tertiary sediments contain a large proportion of quartz gravel, profiles are weakly structured ad weakly differentiated. They are most common near the Gherang Camp in the east, but are also found in isolated areas to the north-west of the Otway Range and on steep exposures of quartzitic sandstones and siltstones near Moggs Creek. Textures are dominated by the gravel fraction, moisture-holding capacity is low. On steep slopes, and particularly where they overlie impermeable sandstones and siltstones, the weak structured surface soils are prone to sheet erosion.

19. **Red gradational soils** with weak structure, in association with the weakly structured yellow gradational soils, occur in the iron-rich Tertiary sediments near Mount Mackenzie, Ferguson Hill and other locations west of the Range. The distribution of the two soils may be related to the form and quantity of iron oxide in the parent material. Textures of the red soils are often somewhat heavier. Black or dark-brown sandy loams into light clay B horizons. Below about 130 cm, yellowish red sandy loams are usually encountered, but along Pipeline Road to the west of the Gellibrand River layers of ironstone are found. Profiles are permeable, with moderate nutrient levels.

20. **Pale-brown gradational soils with weak structure.** On Tertiary sediments just inland from Cape Otway, high points in the landscape have poorly drained gradational soils supporting rare stands of *Eucalyptus kitsoniana*. The parent material is silty clay, containing high proportions of kaolin. Surface horizons are black silty loams with high organic matter content. These grade into pale-brown silty clay loams with marked oxidation of root channels and gleaming, indicating high seasonal water tables. Both surface and subsoils have low mechanical strength, tending to form a slurry when disturbed. Nutrient levels and permeabilities are low.

21. **Grey-brown gradational soils** with well-developed B horizons are found surrounding Ferguson Hill and on some steeper concave slopes further east. Dark-grey sandy loam A₁ horizons overlie greyish brown sandy loam A₂ horizons. Textures grade through sandy clay loams at about 30 cm to fine-structured grey clays with brown and yellow mottles. Red mottles occur at depth. Sandy clay C horizons occur at about 120 cm. The reaction is mildly acidic, and profiles are well drained.

22. **Mottled yellow and red gradational soils** with ironstone have formed on weathered remnants of Tertiary lateritic profiles on coastal plains in moderately high-rainfall areas. The main areas are around Simpson, with isolated pockets near Hordern Vale and Rivernook. A₁ horizons of shallow greyish brown sandy clay loams overlie brown structureless clay loams, grading into yellow and red mottled silty clays at about 40 cm. Very stable fine angular blocky structures are characteristic of the B horizons. Ironstone gravel is present throughout and, at approximately 150 cm depth, horizontal bands of sheet ironstone alternating with bands of kaolinitic clay restrict water movement through the soil. Soil reaction is acidic and intense leaching has resulted in low levels of many plant nutrients. High sesquioxide levels lead to fixation of applied phosphate.

23. **Mottled yellow and red gradational soils** occur at comparable levels in the landscape to previous soils; their profiles are similar but lack ironstone. They are found in the moderately high-rainfall areas in the west near Wonga Road, Ferguson Hill, Barongarook and Kawarren and also on the highest alluvial terraces at Carlisle River and Gellibrand. The variation in ironstone context may be due to variation in parent material or weathering history. Below 150 cm red, yellow and grey mottled clays continue to indefinite depths. Profiles are acidic and fertility is again low.

24. **Yellow-brown gradational soils with coarse structure.** Along the hillslopes into Tomahawk Creek, Kennedys Creek and other tributaries of the Gellibrand River closer to the coast, the intensely weathered mottled clays mentioned above have been stripped away. This has exposed less-weathered underlying Tertiary sands and clays and occasionally some gently sloping outcrops of Cretaceous sandstones. Very dark grey fine sandy loams overlying greyish brown sandy loams merge into yellowish brown clay B horizons, with grey mottles at about

26. **Brown gradational soils** are the most common ones in the study area, occurring on steep slopes and crests of the Otway Range under a wide variety of rainfall. At rainfalls of about 1,000 mm they are confined to the wetter southern and eastern aspects, while in the highest-rainfall areas they are often associated with more resistant strata where the depth of weathering is comparatively shallow. Although mainly on Cretaceous sediments, they also occur on Tertiary clays near Hordern Vale and Cape Otway.

Dark-brown loam surface soils grade into brown or yellowish brown medium clays or silty clays at 20 cm. Weathering parent material is encountered between 80 and 130 cm depth. Structure is well developed and rock floaters are common on Cretaceous sediments. The reaction trend is acidic and nutrient levels are relatively high by Australian standards. Although soil permeability is moderate, heavy rainfall leads to considerable surface run-off and erosion of surface soil layers when disturbed. Landslips are common on steep slopes, even under native vegetation.

27. **Brown friable gradational soil.** Deep profiles have developed on gentle crests in the high-rainfall parts of the Range, particularly on the more weathered outcrops of Cretaceous sediments. A continuum exists between these profiles and the previous soils. Well-structured dark-brown loams or clay loams about 30 cm deep grade into friable dark-brown light clay B horizons, continuing to depths of more than 2 m in places. Brown clay loams or light clays with evidence of original bedding constitute the C horizons. The reaction is acidic. Organic matter levels and fertility are high. Good site drainage and high permeability contribute to the salinity of these soils for plant growth.

28. **Dark-brown gradational soils.** Most of the minor drainage lines and many of the larger streams and rivers in the Otway Range are bounded by colluvial-alluvial slopes of variable grade. The soils contain varying amounts of gravel and stones, with occasional boulders. Textures range from black loams or clay loams at the surface to dark-brown light clays below about 30 cm. Below about 120 cm, parent material occurs as chaotic mixtures of soil, gravel and stone. Although most plant nutrients have high levels, acidic reactions restrict their availability. Profiles are permeable, but water tables are close to the surface for much of the year.

29. **Stony brown gradational soils.** On drier exposures of Cretaceous sediments, steep slopes prone to soil loss have young profiles developed on colluvium. The coastal parts of the Range and the steep slopes near Yahoo Creek are the main areas of occurrence. Surface horizons are thin dark-brown fine sandy loams overlying weakly structured yellowish brown sandy clay loams with varying amounts of gravel and stone. Profiles are shallow and weathering sandstones frequently occur within 60 cm of the surface. On some slopes, clay layers are found below the mantle of colluvium. Levels of organic matter and soil nutrients are notably lower than in other soils on Cretaceous sediments. Reaction is acidic and moisture holding capacity is also low.

30. **Stony red gradational soils.** On the edges of some of the lateritic plateaux, steep concave scarpas have colluvial deposits of ironstone with shallow stony or gravelly soils. Such soils are found around the edge of the Timboon Surface (Gill 1964), along the top of the scarp west of the Gellibrand River at Carlisle River, and in some of the coastal areas near Anglesea.

Profiles consist of dark reddish brown sandy loams with gravel overlying weakly structured red gravelly clay loams and light clays at about 30 cm depth. Lateritic ironstone underlies the soils at depth ranging from 60 to 120 cm. The drier areas near Anglesea have frequent ironstone outcrops. Lower down the scarpas, unconsolidated Tertiary sediments underlie the soils. Fertility and moisture-holding capacity are low, although the frequent emergence of springs from aquifers below the laterite often promotes good growth of deep-rooted native vegetation.

31. **Stony red-brown gradational soils** are widespread on the scarpas and stony rises of basaltic landscapes south of Mount Gellibrand. Pockets of soil between basalt outcrops consist of dark-brown loams overlying rock or reddish brown clay loams and clays. Depth varies, but seldom exceeds 40 cm. Deeper profiles do occur on some of the isolated Tertiary basalt outcrops in the higher-rainfall areas near Gellibrand. The reaction is neutral and nutrient levels are moderately high. Shallowness and stoniness are the main limitations for most uses.

32. **Red calcareous gradational soils.** Outcrops of Tertiary limestone near Bellbrae and of calcarenite east of Torquay have red gradational soils on well-drained sites. Surface horizons consist of brown sandy clay loams grading to well-structured red clays at about 15 cm. Weathering limestone occurs at depths of 30 – 80 cm. The reaction is alkaline although the surface is usually neutral. Nutrient levels are moderate, but the shallow depths result in low water-holding capacities.

33. **Black calcareous gradational soils.** Exposures of limestone and calcareous clays occur on steep well-drained slopes near Hordern Vale and along Curdies Fault north of Princetown. The soils are shallow black fine sandy clay loams or light clays overlying dark-brown clays. Structure is strong throughout and aggregates are stable. At a depth of 40 – 80 cm weakly consolidated limestone and marl occur. The reaction trend is alkaline, although the surface soil is close to neutral. Fertility is moderate, but the shallowness leads to low moisture-holding capacity.

Soils with Duplex Profile Forms

34. **Yellow sodic duplex soils.** The lower positions of the landscape on Tertiary and Quaternary sediments in the north and east are frequently occupied by colluvial-alluvial deposits on which strongly differentiated soils have developed. Surface horizons are usually dark-grey sandy loams overlying bleached sandy loam or sandy clay loam A₂ horizons at about 15 cm. Ironstone nodules may occur at the base of the A₂ horizon. Yellow or yellowish brown clays with earthy fabric and occasional brown and grey mottles are found at 30 cm. Strong mottling in some profiles indicates poor drainage. At about 110 cm, sandy clay parent material is encountered. The reaction has a strong alkaline trend, ranging from acidic at the surface to a pH greater than 8 in the subsoils.

Most of these soils occur in reasonably well-drained positions, and soluble salts tend to accumulate in the subsoil. They are sodic, sodium comprising as much as 30% of total exchangeable cations. Rising groundwater may tend to concentrate these salts at the surface. The clay subsoils are dispersible and are thus also susceptible to gully and tunnel erosion.

35. **Red-yellow duplex soils.** In the steeply dissected hills on the eastern margin of the Range, Tertiary unconsolidated sediments with some areas of silica-cemented quartzitic siltstones and sandstones have well-differentiated duplex profiles. The main occurrence is in the catchment of Moggs Creek. Profiles are well drained, and consist of dark-brown fine sandy loams overlying mildly bleached greyish brown sandy loam A₂ horizons at about 10 cm depth. Surface structure is weak. Weakly mottled reddish yellow clays of moderate dispersibility are encountered at 25 cm depth and continue with increased mottling to about 90 cm. These B horizons have moderate structure and an earthy fabric. The C horizons are apedal silty clays, frequently containing quartzitic siltstones and sandstones.

The reaction trend is acidic, becoming close to neutral in the subsoil. Nutrient levels are moderately low, but these soils have not been as intensively weathered and leached as other older soils on Tertiary sediments.

36. **Brown duplex soils** are widespread on Cretaceous sediments in drier parts of the Range. The Barrabool Hills have similar profiles. Along the coastal strip of the Range, the effect of high atmospheric salt levels passing through the soil appears to have extended the range of duplex profiles into higher-rainfall areas.

Surface soils are well-structured black loams to fine sandy clay loams, overlying sporadically bleached loams or clay loams at about 15 cm depth. On gentle less freely drained slopes such as those of the Barrabool Hills, these A₂ horizons are often absent. At 30 cm depth, brown or yellowish brown medium to heavy silty clays with strongly developed structure and low dispersibility are encountered. Weathering sandstones and mudstones are found at a depth of approximately 1 m. Profiles are acidic and fertility levels moderate.

37. **Grey calcareous sodic duplex soils** with coarse structure characterise large parts of the basaltic plains in western Victoria, and within the study area they occur on gentle slopes and flat plains in the north and east. Dark-grey fine sandy loam to clay loam surface horizons overlie mildly bleached grey fine sandy clay loam to clay loam A₂ horizons at 15 cm. Ironstone gravel is abundant at the base of the A₂ horizon and the top of the B horizon. At approximately 35 cm depth there is an abrupt change to grey, yellow and black mottled heavy clays with coarse angular blocky peds separated by large shiny ped faces. Paler B₂ horizons with more mottled and less ironstone gravel are often present. Soft accumulations of calcium carbonate are visible at 70 cm and may become abundant with depth. These accumulations are more prominent in the stony rise landscapes south of Mount Gellibrand. Weathering basalt floaters are common and the parent rock is usually encountered between 1 and 3 m depth.

The reaction trend is alkaline, with mildly acidic surface soils. The plains are usually gilgaiied and may be interspersed with unusual microrelief features such as sink holes. Plant growth is limited by the low permeabilities of the clays, leading to seasonal waterlogging.

38. **Yellow-brown calcareous sodic duplex soils with coarse structure** occur on calcareous clays in ancient lake deposits around Birregurra and on deeply weathered Tertiary sediments at Bellbrae. Surface horizons are black mildly acidic fine sandy loams. Near Birregurra, dark-grey sandy clay loam A₂ horizons are present. An abrupt change to yellowish brown medium or heavy clays occur at between 25 and 35 cm. The heavier textures occur where the parent material has been derived from basalt, and here the soils are gilgaiied. The B horizons have coarse angular blocky peds

with shiny faces and these clays are quite dispersible. At about 120 cm, calcareous clay parent material is encountered. The B horizons are sodic and the permeability is low. Seasonal waterlogging occurs on the flat or gently sloping sites. Nutrient levels are generally low.

39. **Yellow-brown sodic duplex soils with coarse structure.** On more siliceous deposits of clay and silt in the eastern and north-central parts of the study area, well-differentiated duplex soils are again encountered. They have similar profiles to the previous soils, but the B horizons are not calcareous. The reaction trend is alkaline with mildly acidic surfaces. Yellow and red sandy clays are found below yellow, brown and grey mottled heavy clays at about 170 cm. Permeabilities of the dispersible sodic clays are low.

40. **Yellow-brown duplex soils with coarse structure** occur on similar parent material to the previous soils, but on better-drained foothill slopes of the Range near Pennyroyal and Anglesea. Dark-brown fine sandy loams overlie greyish brown A₂ horizons at about 10 cm. An abrupt change to heavy clay B horizons with coarse structures occurs at 30 cm. Sandy clays, or sometimes sandstones, are generally encountered below 120 cm, although sandstones may be as shallow as 60 cm. The dispersible clays have slow permeabilities and the reaction trend is usually acidic. Nutrient levels are low.

41. **Brown duplex soils with coarse structure.** On high parts of the landscapes at Bellbrae and Princetown, strongly differentiated soils have developed on the base of former lateritic profiles developed from calcareous material. Black fine sandy loams overlie strongly bleached loamy sand or sandy loam A₂ horizons. Abrupt boundaries mark the change to brown dispersible medium clays with coarse structures and large shiny ped faces at approximately 35 cm. Below about 1 m, red and grey mottled become abundant and the soil reaction changes from mildly acidic to alkaline. Ironstone gravel and stone occurs in this B₂ horizon, which merges into structureless mottled zones below 2 m. Permeability is restricted by the dense nature of the clay B horizons and fertility levels are low.

42. **Mottled yellow and red duplex soils.** Older soils with finely structured subsoils are encountered on higher gentle parts of the landscape in the eastern and north-central plains. They occur on Tertiary sediments, alluvium and deeply weathered basalt. Shallow brown sandy loam A₁ horizons overlie bleached sandy loams or loamy sands, often with ironstone gravel. Finely structured yellow and red mottled clays are encountered at approximately 40 cm, the mottling becoming stronger and coarser with depth. The clays are prone to slaking, but seldom disperse readily. At about 140 cm depth, the structure becomes weaker and mottled red and grey sandy clays or mottled weathered basalt continue indefinitely.

43. **Mottled yellow and red duplex soils with ironstone** similar to the previous soils, but with lateritic ironstone throughout, are encountered on remnants of lateritic plateaux on the north and east of the Range. Large blocks of ironstone may form a discontinuous layer at about 90 cm. More commonly, abundant ironstone gravel occurs in the B horizons, merging to horizontal bands of sheet ironstone with white kaolinitic clay in the interstices below 120 cm. Permeabilities are often severely restricted by the ironstone layers.

Miscellaneous Soils

44. **Grey sand soils with weak-structured clay underlay.** As mentioned in the discussion of geomorphology, surface redistribution of sand has been common in many parts of the Gellibrand catchment, and to a lesser degree in the central and eastern parts of the study area. Dark-grey sandy loam A₁ horizons with abundant organic matter overlie grey loamy sand A₂ horizons at about 25 cm depth. Depths of the sand vary, but at about 50 cm depth a weak hardpan has frequently developed.

The underlying weakly structured layers are yellow and grey mottled clays and clay loams. They merge into structureless sandy clays and sandy clay loams with depth. Permeability is often restricted by the clay layers, and this combines with bad site drainage to result in seasonal waterlogging.

45. **Grey sand soils with structured clay underlay** are found mainly in the Gellibrand catchment and again owe their origin to redistribution of sand. However, the clays are well structured and the overlying hardpans are more strongly developed. These buried clays frequently resemble the subsoils of the mottled yellow and red gradational soils.

Black sandy loams, rich in organic matter, overlie dark-grey sandy loam A₂ horizons at about 15 cm depth. Shallow hardpans about 20 cm thick are found from 25 to 60 cm below the surface. These hardpans are cemented by iron and organic matter forming coffee rock, or 'wombat' as it is locally known. Dense well-structured clays are found below the hardpan.

The reaction trend is acidic with highly acidic surface horizons. Nutrient levels are low, with slight concentrations at the top of the hardpan as well as at the surface. Carbon-nitrogen ratios are particularly unfavourable. The hardpans often severely restrict drainage, and waterlogging is common in the wetter months. During summer, however, the hardpans serve to hold water within the root zone.

46. **Grey sand soils with kaolinitic clay underlay.** The Tertiary sediments outcropping in the Bald Hills west of Anglesea are particularly variable. Some beds appear to consist of kaolinitic clays that weather to pale-brown clay

horizons. The surface horizons consist of coarse sandy loams or loamy sands of variable depth. The absence of significant quantities of sand in the kaolinitic clays indicates that this sand is sheet wash derived from sands further upslope. Abrupt boundaries mark the change to B horizons, which contain large weakly developed pedes. Roots appear unable to penetrate the pedes and confined to the cracks between them. Nutrient levels are extremely low in these soils, as is the case with other soils in the Bald Hills.

47. **Variable sodic duplex soils.** In some coastal areas, accretions of aeolian calcareous sand and continual leaching with salt spray have resulted in partial salting of soils of variable organic morphology. This has occurred most widely along cliff tops and seaward-facing slopes of the Anglesea area and on similar outcrops of Tertiary clays near Cape Otway. Surface horizons are black sandy loams, rich in organic matter, and these persist to about 25 cm where variably coloured, mottled and structured clays are found.

The reaction ranges from highly alkaline at the surface to neutral in the subsoil. Clay subsoils, and often surface horizons, have high levels of sodium on the exchange complex and are highly dispersible. Levels of soluble salts are also high.

48. **Saline soils** occur in estuarine swamps along the coast and in isolated saline lakes and drains in the northern parts of the study area. The major examples are at the mouths of Thompson Creek, Painkalac Creek, Aire River and Gellibrand River. Grey and yellow mottled silty clays high in organic remains and lacking structure occur throughout. The surface may show polygonal cracking when dry.

Table 3 – Soils of the Otway Range and Adjacent Plains

Soil	Parent Material	Sampled Profile No. (Appendix I)	Classification	
			Northcote (1974)	Stace <i>et al.</i> (1968)
Soils of uniform texture				
1. Yellow calcareous sand soils	Recent aeolian sand	-	Uc1.13, Uc1.11	Calcareous sands
2. Brown calcareous sand soils	Recent aeolian sand	415	Uc5.11	Calcareous sands
3. Red-yellow calcareous sand soils	Recent aeolian sand	-	Uc5.11	
4. Stony black calcareous sand soils	Recent aeolian sand	-	Uc5.12	Lithosols
5. Grey sand soils	Tertiary sand	742	Uc2.33, Uc2.31, Uc2.32	Podzols
6. White sand soils	Tertiary sand	426	Uc2.2	Siliceous sands
7. Grey sand soils with hardpans	Tertiary sand	608	Uc4.33, Uc4.32, Uc3.32	Humus podzols
8. Yellow sand soils	Tertiary sand	740	Uc5.11	Yellow earths
9. Black sand soils	Recent alluvium, plant remains	609,739	Uc4.0	Peaty podzols
10. Red sandy loam soils	Tertiary sands and clay	-	Uc6, Uc5.21	Red earths
11. Grey calcareous sodic clay soils	Recent alluvium plant remains	-	Uc6.4	Grey clays
12. Black calcareous clay soils	Quaternary basalt	-	Uc5.14	Black earths
13. Brown sandy loam soils	Recent alluvium	-	Uc1.23	Alluvial soils
Soils with gradational profile forms				
14. Brown gradational soils, weak structure	Recent alluvium	607	Gn2.41, Gn2.44, Um5.52	Prairie soils
15. Grey gradational soils	Recent alluvium	733	Gn4.52	Wiesenboden
16. Mottled yellow and grey gradational soils	Tertiary sand and clay, alluvium	-	Gn4.55	Yellow podzolic soils
17. Yellow gradational soils, weak structure	Tertiary sand and clay	497, 741	Gn2.51, Gn1.41, Gn2.44	Yellow podzolic soils
18. Stony yellow gradational soils	Tertiary sandstone, gravel	-	Gn1.24, Gn2.21, Gn2.44	Lithosols
19. Red gradational soils, weak structure	Tertiary sand and clay	749	Gn2.11, Gn4.11	Red podzolic soils
20. Pale-brown gradational soils, weak structure	Tertiary sand and silt, plain remains	-	Gn2.84	Humic greys
21. Grey-brown gradational soils	Tertiary sand and clay	-	Gn4.52, Gn4.55	Yellow podzolic soils
22. Mottled yellow and red gradational soils with ironstone	Tertiary lateritized sand and clay	782	Gn3.94, Gn3.51	Lateritic podzolic soils
23. Mottled yellow and red gradational soils	Tertiary sand and clay	746	Gn3.94, Gn3.51, Gn3.54, Gn3.841	Lateritic podzolic soils
24. Yellow-brown gradational soils, coarse structure	Tertiary sand and clay, Cretaceous sediments	750	Gn3.54, Gn3.24, Gn4.71	Yellow podzolic soils
25. Brown calcareous gradational soils, coarse structure	Tertiary marl, limestone and calcareous clay	784	Gn2.21	Chernozems
26. Brown gradational soils	Cretaceous sandstone, mudstone and siltstone, Tertiary clay	414, 416, 748	Gn3.51, Gn3.91, Gn3.54	Brown podzolic soils
27. Brown friable gradational soils	Cretaceous sandstone, mudstone and siltstone	418, 736	Gn4.31	Brown podzolic soils
28 Dark-brown gradational soils	Cretaceous sandstone, mudstone and siltstone	428	Gn4.71	Brown podzolic soils
29. Stony brown gradational soils	Cretaceous sandstone, mudstone and siltstone	732	Gn2.41, Gn2.81	Lithosols

Soil	Parent Material	Sampled Profile No. (Appendix I)	Classification	
			Northcote (1974)	Stace <i>et al.</i> (1968)
30. Stony red gradational soils	Tertiary lateritized sand and clay	-	Gn2.11	Lithosols
31. Stony red-brown gradational soils	Quaternary basalt	-	Gn4.12	Lithosols
32. Red calcareous gradational soils	Tertiary limestone and marl, Quaternary calcarenite	489	Gc2.21	Terra rossa soils
33. Black calcareous gradational soils	Tertiary limestone and marl	-	Gc2.21	Redzinas
Soils with duplex profile forms				
34. Yellow sodic duplex soils	Tertiary sand and clay, alluvium	734	Dy5.33, Dy5.32, Dy5.43	Solodic soils
35. Red-yellow duplex soils	Tertiary sand, silt, clay and sandstone	-	Dy5.21, Dy5.31m Dy4.21	Red podzolic soils
36. Brown duplex soils	Cretaceous sandstone, mudstone and siltstone	424, 735	Db3.31, Db3.21, Db4.21	Yellow podzolic soils
37. Grey calcareous sodic duplex soils, coarse structure	Quaternary basalt	-	Db4.23	Solodic soils
38. Yellow-brown sodic duplex soils, coarse structure	Tertiary calcareous clays and marl	490, 743	Db4.23, Dy5.23	Solodic soils
39. Yellow-brown sodic duplex soils, coarse structure	Tertiary clay and sand, alluvium	606	Dy5.22, Db4.31, Db4.22	Solodic soils
40. Yellow-brown duplex soils, coarse structure	Tertiary clay, sand and sandstone	499	Db4.31, Dd4.22, Dy5.22, Dd4.21	Soloths
41. Brown duplex soils, coarse structure	Tertiary lateritized sand and clay	783	Db4.43, Db4.33	Solodic soils
42. Mottled yellow and red duplex soils	Tertiary clay and sand	492, 744	Dd4.41, Dy5.41, Dy5.31, Dy5.21, Db4.31	Lateritic podzolic soils
43. Mottled yellow and red duplex soils with ironstone	Tertiary lateritized sand and clay	601	Dy5.21, Dy5.31, Db4.21	Lateritic podzolic soils
Miscellaneous soils				
44. Grey sand soils, weakly structured clay underlay	Quaternary sand, Tertiary sand and clay	-	Uc4.1/Gn2.8	(polygenetic soils)
45. Grey sand soils, structured clay underlay	Quaternary sand, Tertiary clay and sand	737	Uc4.1/Gn3	(Polygenetic soils)
46. Grey sand soils, kaolinitic clay underlay	Quaternary sand, Tertiary clay	500	Uc4.1/Dy4.21, Dy4.21	(polygenetic soils)
47. Variable sodic duplex soils	Recent aeolian sand, Tertiary clay and sand	-	Db4.32, Db4.33	Solodic soils
48. Saline soils	Recent marine clay and silt, plant remains	-	-	Solonchaks

Physical and Chemical Analyses

A range of representative profiles was sampled for laboratory analysis. In an attempt to achieve a standard unmodified conditions, samples were taken from sites where the soils and native vegetation had had little disturbance, usually on Crown land. The results of the analyses and descriptions of the profiles are given in Appendices I and III respectively. Appendix II lists the laboratory techniques.

Particle Size Analysis

There is general agreement between particle size analyses and field textures. The main departures are in the surface horizons of many of the poorly drained sands, where high levels of organic matter impart a loamy or silty feel.

Fine-sand fractions generally exceed coarse-sand fractions except in the infertile Tertiary deposits to the east and west of the Range. Coastal dune sands are also dominated by the coarse fraction. Extreme changes in the coarse sand, or the fine-sand fraction down the profile, can indicate polygenesis. The soils developed on Cretaceous sandstones and mudstones tend to have high silt contents, and the lateritic profiles have the highest clay contents of the soils examined.

Soil Reaction

Many of the soils in the high-rainfall areas are sufficiently acidic to strongly restrict the availability of plant nutrients and to impede plant germination and growth. Some of the poorly drained sand soils have exceptionally low values (pH 4 or lower). Concrete and metal structures need to be heavily protected for durability in these areas.

High pH values are encountered in calcareous sands and in areas subject to soil salting in the northern and western parts of the study area.

Electrical Conductivity

Values in excess of 500 – 1,000 microsiemens per cm will reduce the growth of many plants and favour salt-tolerant species with values of about 12,000 microsiemens per cm and in the lower parts of the variable sodic duplex soils. Metal structures corrode rapidly in these areas.

Isolated patches of secondary soil salting occur in the drier parts of the study area on soils of low permeability or on areas receiving saline seepage and drainage.

High electrical conductivity in the subsoils of the Anglesea area indicates the sensitivity of this area to soil salting.

Organic Carbon and Nitrogen

Many of the soils have low organic carbon levels. Those with high levels have high carbon-nitrogen ratios, indicating strong competition between plant roots and micro-organisms for the available nitrogen.

Biological activity by micro-organisms tends to decrease the organic matter; they use the organic carbon to provide energy and release it as carbon dioxide. This activity depends on the soil environment. As the soils become wetter in high-rainfall areas and soil temperatures fall, the biological activity declines and organic matter levels increase. This trend can be observed in the general increase in organic carbon with elevation in the soils on Cretaceous sediments, from the brown duplex soils through brown gradational soils to the friable brown gradational soils.

The taller and more luxuriant vegetation on these last soils supplies plant litter at a higher rate for decay.

Other trends in organic matter can also be related to the soil environment. High water tables decrease the oxygen supply for soil microorganisms and lead to a build up of organic matter in poorly drained areas. High electrolyte concentration in the surface soil along the coast are presumed to restrict biological activity, resulting in high organic matter levels, particularly in soils on seaward-facing slopes.

Free Ferric Oxide

Some of the soils developed on lateritic profile remnants show extremely high values of free ferric oxide. Associated high levels of sesquioxide clays and ironstone combine with these to make the soils particularly prone to fixation of applied phosphate into complex insoluble compounds.

With the exception of the leached sands, the more acidic soils tend to have higher levels of free ferric oxide.

Phosphorus

Values of available phosphorus below 10 parts per million (ppm) are considered to be generally limited to plant growth. These apply in the surface horizons of many soils in the study area. Of particular note are the very low values for soils in the Bald Hills and surrounding areas near Anglesea. Soil developed on remnants of lateritic profiles are also very deficient in phosphorus.

Comparatively high values of available phosphorus are found in soils developed on Cretaceous sediments, particularly in the higher-rainfall areas. The reserves of phosphorus, as indicated by the hydrochloric acid extract, are generally higher than in the soils developed on surrounding Tertiary sediments.

The soils of the alluvial flats of the Gellibrand River that have been analysed have shown some exceptionally high values of available phosphorus.

Potassium

Potassium is present in the soil in soluble salts and as exchangeable cations on colloidal clays and organic complexes. Both forms are available to plants. It is generally considered that levels of available potassium below 200 ppm will limit plant growth. Again, many soils in the study area have values below this in the surface horizon.

Very low values of available potassium are found on leached sands on the eastern and western flanks of the Range. Soils developed on lateritic profile remnants also have very low values.

The soils developed on Cretaceous sediments are marginally deficient in the lower- and middle-rainfall areas, but available potassium is high in the wetter areas. Alluvial soils are also well supplied. Some of the highest values are found on the calcareous soils at Bellbrae and Princetown.

Exchangeable Cations

Exchangeable cations are generally available for plant growth and are a guide to fertility. High exchangeable sodium adversely affects soil structure and permeability. Most of the sand soils in the study area have very low cation exchange capacities, organic complexes in the surface horizons providing almost the entire source of colloidal particles. They are usually almost saturated with hydrogen ions.

Soils developed on lateritic profile remnants and those on Cretaceous sediments in high-rainfall areas are also virtually hydrogen-ion-saturated. Calcium is often limiting and this deficiency may be corrected by adding lime and raising the pH, the amount required being dependent on the cation exchange capacity.

5. NATIVE VEGETATION

The wettest areas of the Otway Range with fertile soils, the dry basaltic plains in the north and infertile sands to the east and west carry a wide diversity of vegetative communities. Tall open forest with trees almost 100 m high and closed forests with dense mesophytic understoreys in adjacent drainage lines are characteristic of the uncleared land around Beech Forest. *Eucalyptus regnans* abounds on these sites, but *E. obliqua* is the most common dominant stratum species found throughout the Otway Range and adjacent plains. Various stunted communities such as the open scrubs of *Leucopogon parviflorus* along the coast or the low woodland of *E. nitida* and *E. baxteri* on the acidic sands have developed where adverse environments prevail.

Field investigations have yielded data on the nature of the vegetative communities and their correlation with soils, site drainage, climate, aspect, geology and other features. The structural classification used is based on the height and crown cover of the dominant stratus (Specht 1970). The different species present in each structural formation are discussed below.

Closed Forest

These communities are dominated by trees with a crown cover greater than 70%. The dense foliage filters out most of the incident light, and understorey species are usually mesophytic shrubs or herbaceous creepers and ferns in a fairly open community.

***Nothofagus cunninghamii* and associated species.**

In the wetter parts of the Range and on the southern side of the major ridge, closed forests dominated by *N. cunninghamii* commonly colonize drainage lines and valley floors. These communities sometimes spread to sheltered middle and lower slopes in the wettest areas, preferring sites that are permanently moist with fertile soils. Tree heights are generally about 30 m, although some trees may have attained heights of 60 m (Parsons *et al* 1977).

Acacia melanoxylon is almost co-dominant and some pure strands are found along minor drainage lines in the Aire River catchment. *E. regnans* may also be present. The understorey tends to be open and contains ferns, staghorns, creepers and mesophytic shrubs.

***Leptospermum juniperinum* and associated species.**

Closed forests of *L. juniperinum* in the upper reaches of Redwater Creek catchment occupy sites that are almost permanently moist. Soils have low to moderate fertility and are highly acidic. Stands growth to about 15 m and are normally pure, although some colonization by *Melaleuca sparrosa* does occur. The understorey is usually sparse, but moisture-loving ferns such as *Blechnum nudum* are found. In adjacent areas, unusually tall stands of *L. juniperinum* continue as a second tree stratum below tall open forests of eucalypts.

Tall Open Forest

The dominant stratus of tall open forests comprises trees taller than 30 m with elongated interlacing crowns. A shrub layer of mesophytic species may or may not be present, but a continuous ground cover of ferns, creepers, grasses and herbs with copious litter is always present. The communities are found in areas highly favourable to plant growth.

***Eucalyptus regnans* and associated species**

E. regnans forms pure stands of tall open forests in those parts of the Range with an annual rainfall above 1,500 mm. Fertile, well drained soils are preferred. The heights of mature trees invariably exceed 30 m, and reports list some trees as being more than 100 m (Thornley 1974). Trees growing today in the Arkins Creek catchment and parts of the Calder River catchment certainly approach this height.



Tall open forest formation containing mainly E. regnans. This regrowth stand near Mount Cowley contains some old stags, manifesting the former height of some of the older forests.

Understorey species of *Acacia melanoxylon*, *Phebalium squameum*, *Bedfordia saliciana*, *Olearia argophylla*, *Hedycarya angustifolia* and many others. *Blechnum nudum* and *Microsorium diversifolium*, among other species, form a dense ground cover. *Dicksonia antarctica* and *Cyathea cunninghamii* are also very common, the latter occupying the moister sites.

Mixed stands are not uncommon, and combinations of *E. regnans* with *E. obliqua*, *E. cypellocarpa* and *E. viminalis* can all be found. Associations between *E. regnans* and *E. obliqua* exhibit widespread hybridization, these hybrids being locally known as 'Otway messmate'.

The occurrence of *E. regnans* growing on quartz sand in the Redwater Creek area is possibly unique. Here it is presumed to gain its nutrients through deep roots that penetrate below the layers of quartz sand into the more fertile weathering Cretaceous sandstones and mudstones. By extracting nutrients from this lower depth and returning them to the soil surface by leaf litter drop and decay, it probably performs an indispensable function in maintaining soil fertility at moderate levels – much higher than would otherwise be found on deposits of quartz sand.

Where weak hardpans have developed, leaching of these nutrients is impeded to some degree and the build-up in fertility levels has led to the invasion by shrubs such as *Bossiaea cinerea*, *Plutenaea muelleri* and *Acrotriche serrulata*. Elsewhere, however, where the sands are deeper and coarser, and where hardpans are not present, intense leaching in this high-rainfall environment remove most nutrients as quickly as they are released from the decaying organic matter. The density of *E. regnans* and other tall and fast-growing eucalypts on these sites is much reduced, and open forests of *E. baxteri* with occasional taller trees occur.

During the early years of settlement, clearing of these tall open forests for agriculture or purely for their timber was widespread. Many of the partially cleared areas have been allowed to regenerate to native vegetation. However, *E. regnans* needs full sunlight and no initial dominance in order to regenerate, and several communities of *A. melanoxylon* have become established in its place. It would require clear-felling or wildfire together with seeding to produce the original climax community.

***Eucalyptus cypellocarpa* and associated species**

More widespread through the Otway Range, and penetrating into lower-rainfall areas than *E. regnans*, are the tall open forests of *E. cypellocarpa*. This eucalypt is very common in the medium-rainfall parts of the Range. It is also widespread in some of the drier parts, where its presence delineates exposures of Lower Cretaceous sediments. (Exceptions to this occur near Hordern Vale and Moggs Creek, where presumably the Tertiary sediments are of higher fertility than normal). *E. cypellocarpa* shows a strong preference for freely drained soils of high or moderate fertility with moderate to high annual rainfalls. In the lower-rainfall range of its occurrence, it is confined to moister sites as drainage lines and southern aspects.

Tree heights occasionally exceed 60 m, particularly in the wetter areas. However, in the lower-rainfall parts of its distribution it often occurs in open forest formations. Understorey species include a wide range of mesophytic shrubs and small trees. Ferns and mosses are also abundant. Pure stands are found, such as along Grey River, but generally it grows in mixed stands with *E. obliqua*, *E. regnans*, *E. viminalis*, *E. globulus* and *E. ovata*. There is evidence of hybridization at certain sites between *E. cypellocarpa* and the last two species (Parsons, Kirkpatrick and Carr 1977).

***Eucalyptus globulus* and associated species**

The distribution of *E. globulus* in this part of Victoria has been closely studied (Kirkpatrick 1971). The species grows almost exclusively on soils derived from Cretaceous sediments in a narrow climatic range along the coastal sections of the Otway Range. Its only known occurrence on Tertiary sediments is in the Hordern Vale area just north of Rotten Point.

Its general ecological requirements in this study area are well-drained soils of high fertility, moderate high annual rainfalls, and a mild climate (essentially maritime in the study area). It should be noted that in the more inland frost-prone parts of the Otway Range, *E. globulus* is replaced by *E. cypellocarpa*.

Tree heights may occasionally exceed 50 m, but an average of 35 – 40 m is more normal. One some of the exposed site near the coast, salt pruning has stunted growth to an open forest or low open forest formation. It often occurs in pure stands, but in drainage lines and most other sites it usually shares dominance with *E. cypellocarpa*, *E. ovata*, *E. obliqua*, *Acacia melanoxylon* or, to a lesser extent any other of the many eucalypt species that occur in the study area.



Tall open forest, with moisture-loving species in the understorey and a continuous ground cover of ferns and creepers.

Kirkpatrick (1971) revealed that the whole population in the Otway Range is itself a cline between *E. globulus* subsp. *globulus* and *E. globulus* subsp. *pseudoglobulus*. Trees close to the coast are closely related to subsp. *globulus*, while those further inland possess variable characteristics often intermediate between the two subspecies. *E. globulus* is also known to hybridize with *E. cypellocarpa* in some areas (Parsons, Kirkpatrick and Carr 1977).

Understorey species are closely related to fire history. In coastal areas, it is common to find an open understorey with only occasional shrubs such as *Cassinia aculeata* and *Acacia verniciflua*. *Danthonia* spp. and *Stipa* spp. form a dense ground cover. In moister sites, particularly along drainage lines, mesophytic species invade the understorey and shade out these grasses.

Eucalyptus viminalis* and *E. obliqua

E. viminalis and *E. obliqua* often dominate tall open forest formations in the Otway Range and along the flood-plains of the Barwon and Gellibrand Rivers. It is interesting to note that *E. viminalis* is confined to the western parts of the Range despite the presence of similar sites in the eastern parts. Heights up to 40 m for both species are not uncommon. The main requirement for luxurious growth of *E. viminalis* appears to be a plentiful supply of moisture within rooting depth. In the Chapple Vale area, *E. viminalis* will colonize deep acidic sands immediately adjacent to alluvial flood-plains with a water table close to the surface. Higher up the landscape, *E. viminalis* quickly disappears as the depth to the water table through the sand increases.

Open Forest

Open forests cover a wide ecological range. Towards the wetter limit, they contain dense, tall mesophytic species in the understorey and the dominant stratum contains trees usually with a single main stem and well-developed interlacing crowns. Towards the drier limit, trees are lower and spreading, with sclerophyllous understoreys. Soil characteristics, exposure to coastal winds, aspect and fire history as well as annual rainfall determine the structure and floristics.

***Eucalyptus obliqua* and associated species**

E. obliqua is the most commonly encountered tree species in the study area. It occurs both in the high rainfall parts of the Range and in areas that receive only 600 mm of rainfall, such as the flat-topped hills just inland from Torquay. It is notably common on phosphate-fixing soils exhibiting lateritic weathering. In such areas *E. obliqua* normally dominates, but *E. baxteri* is common and the two species frequently hybridize. On heavier, coarse-structured soils in adjacent areas, *E. obliqua* is again either dominant or co-dominant, but commonly associated with *E. viminalis* and *E. ovata*. The only areas where *E. obliqua* is not found are on excessively drained sands and on heavy-textured poorly drained soils.



Open forests formation of E. obliqua and E. viminalis is one of the rare remnants of the Heytesbury forest.

***Eucalyptus baxteri* and associated species**

E. baxteri occurs in areas of moderate rainfall on soils developed from Tertiary sediments. It is widespread on the outcrops of Tertiary sediments to the west of the Otway Range, and also grows in the Moggs Creek and Anglesea areas and near Hordern Vale and Redwater Creek. Its occurrence is favoured by acidic soils of low natural fertility.

The absence of *E. baxteri* on soils developed from Cretaceous sediments suggests that it is unable to capitalize on these better growing conditions to the same extent as other eucalypts such as *E. obliqua*. A change in dominance from *E. obliqua* to *E. baxteri* in many parts of the study area is frequently associated with changes in soil properties – such as lightening of texture, poorer internal drainage or an increase in acidity. Development of hardpans in polygenetic soils in the northern parts of the Gellibrand River catchment creates a combination of all three.

Heights are generally around 18 m; rarely, trees reach 30 m on particularly favourable sites. Along the ridge to the west of the Gellibrand River near Carlisle River are found tall woodlands of *E. baxteri* and *E. obliqua*. Other eucalypts commonly occurring with *E. baxteri* are *E. radiata* and *E. viminalis*, although *E. obliqua* is the most common. Pure stands are found near Carlisle River, Ferguson Hill and Mount Mackenzie, usually in a woodland formation. Open woodlands and low woodlands also occur on poorly drained acidic sands with hardpans in the Chapple Vale area. Understorey species include *Spyridium parvifolium*, *Acacia verticillata*, *Leptospermum juniperinum*, *Platyllobium obtusangulum*, *Epacris impressa* and *Prostanthera lasianthos*.

***Eucalyptus ovata* and associated species**

E. ovata is also widespread, but its occurrence in any area is usually confined to either heavily textured, coarse-structured soils or low positions in the landscape that are frequently waterlogged. It grows on both acidic soils (near Paraparap) and on calcareous soils (near Princetown and Bellbrae).

Heights sometimes exceed 30 m in the higher-rainfall limits of its occurrence in the Otway Range, but most are closer to 20 m.

E. ovata is very rarely found in pure stands and is often the subordinate species in an association dominated by other eucalypts such as *E. viminalis* and *E. obliqua*. In very waterlogged drainage lines, however, pure stands do occur, often in a woodland formation (near Barongarook and Yeodene). Understorey species in these formations include *Melaleuca squarrosa*, *Leptospermum juniperinum* and other shrubs tolerant of poor drainage. Elsewhere, understorey species vary from site to site and are similar to those found under *E. obliqua* associations on hillslopes, while some mesophytic species occur in drainage lines.

***Eucalyptus aromaphloia* and associated species**

E. aromaphloia is found on the older terraces along the Gellibrand River, on exposures of Cretaceous sediments near Yahoo Creek and, occasionally, on some of the older soils on Tertiary sediments around the margins of the Otway Range. On these sites it is seen to prefer heavy-textured soils with poor drainage and moderate to high annual rainfall. Where free water frequently ponds at the surface, however, *E. aromaphloia* rarely occurs, other species such as *E. ovata* being more common.

Tree heights are normally 20 m, with a few specimens reaching more than 25 m. On the tablelands, inland from Anglesea, heights are considerably lower than 20 m, reflecting the low fertility of the soils there.

Understoreys consist of typical sclerophyllous shrubs such as *Acacia verticillata*, *A. mucronata*, *A. myrtifolia* and *Leptospermum juniperinum*. Other eucalypts commonly associated with *E. aromaphloia* are *E. obliqua*, *E. ovata* and *E. baxteri*.



On dry north- and west-facing slopes, sclerophyllous scrubs form open understoreys in open forests.

***Eucalyptus sideroxylon* and associated species**

Open forests of *E. sideroxylon* occur in the eastern section of the Otway Range and extend along the coastal plains as far as Bells Beach near Torquay. These environments range from north-facing slopes of Cretaceous sediments east of Lorne with shallow stony gradational soils to more sheltered valley floors and drainage lines inland from Point Addis. Thus at the higher-rainfall limits of distribution the driest sites are colonized, while at the lower-rainfall limits the species prefers moist sites.

Freely drained soils of low natural fertility are preferred, and many of the soils on which *E. sideroxylon* thrives are highly sodic. Seaward-facing slopes near Anglesea exposed to salt-laden coastal winds carry stunted communities including *E. sideroxylon*.

Heights of trees are generally around 20 m. Pure stands are most common, but associations between *E. sideroxylon*, *E. obliqua* and *E. baxteri* are common in fringe areas. East of Lorne, associations between *E. sideroxylon* and *E. globulus* are common with the former dominating the northern aspect and the latter dominating the southern.

Understoreys are usually quite open, with *Acacia verniciflua* common in the shrub stratum and *Poa* spp., *Danthonia* spp. and *Themeda australis* forming a ground cover.

***Eucalyptus pauciflora* and associated species**

E. pauciflora can be found at several sites in the Paraparap area, and was probably originally reasonably common. It occurs on phosphate-fixing duplex soils of low fertility with light-textured topsoils and moderate drainage. The average annual rainfall is about 650 mm.

One clump of trees south of Lake Modewarre suggests a former pure stand, but elsewhere the species grows in association with *E. ovata* and *E. viminalis*. Tree heights are around 20 m with a spreading habit. Understorey communities have become greatly modified, but *Banksia marginata* may have been common.

Low Open Forest

Under environmental stress, tree heights and crown cover are reduced. Low communities with a moderate crown cover (about 30%), where the dominant stratum consists of a species with an obvious main stem and little or no branching close to the ground, are classified as low open forests. The environmental stress is seldom related to strong competition between species. Factors such as highly calcareous soils, proneness to waterlogging, exposure to severe winds and salt spray are responsible for the reduced mature height. Factors related to competition, such as extremely low fertility or low moisture availability, seem to result in decreased crown cover as well as lower heights.

***Melaleuca lanceolata* and associated species**

M. lanceolata is most commonly encountered on coastal dunes, but is also colonizes the most exposed seaward-facing slopes of various Tertiary outcrops. Although it is frequently found on excessively drained soils, the particular environmental characteristics that give *M. lanceolata* and associated species their advantages over other colonists are their abilities to withstand intense salt pruning and to survive on highly calcareous soils.

Some trees in forest remnants to the east of Torquay reach 12 m, but average heights are around 6 m. On the most exposed sites, trees become almost prostrate, hugging the ground surface at less than 1 m and leaning sharply away from the direction of the salt-laden winds.

Other species commonly found in association with *M. lanceolata* and *Leucopogon parviflorus*, *Leptospermum laevigatum* and *Acacia longifolia*. In fringe area, *M. lanceolata* may share dominance with such species as *E. obliqua*, *Casuarina stricta* and *E. sideroxylon*. Understoreys are usually sparse, with large areas of leaf litter and bare ground. The understorey species that do grow vary considerably, but *Helichrysum paralium*, *Tetragonia tetragonoides* and *Spyridium parvifolium* are common.

Woodland

Woodlands have less than 30% crown cover and the trees are more spreading, with rounded crowns emanating from branching and typically crooked trunks. The branching occurs closer to the ground than in open forest formations. Understoreys are usually dense because of the higher light penetration through the more open crown, and consist of either sclerophyllous shrubs or native trees.

***Eucalyptus radiata* and associated species**

E. radiata woodlands are common on the foothills of the Range, where well-drained soils of low fertility have developed on Tertiary sediments. The acidic sands in the west, which suffer severe moisture stress in summer, are mainly colonized by *E. radiata* in association with *E. nitida*, *E. obliqua* and *E. baxteri*.

In many areas, *E. radiata* exists as a minor member of open forest associations, particularly those dominated by *E. obliqua*. It may attain heights of 20 m or more in open forests, but in woodland communities it seldom reaches more than 15 m. Understoreys are usually moderate dense and include *Leptospermum juniperinum*, *L. myrsinoides*, *Banksia marginata*, *Xanthorrhoea australis*, *Platylobium obtusangulum*, *Dillwynia glaberrima* and *Hakea ulicina*. In drier areas, *Acacia suaveolens*, *Epacris impressa* and *Leucopogon glacialis* become common.

***Eucalyptus camaldulensis* and associated species**

E. camaldulensis was formerly common in the northern drier parts of the study area, but most stands have been cleared for agriculture. It is confined to either basaltic plains or alluvial flats largely derived from basalt. It normally occupies poorly drained duplex soils with heavy clay subsoils, but is also observed in well-drained soils on river banks. It is not found in areas with annual rainfall above 650 mm, where other eucalypts such as *E. ovata* and *E. viminalis* become too competitive.

E. camaldulensis usually attains heights of about 20 m and has a spreading habit. Pure stands are most common, although at times *E. ovata* may occur in association with it, particularly on alluvial plains. Original understoreys probably consisted mainly of native grasses such as *Themeda australis*, *Danthonia* spp. and *Stipa* spp. Open woodland formations with dense grass ground cover were probably originally common around Winchelsea.

***Eucalyptus leucoxylon* and associated species**

In the north-eastern part of the study area, woodlands of *E. leucoxylon* were formerly common. Most of these areas have been cleared and the species is now confined to road reserves and occasional clumps in agricultural land, notably on slowly permeable heavy soils with coarse-structured subsoils with alkaline reaction trends. Annual rainfalls here are in the vicinity of 700 mm.

The tallest trees reach about 15 m and are found on the edges of Thompson Creek, but more stunted ones are normally encountered. *E. leucoxylon* appears to be very sensitive to salt spray and trees south of Thompson Creek several kilometres from the sea are severely salt-pruned. Understorey species include *Acacia pycnantha*, which is particularly common in the few remaining communities in road reserves. Associated species in the dominant stratum include *E. ovata* and *Casuarina stricta*, but it is likely that pure stands of *E. leucoxylon* were formerly common.



Woodlands typically contain trees with crooked trunks, which branch close to ground level.

Eucalyptus viminalis

Pure stands of *E. viminalis* in woodland formation are found on calcareous dunes at Cape Otway. The excessively drained soils of these areas contrast with those at other sites with taller stands of *E. viminalis*, where plentiful moisture seems to be required. A ground cover of native grasses with occasional shrubs such as *Bursaria spinosa* occupies the understorey.

Low Woodland

Low woodland communities occur on sites that experience fairly extreme environmental stress. The tree stratum consists of twisted, stunted and branching specimens exerting little or no shading effect on the understorey. Competition for light is not crucial, as other factors such as severe seasonal moisture stress, high acidity or alkalinity, or very low inherent soil fertility are the important ones to overcome for survival.

***Eucalyptus nitida* and associated species.**

E. nitida occurs widely in association with *E. radiata*; they hybridize often, so it is difficult to distinguish between them. However, at the environmental extreme of acidic excessively drained soils with extremely low fertility, *E. nitida* is dominant and may form pure stands. As such, it is widespread on the acidic sands of the Bald Hills, and in similar landscapes between Gellibrand and Chapple Vale. Other areas include Bunker Hill, the catchment area of Porcupine Creek and the foothills east of Forrest.

E. nitida tolerates a wide range of adverse environments. As well as colonizing excessively drained acidic sands, it also grows on sites where hardpans persist close to the surface. Severe waterlogging restricts growth during winter and spring on these sites, and then water stress further impedes survival during summer. Heavy-textured calcareous soils exposed to salt-bearing winds near Princetown also support *E. nitida*, and it is occasionally encountered on shallow stony gradational soils in the eastern part of the study area.

Trees usually reach only around 6 m and often lack a main stem. Taller trees have been observed, and in the Otway Range south of Bambra one stand of *E. nitida* – *E. radiata* hybrids reaches 15 m. Understoreys contain all those species previously listed with *E. radiata*, but *Leptospermum juniperinum* and *Xanthorrhoea australis* are particularly common. These associations between *E. nitida* and *E. radiata* occasionally contain *E. baxteri* on moister sites.

***Eucalyptus kitsoniana* and associated species**

Confined to only three recorded areas in Victoria, *E. kitsoniana* occupies swampy sites with moderately textured acidic soils near Cape Otway. Trees generally grow to about 9 m, but some achieve heights of up to 15 m. Pure stands are most common, although fringe areas possess associations of *E. baxteri*. The tall understoreys are thick impenetrable strands of *Melaleuca ericifolia*, which also seems to be confined to these communities in this part of Victoria.

***Casuarina littoralis* and associated species**

C. littoralis occupies widely different environments in the study area. As a tree in low woodland formations it grows on dry steep slopes with shallow infertile soils near Moggs Creek. It also occurs in similar formations near Paraparap, although its occurrence there has probably increased since settlement.

Tree heights are around 8 m, and understorey specimens include *Hakea ulicina*, *Leucopogon glacialis* and *Isopogon ceratophyllus*. Associated species are quite variable, the most notable being *C. stricta* and *E. nitida*. *C. littoralis* is also a common member of the closed scrub formations found on the black acidic sands in parts of the Gellibrand catchment. Its habit here is quite different, as the trees spread into a number of main erect stems close to the ground and rarely grow higher than 4 m.

Other Species

Eucalyptus obliqua, *E. baxteri* and even *E. ovata* have also been observed to grow in low woodland formations. Of some interest are the low woodlands of *E. gonioclayx* in the study area at sites just north of the Anglesea coal mine and near Demons Bluff.

Closed Scrub

Closed scrubs in the study area consist of dense communities of branching, erect, moisture-loving species. Restrictions to plant growth come from a permanently high water table, and sometimes high acidity. Competition for light is strong, and only a few species such as mosses and ferns exist beneath the canopy.

***Melaleuca squarrosa* and associated species**

M. squarrosa is common in all the wetter sites on Tertiary sediments, and is most common in the Gellibrand River catchment to the west of the Otway Range. It occupies wet sites with black acidic sand soils. The nutrient status is often high, except for strong deficiencies of calcium.

These communities grow to about 4 m. Pure stands are rare, and associated species include *Leptospermum juniperinum*, *Casuarina littoralis*, *Gleichenia circinnata* and *Bauera rubioides*. *L. juniperinum* is suppressed on the wetter sites, while hillside swamps prone to occasional drying out have closed heath formations containing some of the above species but also *Sprengelia incarnata*, *Xanthorrhoea australis* and *Aotus ericoides*.

***Leptospermum lanigerum* and associated species**

More localized than the *M. squarrosa* associations are the occurrence of *L. lanigerum*, found in wet, broad drainage lines in three areas – Princetown, Hordern Vale and the Bald Hills. The soils are heavily textured with the water table at the surface for much of the year. Tree heights are between 4 and 6 m. Pure stands are most common although *L. juniperinum* and *E. ovata* may be present.



Like sentinels on perpetual guard, the flowering stems of Xanthorrhoea australis dominate the understorey of this low woodland of E. nitida.

Open Scrub

On exposed coastal sites, salt pruning of the vegetation severely restricts growth and the range of species. Trees and shrubs that do survive are often twisted and branch close to the ground. They usually lean strongly away from the direction of prevailing winds, forming a salt-planed surface due to successive dieback on the windward side. Many species such as *Eucalyptus obliqua*, *E. nitida*, *E. sideroxylon* and *E. baxteri* persist right to the edge of coastal cliffs or the base of sand dunes, but the habit of the trees differs markedly from that normally exhibited further inland.

The more open communities caused by dieback permit the invasion of many other salt-spray-tolerant species not normally found in associations, such as *Melaleuca lanceolata*, *Casuarina stricta*, *Leucopogon parviflorus* and a richly diverse heath stratum. These vegetative communities are sensitive to disturbance and difficult to re-establish in these harsh environments. Care is needed in management of these areas.

Coastal dunes have various associations of species adapted to living on calcareous, infertile excessively drained sands. Of those in the study area, the most common dominant species is *Leucopogon parviflorus*, but others are *Helichrysum*

paralium, *Alyxia buxifolia*, *Melaleuca lanceolata* and *Leptospermum laevigatum*. These form stunted salt-pruned open scrubs and open heaths on the leeward side of the primary dune and on most secondary dunes. Communities are generally around 3 m in height, although some species may achieve heights of up to 10 m in sheltered areas. Understoreys are usually very open with large areas of bare ground, the most common species being *Tetragonia tetragonoides*.



Salt-pruned open scrubs are often very sensitive to disturbance

Low Shrubland

Low shrublands occur in extremely adverse environmental conditions. Crown cover is sparse, usually below 30%, and plants are generally below 2 m in height with semi-succulent leaves.

The estuarine swamps near Breamlea and in other isolated parts of the coastline support communities of *Arthrocnemum arbusculum*, often in pure stands. The height of the community depends on microrelief and hence on the elevation above mean tide level, with the tallest communities reaching 2 m. *Samolus repens* and *Frankenia pauciflora* become more common on lower parts of the swamp. Inland, where the waters are less saline, *Gahnia filum* becomes dominant.

Grasslands and Herbfields

Grasses and halophytic plants less than about 1 m in height form various grasslands or herblands. Individual plants are often in such close contact that their canopies interlace. Conditions – such as shifting sands subject to salt spray and high-velocity sand-laden winds, high water tables or soils prone to excessive shrinking and swelling – are unfavourable for the growth of woody plants.

Swampy depressions on the basalt plains support sedgeland communities containing *Juncus* spp., *Ranunculus* spp. and others. The heavy clay soils are strongly alkaline, only rarely dry out and are strongly gleyed right to the surface. Anaerobic conditions presumably restrict the root development necessary for colonization by larger vegetation. Leeper, Nicholls and Wadham (1936) studied these communities in some detail, but now little remains of them because of levelling of paddocks, draining of larger swamps and pasture improvement.

Spinifex hirsutus is confined to shifting coastal dunes, where it has the ability to survive and actively grow on excessively drained infertile sands regularly blasted by sand and salt spray. Spreading by rhizomes, it quickly colonizes recent sand accretions to the dunes. However it is susceptible to damage by trampling, the roots breaking easily under the loose sand, and many areas have become devoid of this valuable stabilizing species. The stability of coastal dunes has been maintained by hand planting of the vegetatively propagated *Ammophila arenaria*, introduced to Australia from Western Europe. Other primary colonists of these unstable dunes are *Tetragonia tetragonoides* and *Carpobrotus rossii*.

6. LAND USE

Tow major periods of settlement occurred in and around the Otway Range in the 19th Century. In the 1840s, squatters realized the grazing potential of the plains west of Geelong, and large holdings of 8,000 – 10,000 ha were established (Thornley 1974). Within a decade most of the land had been taken up. The Otway Range, however, continued to remain a remote area, where the only two settlements, at Apollo Bay and Loutit Bay, depended mainly on ships for supplies.

Towards the end of the gold rush era in the 1860s and 1870s, men leaving the diggings created a strong demand for land. With most of the land on the plains locked up by squatters, the selectors were forced to other areas. In the 1870s and 1880s, vast areas of the Otway forests were opened up for selection (Thornley 1974).

Many of the selectors faced enormous problems. Most of them bought blocks site-unseen, and when they arrived at their selection they were confronted with impenetrable forest, non-existent transport and often extremely steep slopes. A promised railway did not eventuate until 1902. After 1980, the Crown started to resume blocks of land that were unoccupied and these were subsequently permanently reserved for forest production.

At the beginning of the 20th Century, transport services in the Otways improved dramatically. This allowed agricultural industries such as dairying and potato-growing to develop, and resulted in a boom in timber production. Some of the less productive farms were abandoned by farmers joining the timer industry, and in 1930 the Forests Commission purchased much of the abandoned farmland in the Aire valley and planted it to softwoods.



Beef cattle grazing on recently cleared land in the Heytesbury Settlement area.

The most recent major development was initiated in 1956 when the Rural Finance and Settlement Commission (then the Soldier Settlement Commission) began to clear 50,000 ha of the Heytesbury forest to be developed as dairy farms.

The main forms of land use at present depend in part on the history of settlement, but more importantly on the nature of the land. The steep hills of the Otway Range are mainly used for forestry, water supply, nature conservation and recreation. The adjacent plains and some flatter areas on top of the Range mainly support agriculture. The coastal areas cater for recreation and residential subdivision. Minor areas throughout the study area are used for the extraction of minerals, service easements, refuse disposal and water storage.

Agriculture

Well over half the farms in the study area are dairy farms, particularly in the higher-rainfall districts. Milk is sold both for manufacturing and as whole milk for the large residential populations of Colac and Geelong. Supplementary feeding is practised – generally with hay and silage, but fodder crops of oats, rape, turnip and millet are also grown. Pastures are based on perennial grass-legume mixtures. The main grass species are *Lolium perenne*, *Dactylis glomerata*, *Phalaris tuberosa* and *Festuca arundinacea* cv. Demeter, while the main legumes are *Trifolium repens*, *T. pratense* and *T. subteraneum* (see Table 4). Most farms rely on natural rainfall to maintain vigorous pasture growth, but some of those along the Gellibrand River do supplement summer growth by irrigation. Some dairy-farmers run a sideline beef enterprise to supplement their income.

Sheep and beef cattle grazing are normally combined, as these enterprises tend to make the best use of pastures. Sheep are grown for both wool and prime lamb production. Wool growing is the main industry in the drier northern areas on the basalt plains, while the prime lamb industry is concentrated in the medium-rainfall belt north of the Otway Range. Some of the farms on the steep hill country in and around the Range are primarily beef producers. In the high-rainfall country, breeding cows produce calves that are sold as veal. Further north, beef production relies on the calves being kept until one and a half to two years of age and sold as mature beef. Fodder conservation is practised on most farms.

The Victorian Department of Agriculture has recommended fertilizer requirements and pasture species for different areas. As a rule, phosphorus, potassium and molybdenum are necessary for vigorous pasture growth. Nitrogen is also lacking, but the inclusion of legumes in pasture mixtures has overcome the need to apply nitrogen fertilizers. Although copper in soils is at a sufficiently high level for plant growth, it is often not sufficient for animal nutrition and is included in fertilizer recommendations. Lime is required for pasture establishment on the highly acidic soils and is mainly applied with the superphosphate at sowing time or as lime-coating on inoculated clover seed.



The high rainfall, cool climate and free-draining soils are highly regarded for their capacity to produce seed potatoes.

Both the highest-rainfall areas at Beech Forest and the middle- and lower-rainfall areas to the north and east of the Otway Range support cropping. Potatoes are grown at Beech Forest, where the isolation, soils and climate confer decided advantages for the production of disease-free tubers. Pears are grown near Winchelsea, Deans Marsh and Birregurra on a contract basis for frozen-food companies. The area sown to oilseed crops such as rape, linseed, sunflowers and mustard increases each year with large enterprises around Birregurra.

Forestry

Hardwood forestry. The Forest Commission manages large areas of reserved forest in the Otway Range for hardwood production. Some additional hardwood supplies come from the clearing of privately owned land during pine conversion operations. The tall open forests supply the best timber, preferred species being *Eucalyptus regnans*, *E. obliqua*, *E. cypellocarpa* and *E. globulus*. Sawlogs are used for general construction purposes such as house-framing, while pulpwood is used for the production of paper and hardwood. Growth rates are high. The drier parts of the Range and the surrounding foothills support slower-growing open forests of *E. obliqua*, *E. viminalis*, *E. baxteri*, *E. cypellocarpa*, *E. globulus*, *E. sideroxylon* and *E. ovata*. Sawlogs and pulpwood are the main products. Harvesting of *E. baxteri* and *Leptospermum juniperinum* saplings for ‘tea tree’ stakes is a minor industry. The infertile sands on the eastern and western sides of the Range support low open forests suitable only for use as fuel.

Softwood forestry. The Forests Commission manages softwood plantations in the Aire valley and at Webster Hill, Boonah and Forrest. *Pinus radiata* is the main species planted, although significant areas carry *P. laricio*, *Pseudotsuga menziesii* and *Picea sitchensis* in the Aire valley. Harvested timber supplies both sawlogs and pulpwood.

Private softwood companies operate mainly on disused farmland. Collectively, they control a more extensive area for present and future plantings of softwoods than government-owned plantations. Their operations are located throughout the Otway Range, mainly on the steep hills and upper gentle slopes of the Cretaceous sediments and, less commonly, on the outlying foothills of the Tertiary sediments.



Softwood plantations are being established by private companies on both disused farmland and privately owned forested land.

Water Supply

Different parts of the study area vary in their potential water supply catchments, as shown in Figure 5. At Beech Forest, in the middle of the Otway Range, the excess of precipitation over potential evapotranspiration is far greater than at any other site. Here groundwater stored during winter can continue to supply creeks during the summer, thus maintaining flow. In other areas, only major rivers that lie deep in the landscape at levels below the regional water table continue to flow during the summer, but at a much reduced rate.

Many towns draw supplies of water from the Range for domestic and industrial uses. The Upper Barwon dam at Forrest contributes to Geelong's water supply, with additional reserves being tapped when needed from several north-flowing creeks to the east of the dam. Birregurra, Winchelsea, Forrest, Anglesea, Torquay and settlements on the Bellarine Peninsula also derive their water from this Geelong Waterworks Trust system.

The Gellibrand catchment is another major source of domestic water. Colac is supplied from dams on the West Gellibrand River and Oolangolah River, while Warrnambool, Cobden, Camperdown, Terang and several other towns are supplied from offtake on Arkins Creek and on the middle reaches of the Gellibrand River.

The townships of Lorne, Apollo Bay, Skenes Creek and Wye River derive their water from creeks and rivers on the southern side of the main ridge. Only Lorne has a supply that includes a reservoir.

Water quality from these supply systems varies. The water in the Gellibrand River is discoloured and turbid and will eventually require expensive treatment as usage increases. The black sand soils in many of the drainage lines in the middle and lower reaches of the catchment impart organic stains to the water. Thus the high organic content of these soils, although it helps to mains perennial flow, also imparts undesirable colour.



Contour ripping and planting has recently been tried in some pine conversion programs on an experimental basis in an effort to reduce surface run-off and associated erosion.

Nature Conservation

Some areas of land provide habitats for rare and endangered species. For example the hills west of Chapple Vale provide one of the few nesting sites for the rare ground parrot, *Pezoporus wallicus*, and the sheltered gullies of the Parker River catchment from the major habitat for Victoria's endemic tree fern, *Cyathea marcescens* (Land Conservation Council 1976).

Other areas have been reserved as parks where people can enjoy the spiritual wealth of the natural environment. Closely related areas with landscape conservation values have scenery of exceptionally high standard. The study area contains large park reserves at Lorne and Aireys Inlet. Smaller flora and fauna reserves exist at localities such as Bambra, Anglesea and Gellibrand.



The Oolangolah Weir supplies good-quality water to Colac.



The coastal margins of the study area provide many exceptional views

Table 4 – Agricultural Land Uses, Pasture Species and Fertilizer requirements of the Land System

Land Systems	Annual Rainfall	Major Soils	Main Agricultural Land Uses	Pasture Species	Fertilizer Requirements	Main Weeds
Aire, Beech Forest, Mount Sabine, Forrest, Lorne, Yahoo Creek	1,000 – 2,000 mm	Brown gradational soils; brown friable gradational soils; dark-brown gradational soils; brown duplex soils.	Dairying, grazing, potato cropping	<i>Lolium perenne</i> <i>Dactylis glomerata</i> <i>Trifolium repens</i> <i>Festuca arundinacea</i> cv. Demeter	Superphosphate, potash, lime, copper molybdenum	<i>Pteridium esculentum</i> , <i>Senecia jacobaea</i> , <i>Rubus</i> spp.
Chapple Vale, Carlisle, Yeodene, Ferguson Hill, Porcupine Creek, Barongarook	750 – 1,200 mm	Grey sand soils, uniform texture; grey sand soils with hardpan, uniform texture; black sand soils, uniform texture; grey sand soils, structured clay underlay; grey sand soils, weakly structured clay underlay.	Grazing, dairying	<i>L. perenne</i> <i>Phasmar tuberosa</i> <i>D. glomerata</i> <i>F. arundinacea</i> cv. Demeter <i>T. subterraneum</i> <i>T. repens</i> <i>T. fragiferum</i>	Superphosphate, potash, lime, copper, molybdenum (heavy rates required for establishment and maintenance)	<i>P. esculentum</i> , <i>Agrostis</i> spp.
Ferguson Hill, Mount Mackenzie, Hordern Vale	1,000 – 1,200 mm	Red sandy loam soils, uniform texture; yellow gradational soils, weak structure; red gradational soils, weak structure	Grazing, dairying	<i>L. perenne</i> <i>D. glomerata</i> <i>P. tuberosa</i> <i>F. arundinacea</i> cv Demeter Mainly <i>T. subterraneum</i> but also <i>T. fragiferum</i> and <i>T. repens</i>	Superphosphate, possibly potash, copper, molybdenum	<i>P. esculentum</i>
Cape Otway	900 – 1,100 mm	Brown calcareous sand soils, uniform texture; red-yellow calcareous sand soils, uniform texture	Grazing	<i>P. tuberosa</i> <i>D. glomerata</i> <i>L. perenne</i> <i>T. subterraneum</i> <i>T. incarnatum</i> <i>Medicago sativa</i>	Superphosphate, potash, copper, molybdenum	
Kennedys Creek, Simpson, Tomahawk Creek, Waare Barongarook, Kawarren, Carlisle, Hordern Vale, Mount Mackenzie, Wonga	750 – 1,100 mm	Yellow-brown gradational soils, coarse structure; brown calcareous gradational soils, coarse structure; mottled yellow, red gradational soils; mottled yellow, red gradational soils with ironstone; mottled yellow, grey gradational soils	Dairying, grazing	<i>L. perenne</i> <i>D. glomerata</i> <i>F. arundinacea</i> cv Demeter <i>P. tuberosa</i> <i>T. repens</i> <i>T. subterraneum</i> <i>T. fragiferum</i>	Superphosphate, potash, copper, molybdenum	<i>R. esculentum</i> <i>Rubus</i> spp.

Land Systems	Annual Rainfall	Major Soils	Main Agricultural Land Uses	Pasture Species	Fertilizer Requirements	Main Weeds
Deepdene, Faraparap, Pennyroyal, Barragool, Bellbrae, Thompson Creek, Freshwater Creek, Birreguarrra	600 – 750 mm (some area up to 1,000 mm)	Mottled yellow, red duplex soils; mottled yellow, red duplex soils with ironstone; yellow-brown duplex soils, coarse structure; yellow brown sodic duplex soils, coarse structure; yellow sodic duplex soils; yellow-brown calcareous sodic duplex soils, coarse structure; grey calcareous sodic duplex soils, coarse structure.	Grazing, dairying, vegetable cropping, oilseed cropping	<i>L. perenne</i> <i>D. glomerata</i> <i>P. tuberosa</i> <i>F. arundinacea</i> cv. Demeter <i>T. subterraneum</i> <i>T. repens</i> <i>T. fragiferum</i>	Superphosphate, potash, copper, molybdenum	<i>Agrostis</i> spp
Mooleric, Winchelsea	550 – 650 mm	Black calcareous clay soils, uniform texture; grey calcareous sodic clay soils, uniform texture; yellow-brown calcareous sodic duplex soils, coarse structure; grey calcareous sodic duplex soils, coarse structure; stony red-brown gradational soils.	Grazing; cereal and oilseed cropping	<i>L. perenne</i> <i>P. tuberosa</i> <i>F. arundinacea</i> cv. Demeter <i>T. subterraneum</i> <i>T. fragiferum</i>	Superphosphate	<i>Silybum marianum</i> <i>Cirsium vulgare</i> <i>Carduus terniflorus</i>
Barwon River, Gellibrand River, other drainage lines and alluvial flats	600 – 1,000 mm	Brown sand loam soils, uniform texture; brown gradational soils, weak structure; grey gradational soils.	Dairying	<i>L. perenne</i> <i>P. tuberosa</i> <i>F. arundinacea</i> cv. Demeter <i>T. subterraneum</i> <i>T. fragiferum</i>	Superphosphate	<i>Agrostis</i> spp. <i>Juncus</i> spp. <i>Carex</i> spp.
Gherang Gherang, Anglesea	600 – 800 mm	Mottled yellow, red duplex soils with ironstone; yellow-brown duplex soils, coarse structure, yellow-brown sodic duplex soils, coarse structure; mottled yellow, red gradational soils.	Grazing	<i>D. glomerata</i> <i>L. perenne</i> <i>F. arundinacea</i> cv. Demeter <i>P. tuberosa</i> <i>T. subterraneum</i>	Superphosphate, potash, copper, molybdenum	<i>P. esculentum</i>

Source: D. Conley, Department of Agriculture, Colac



Cost cutting development methods in sensitive coastal areas threaten to destroy the natural landscape that prospective owners of holiday homes seek to capture.

Recreation

Recreational pursuits include bushwalking, camping, picnicking, pleasure driving, fishing, water sports, all-terrain vehicle driving. The last category is often incompatible with other pursuits and can cause severe damage to tracks and vegetation, with resulting soil deterioration. It may involve trail bikes, dune buggies and four-wheel-drive vehicles.

The most popular recreational areas are along the coast, particularly the eastern parts, which are closer to the population centres of Geelong and Melbourne. However, people use the whole of the Otway Range in a variety of pursuits. The plains to the north also provide for picnickers and pleasure drivers.

Residential Uses

The larger towns are Anglesea, Lorne, Torquay, Winchelsea, Birregurra, Forrest, Apollo Bay and Simpson. Some of these have large transient populations during the holiday season. However, holiday homes are not confined to townships; any are built along the coastal strip from Apollo Bay to Breamlea, with particular concentrations between Lorne and Aireys Inlet. Because of the scattered nature of these communities, normal services such as reticulated water, sewerage, roading and fire protection are not adequately supplied.

Extractive Industries

Many of the Tertiary deposits of sand and gravel on the western and eastern flanks of the Otway Range have been developed as extraction sites. The material is mainly used for road construction, although some deposits have been tested and used for glass-making. Other sources of gravel come from colluvial lateritic ironstone. Many disused pits have not been properly reclaimed, and remain as scars on the landscape. The compacted sand in many pits have been deeply scoured by run-off waters, which had led to siltation problems elsewhere.

Coal reserves at Anglesea are at present being mined by open cut. A former mine also exists at Wensleydale, and reserves have been located at Benwerrin, Deans Marsh and Kawarren (Land Conservation Council 1976).

Other extractive industries include the mining of bentonite just south of Gellibrand, calcarenite near Princetown and Cretaceous sandstone at Lorne.



Large extraction pits are common in the unconsolidated Tertiary sands and gravels.

7. LAND SYSTEMS

Land systems are areas of land each with a characteristic pattern of the environmental variables climate, geology, topography, soil and vegetation.

They comprise land components, within which these five variables have uniform values within narrow limits. Changes in the dependent variables of soil and native vegetation usually distinguish land component boundaries. The different land systems are distinguished by a change in the pattern or nature of the land components, usually accompanied by a major change in one or more of the independent variable such as geology and topographic pattern.

The land systems of the study area have been delineated by a combination of aerial photo interpretation and field examination. Black and white aerial photographs at a scale of 1:80,000 were examined stereoscopically to reveal geomorphic patterns. Each area was examined in the field to check the accuracy of the aerial photo interpretation and to collect data on the nature of the soils, the native vegetation, the angle and shape of slopes and the nature of the parent material. With the addition of climatic data, correlations were made to draw up a full representation of each land system. Representative sites were chosen for each of the most commonly occurring land components to examine in detail the nature of the soils, the structure and floristics of the associated native vegetation, and their interrelations with other variables.

The 43 land systems recognized in the study area range in size from 8 sq km to 762 sq km. Some of the smaller ones near the edge of the study area are widespread in adjacent regions.



Aerial photo show land systems near the junction of the Gellibrand and Carlisle Rivers

This air photograph is Crown Copyright and has been reproduced by courtesy of the Director, Division of National Mapping, Department of National Development, Canberra.



Dendritic drainage patterns are a typical feature of the Otway land system.

Tabular Descriptions

Data collected on each land system are presented in tabular form.

Components are allotted numbers to aid in identification. Representative parts of each land system have been mapped on photomosaics at a scale of approximately 1:15,000 to measure the areas of the individual components. These areas have

been extrapolated to give an estimation of the relative proportions of each component. For land systems near the edge of the study area, these proportions may not be relevant to adjacent areas. Components of minor occurrence are listed in Appendix IV.

Bureau of Meteorology data show the annual rainfall for each land system, including the range from its driest to its wettest parts. The wettest month and the driest month, with the average precipitations received then, are also given.

Temperature data refers to average daily value and not to extreme maximums and minimums. The annual range on a monthly basis lists the average temperature for July (coldest month) and February (hottest month).

Major climatic limitations to plant growth are listed in Chapter 2. Restrictions to potential plant growth occur to varying extents in winter, due to low temperatures, and in summer, due to lack of available water. It should be noted that soil moisture storage extends the growing season beyond the point where potential evapotranspiration exceeds precipitation.

Local relief is a measure of the average change in elevation from the top of a hill or ridge to the nearest drainage line within the land system. Aerial photographs and large-scale topographic maps have been used to determine drainage patterns (Thornbury 1969) and their density.

The native vegetation has been classified according to the structure of the dominant stratum (Specht 1970). The species commonly found in the dominant stratum are listed in their normal order of abundance.

A five-class system has been used for the estimation of permeability based on profile characteristics such as porosity and texture. The estimate refers to the vertical hydraulic conductivity of the solum, which is limited by the least-permeable horizon. Sands with no compacted layers have very high permeabilities while clays, with few pores or cracks, have very low ones. Soil depth refers to the distance below the surface to solid rock or to a cemented layers that severely restricts root penetration and water movement.

The main existing land uses have been listed. Active recreation includes the use of vehicles such as trail bikes, dune buggies and four-wheel drive vehicles. Passive recreation refers to less potentially destructive pursuits such as picnicking, camping and bushwalking.

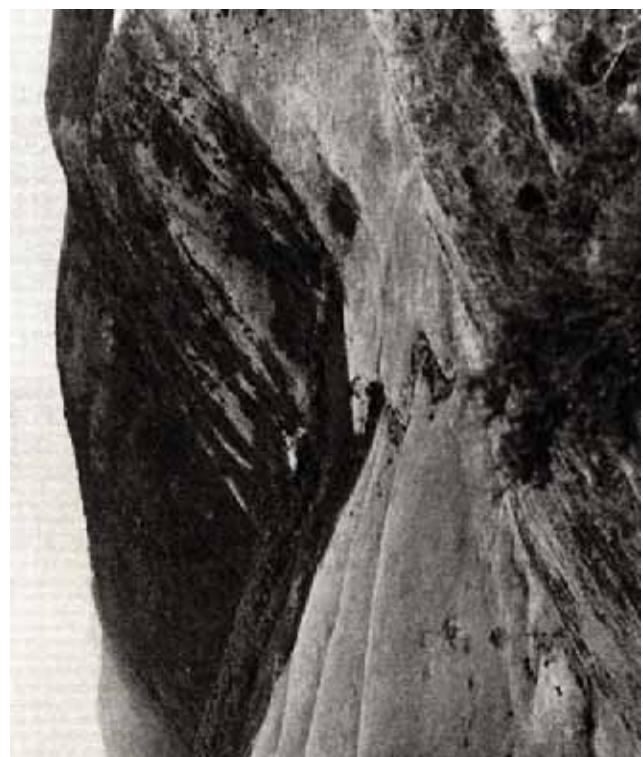
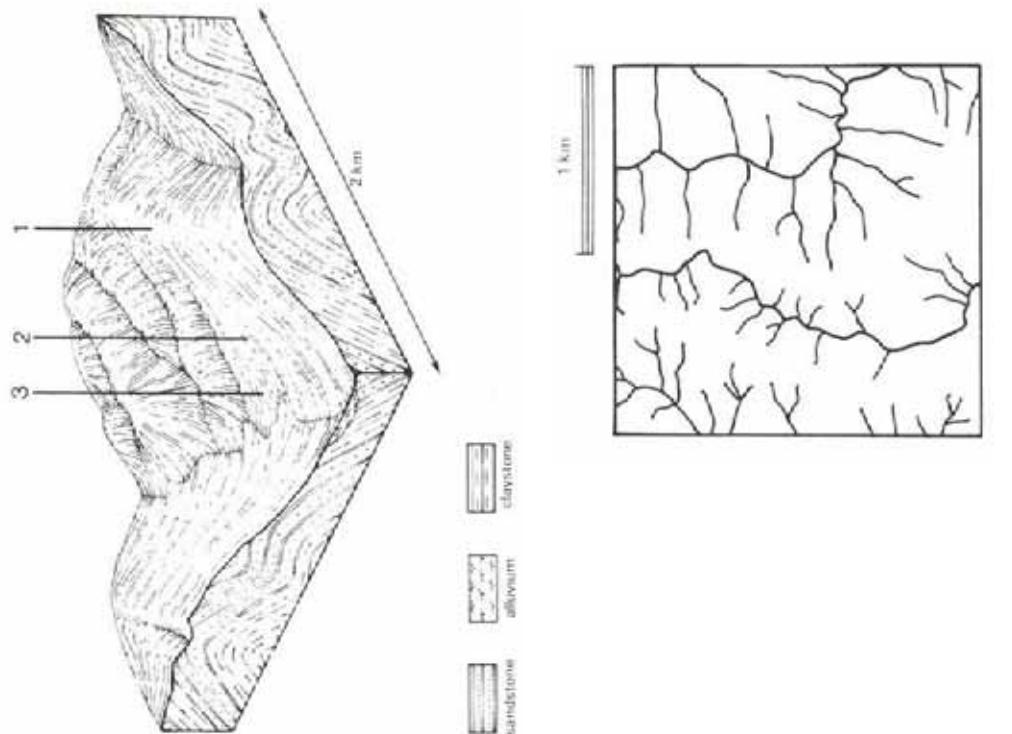
The forms of soil deterioration found to occur in each component, the critical features of the landscape and the processes leading to these forms of soil deterioration are outlined.

7.1 Aire Land System

The steeply dissected spurs and ridges in the wetter parts of the Otway Range comprise the Aire Land System, the largest land system in the study area. Rapid downcutting of streams following uplift of the Range has been responsible for forming this rugged landscape, with many slopes more than 60% and cliffs and bluffs in the central part north of Apollo Bay.

The soils are young and moderately fertile. Tall open forests of Eucalyptus regnans reach heights approaching 100 m in the Calder River catchment, but most of the tallest trees have now been milled. *E. obliqua* and *E. cypellocarpa* are also common, while *E. viminalis* occurs in the west and *E. globulus* is found close to the coast.

Pine forests cover large areas of this land system and other parts have been cleared for agriculture. The main hazards to land use are landslips and sheet erosion. Losses in organic matter and soil structure are often apparent following clearing.



Some areas of the Aire land system have been cleared for agriculture, but the terrain is difficult to manage and many areas have become covered in bracken an non-productive scrub.

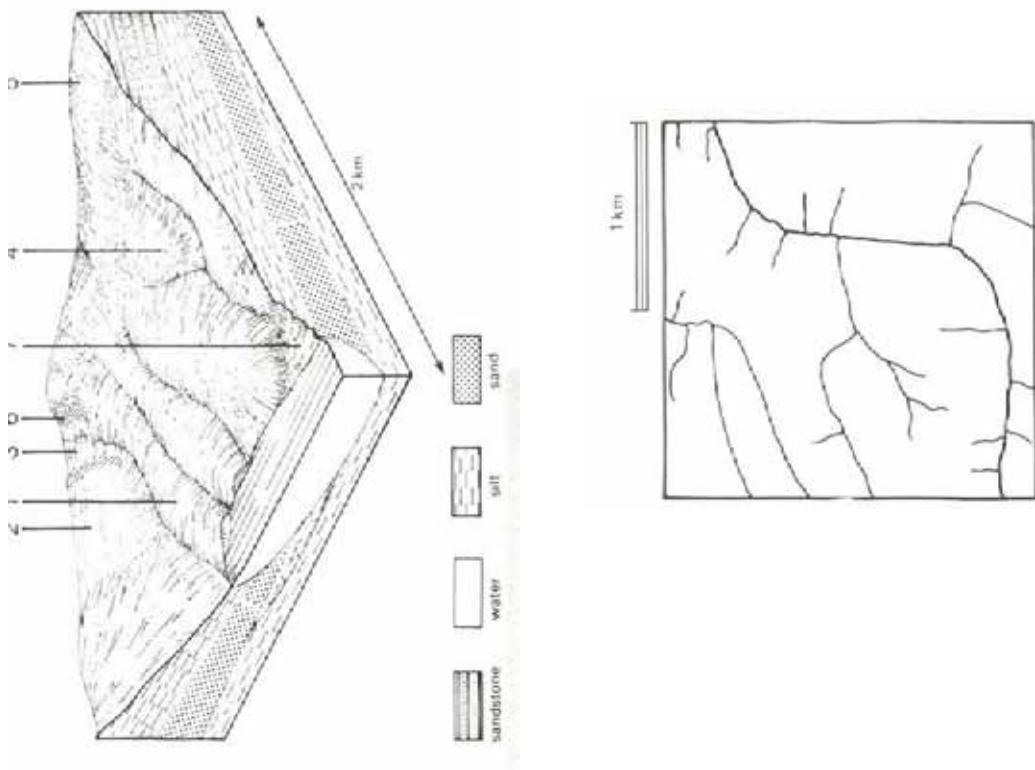
AIRE		Component and its proportion of land system		
		1 10%	2 80%	3 10%
CLIMATE				
Rainfall, mm	Annual: 1,100 – 1,750, lowest January (60), highest August (170)			
Temperature, °C	Annual: 11, lowest July (7), highest February (16)			
Seasonal growth limitations	Temperature: less than 10°C (av.) May – September			
GEOLOGY	Precipitation: less than potential evapotranspiration December – February			
Age, lithology		Lower Cretaceous feldspathic sandstone and mudstone		
TOPOGRAPHY		Deeply dissected hills of the Otway Range		
Landscape		90 – 560		
Elevation, m		165		
Local relief, m		Trellis pattern with isolated radial areas		
Drainage pattern		4.7		
Drainage density, km/km ²		Hill		
Land form		Upper and middle slope		
Land form element		20 (5-80)		
Slope (and range), %		25 (5-40)		
Slope shape		Concave		
NATIVE VEGETATION		Upper and middle slope		
Structure		Linear		
Dominant species		Tall open forest		
		<i>E. regnans</i> , <i>E. cypellocarpa</i> , <i>E. obliqua</i> , <i>E. ovata</i> , <i>E. globulus</i> , <i>E. viminalis</i> , <i>Acacia melanoxylon</i>		
SOIL		<i>E. viminalis</i> , <i>E. globulus</i>		
Parent material		Tall open forest		
Description		<i>E. regnans</i> , <i>E. cypellocarpa</i> , <i>E. obliqua</i> , <i>E. ovata</i> , <i>E. globulus</i> , <i>E. viminalis</i> , <i>Acacia melanoxylon</i>		
Surface texture		Alluvium and colluvium		
Permeability		Dark brown gradational soils		
Depth, m		Loam		
		Moderate		
		High		
		>2		
LAND USE		In-situ weathered rock		
		Brown gradational soils		
		Loam		
		Moderate		
		1.4		
		1.2		
		Uncleared areas: Hardwood forestry for scantlings, posts, pole and pulpwood; softwood plantations for sawlogs and pulpwood; nature conservation; water supply; passive recreation.		
		Minor cleared areas: Beef cattle grazing and dairy farming on mainly improved pastures; row cropping on gentler slopes.		
SOIL DETERIORATION HAZARD		Rapid surface run-off from adjacent hills lead to scour gullying, siltation and flooding. High rainfall, high permeability and leaching plus loss of organic matter and soil structure upon disturbance lead to nutrient decline and soil compaction.		
Critical land features, processes, forms		Clay subsoils on steep slopes subject to periodic saturation are prone to landslips. Steep slopes are prone to sheet and rill erosion. High rainfall, moderate permeability and leaching plus loss of organic matters and soil structure upon disturbance lead to nutrient decline and soil compaction.		

7.2 Anglesea Land System

Stretching inland from the coast between Bells Beach and Mogg's Creek lies a dissected plain on Tertiary sediments. Long straight slopes emanate from spurs and ridges. The coastal margins are retreating an often about the sea in steep cliffs or massive landslips and earthflows.

The parent material is very variable, ranging from lateritized sediments on the ridges to relatively unweathered alluvium in the drainage lines. Thus the soils are particularly variable.

In general, plant nutrient levels are low and surface horizons are weakly structured. Plant communities are mainly open forests less than 15 m in height; the height decreases towards the coast under the influence of salt-bearing winds. The area is highly regarded for its diversity of flora. Some parts have been cleared for agriculture. The main hazards to land use are gully erosion and sheet erosion.



Exposed coastal sites carry salt-pruned open scrubs that are sensitive to disturbance, and revegetation of eroded areas is difficult.

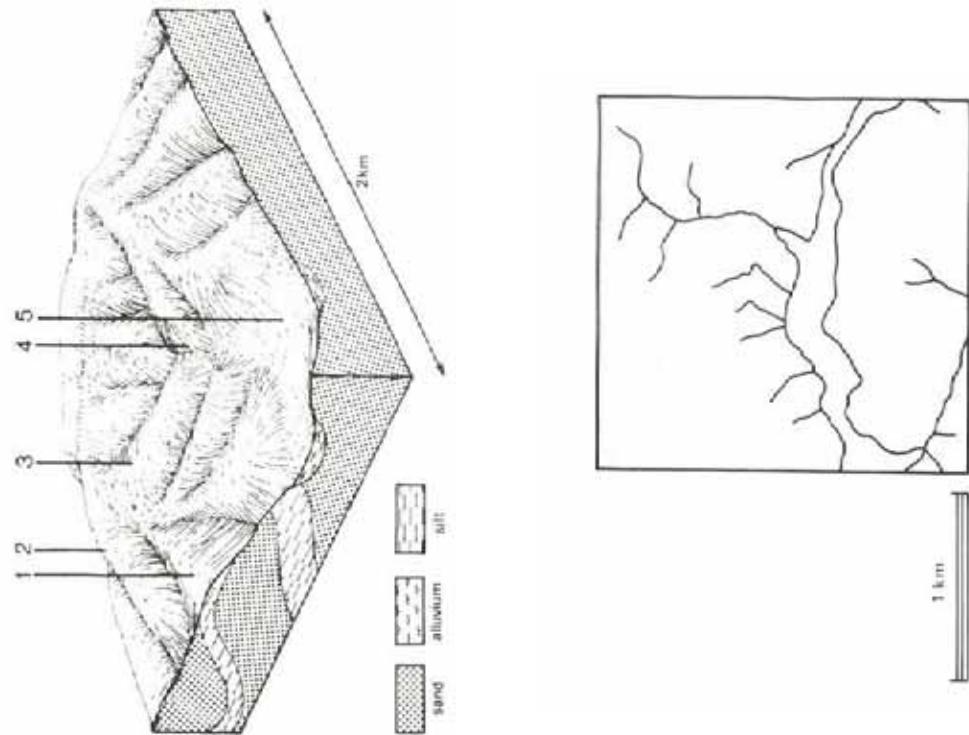
ANGLESEA		Component and its proportion of land system					
Area: 74 km ²	1 25%	2 5%	3 10%	4 30%	5 %25%	6 2%	7 3%
CLIMATE							
Rainfall, mm	Annual: 600 - 800; lowest January (35), highest August (80)						
Temperature, °C	Annual: 14, lowest July (9), highest February (17)						
Seasonal growth limitations	Temperature: less than 10°C (av.) July						
GEOLOGY	Precipitation: less than potential evapotranspiration mid October – early April						
TOPOGRAPHY							
Age, lithology							
Landscape							
Elevation, m	Moderately dissected hills lying below and on the seaward side of the lateritic plateaux						
Local relief, m	0 - 195						
Drainage pattern							
Drainage density, km/km ²							
Land form							
Land form element							
Exposed coastal slope	Slope, crest	Lower slope line	drainage	Middle slope	Upper slope, crest	Steep slope	Landslip
20 (5-45)	2 (5-15)	8 (1-15)		15 (5-35)	10(1-20)	45 (25-55)	(5-90) Irregular
Linear/irregular	Linear	Concave		Convex	Convex	Linear	
Slope (and range), %							
Slope shape							
NATIVE VEGETATION							
Structure							
Dominant species	Open scrub <i>E. obliqua, Casuarina stricta, E. sideroxylon</i>	Woodland <i>E. viminalis, E. radiata, E. baxteri</i>	Open forest <i>E. sideroxylon</i> <i>E. obliqua</i>	Open forest <i>E. sideroxylon</i> <i>E. obliqua</i>	Open forest <i>E. obliqua</i> <i>E. sideroxylon</i> <i>E. baxteri</i>	Open forest <i>E. obliqua, E. baxteri, E. sideroxylon</i>	Low woodland <i>E. sideroxylon</i> <i>E. obliqua</i> <i>Mealeuca lanceolata, Casuarina stricta</i>
SOIL							
Parent material	Calcareous sand, clay silt, sand and gravel	Clay, silt and sand	Slag, silt and sand, sandstone	Deeply weathered clay, silt and sand	Lateritic ironstone, sandstone	Clay, silt and sand; some aeolian sand	
Description	Variable sodic duplex soils	Yellow-brown sodic duplex soils, coarse structure	Yellow-brown duplex soils, coarse structure	Mottled yellow and red duplex soils	Stony red gradational soils	Variable sodic duplex soils	
Surface texture							
Permeability							
Depth, m							
LAND USE							
SOIL DETERIORATION HAZARD							
Critical land features, processes, forms	Uncleared areas: Nature conservation; active and passive recreation; landscape conservation; gravel extraction						
Cleared areas: Beef cattle grazing on mainly unimproved pastures; residential; active recreation							
Native vegetation is sensitive to salt pruning and disturbance. Highly dispersible soils on steep slopes are prone to sheet erosion, gully erosion and tunnel erosion	Very low inherent fertility and high permeability lead to nutrient decline.	Highly dispersible soils are prone to gully and tunnel erosion.	Sodic, highly dispersible subsoils are prone to gully and tunnel erosion. Weakly structured surface soils over slowly permeable subsoils on steep slopes are prone to sheet erosion.	Low inherent fertility, phosphorus fixation and leaching of permeable A horizons lead to nutrient decline.	Stony shallow soils with low organic content, weak structure and low water-holding capacity on steep slopes are prone to sheet erosion.	Native vegetation is sensitive to salt pruning and disturbance. Marine under-cutting of highly dispersible soils maintains active landslips and earth flows.	

7.3 Bald Hills Land System

Inland from Anglesea is a deeply dissected landscape with very stunted native vegetation, referred to as the Bald Hills. The Tertiary sediments exposed here include both sands and clays and are characterized by soils of extremely low fertility.

Heaths and low woodlands are found on the upper parts of the landscape, where the sand soils tend to predominate. *Xanthorrhoea australis* is particularly common and tends to dominate on sites with hardpans developed in the soil profile. Lower down in the landscape, low forests or open forests of *Eucalyptus nitida* and *E. obliqua* tend to occur.

Productive land uses are limited to the mining of sand and gravel in numerous shallow extraction pits, and mining of coal near Anglesea. Nature conservation and recreation are other forms of land use.

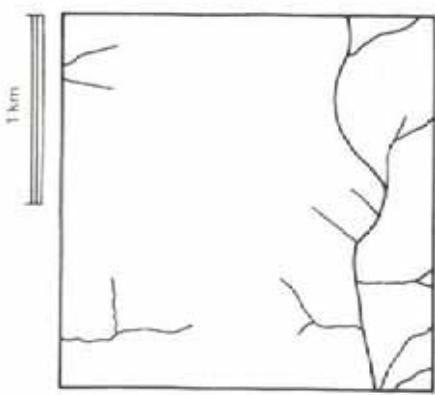
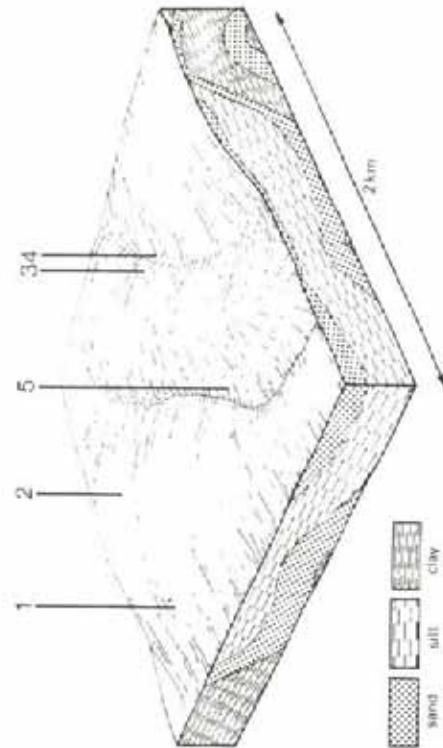
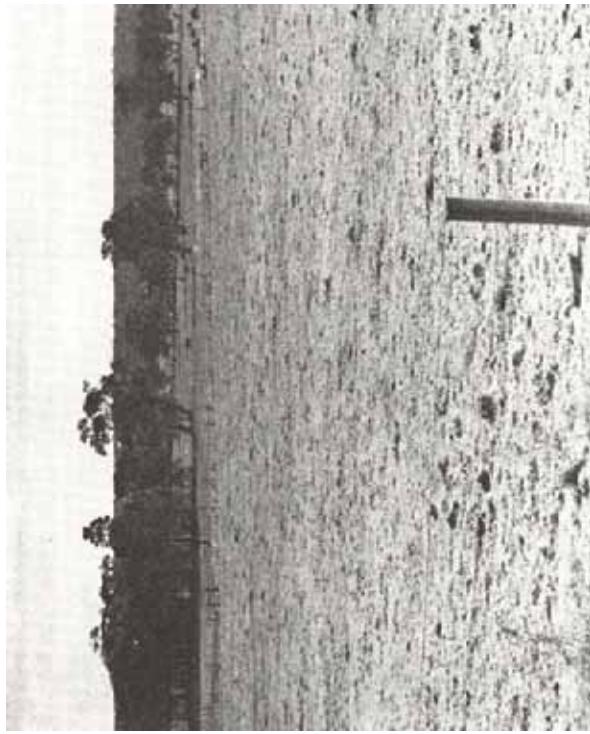


Low open woodlands of E. nitida with Xanthorrhoea australis in the understorey typify this land system, hardpan areas being demarcated by the absence of the tree stratum.

7.4 Barongarook Land System

North of Forrest and extending towards Colac, undulating plains with often deeply weathered soils are found. The geology is mainly Tertiary clay with minor outcrops of sand. Redistribution of surface sand has resulted in polygenetic soils over much of the landscape, with weak hardpan development and impeded drainage. Surface soils seem to be naturally low in plant nutrients.

Many areas remain uncleared and support open forests dominated by *Eucalyptus obliqua* and *E. radiata*. *E. baxteri* is notably absent in this slightly drier region. Other areas have been cleared for agriculture or converted to pines. The main hazards to land use are loss of soil structure, by compaction, and leaching of nutrients.



Poor site drainage and low soil permeability lead to waterlogging and pugging of the soil by stock in many parts of this land system.

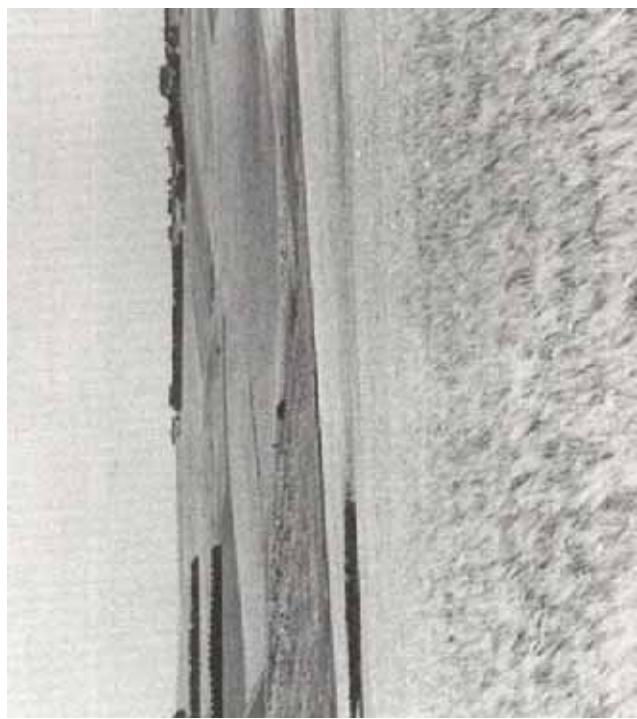
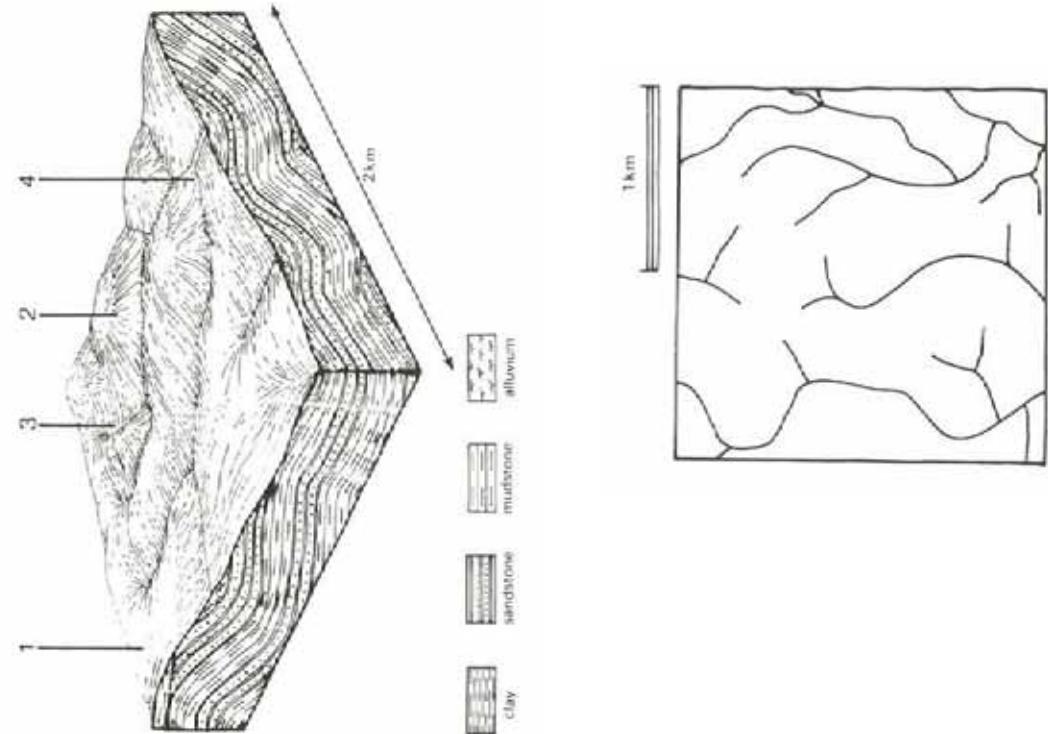
BARONGAROOKArea: 92 km²

		Component and its proportions of land system		
		1 8%	2 55%	3 15%
		4 15%	5 7%	
CLIMATE				
Rainfall, mm				
Temperature, 0°C	Annual: 100 – 900, lowest January (40), highest August (80)			
Seasonal growth limitations	Annual: 13, lowest July (8), highest February (18)			
	Temperature: less than 10°C (av.) June – August			
	Precipitation: less than potential evapotranspiration late October – early April			
GEOLOGY				
Age, lithology		Pliocene unconsolidated clay, silt and sand		
		Recent sand veneer		
TOPOGRAPHY				
Landscape		Gently undulating to rolling plain in the western parts of the Barwon catchment		
Elevation, m		120 – 280		
Local relief, m		30		
Drainage pattern		Dendritic		
Drainage density, km/km ²		1.2		
Land form		Undulating plan		
Land form element		Crest, upper slope		
Slope (and range), %	Steep slope 25 (15–40)	5 (0–10)		
Slope shape	Linear	Convex		
		Upper and middle slope		
		5 (0–10)		
		Convex		
		Lower slope		
		7 (1–15)		
		Linear		
		Drainage line		
		1 (10–2)		
		Concave		
NATIVE VEGETATION				
Structure		Woodland		
Dominant species		<i>E. radiata, E. nitida</i>		
		<i>E. radiata, E. nitida</i>		
		<i>E. radiata, E. nitida</i>		
		<i>E. radiata, E. nitida</i>		
		<i>E. radiata, E. nitida</i>		
SOIL				
Parent material	Clay, silt and sand	Clay, silt and sand with quartz sand veneer		
Description	Yellow gradational soils, weak structure	Grey sand soils, structured clay underlay		
Surface texture	Sandy loam	Sandy loam		
Permeability	High	Low		
Depth, m	>2	>2		
		Clay, silt and sand with quartz sand veneer		
		Grey sand soils, weakly structured clay underlay		
		Sandy loam		
		Low		
		>2		
LAND USE		Clay, silt and sand with quartz sand veneer		
		Grey sand soils, weakly structured clay underlay		
		Sandy loam		
		Low		
		>2		
SOIL DETERIORATION		Cleared areas: Sheep and beef cattle grazing; dairy farming.		
HAZARD		Uncleared areas: Hardwood forestry for sawlogs, post and poles; nature conservation; active and passive recreation; softwood forestry; forest grazing.		
Critical land features, processes, forms		Steeper slopes with weak-structured surfaces are prone to sheet erosion.		
		Low inherent fertility and phosphorus fixation lead to nutrient decline.		
		Low permeability and seasonal perched water table lead to waterlogging and soil compaction.		
		High seasonal water table leads to waterlogging and soil compaction.		

7.5 Barrabool Land System

Rolling hills with fertile soils to the west of Geelong lie mainly to the north of the present study area, but a small section forms the northern part of the catchment of Thompson Creek. These hills are on Lower Cretaceous sandstones and mudstones similar to those outcropping extensively in the Otway Range, but the landscape is more subdued and the rainfall is significantly lower.

The original structure and species composition of the native vegetation are difficult to determine. The area has been extensively cleared for cropping and grazing and subdivided into somewhat smaller paddocks than the less fertile areas to the south. From the presence of isolated trees, *Eucalyptus globulus* and *E. cypellocarpa* formed part of the original vegetative community, and it is probable that *E. radiata* was also common.



These rolling hills have been extensively cleared, and only single trees remain as indicators of the former native vegetation.

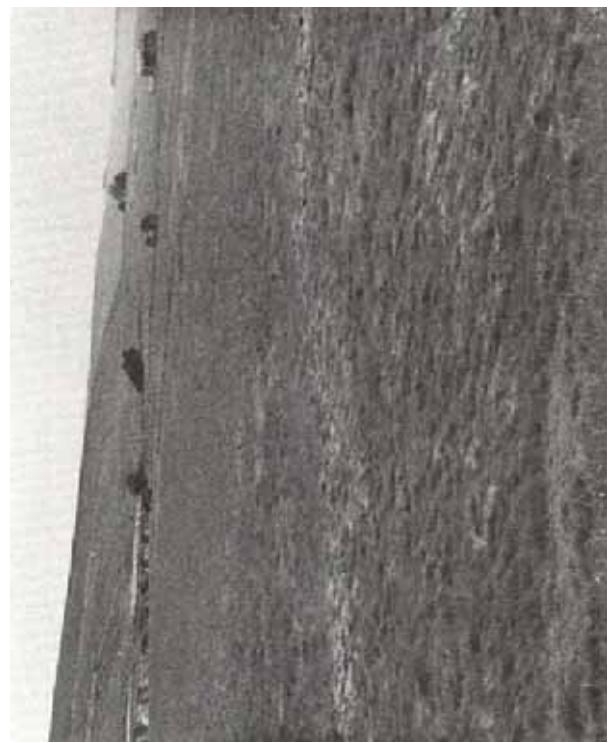
BARRABOOL
Area: 17 km²

Component and its proportion of land systems			
	1	2	3
CLIMATE	10%	60%	25%
Rainfall, mm			
Temperature, 0°C			
Seasonal growth limitations			
GEOLOGY			
Age, lithology	Tertiary and Quaternary clay, silt and sand cappings		Lower Cretaceous feldspathic sandstone and mudstone
TOPOGRAPHY			
Landscape		Rolling Hills 100-170	
Elevation, m		25	
Local relief, m		Dendritic	
Drainage pattern		3.1	
Drainage density, km/km ²			Valley Floor
Land form			
Crest, upper slope	Hill		
4 (1-5)	Crest, slope 11 (1-15)		
Convex	Convex	Lower slope 8 (2-10)	
Slope shape		Linear	
NATIVE VEGETATION			
Structure	Woodland	Open forest <i>E. glochidion</i> , <i>E. cypellocarpa</i>	Open forest <i>E. viminalis</i> , <i>E. cypellocarpa</i>
Dominant species	<i>E. ovata</i> , <i>E. viminalis</i>	In-situ weathered sandstone and mudstone	
SOIL			
Parent material	Clay, silt and sand (Variable soils)	Colluvial weathered sandstone, mudstone	Alluvial silt, clay, sand, sandstone,
Description	Sandy loam	Brown duplex soils	mudstone
Surface texture	High to moderate	Loam	Grey gradational soils
Permeability	>2	Moderate	Clay loam
Depth, m	1.0	1.4	Low
LAND USE			
SOIL DEGRADATION HAZARD	Dairy farming; cropping; beef and cattle grazing. Low inherent fertility and high permeability lead to nutrient decline.	Steeper slopes are prone to sheet erosion.	Run-off from adjacent hills may result in gully erosion. High seasonal water table leads to waterlogging and soil compaction.

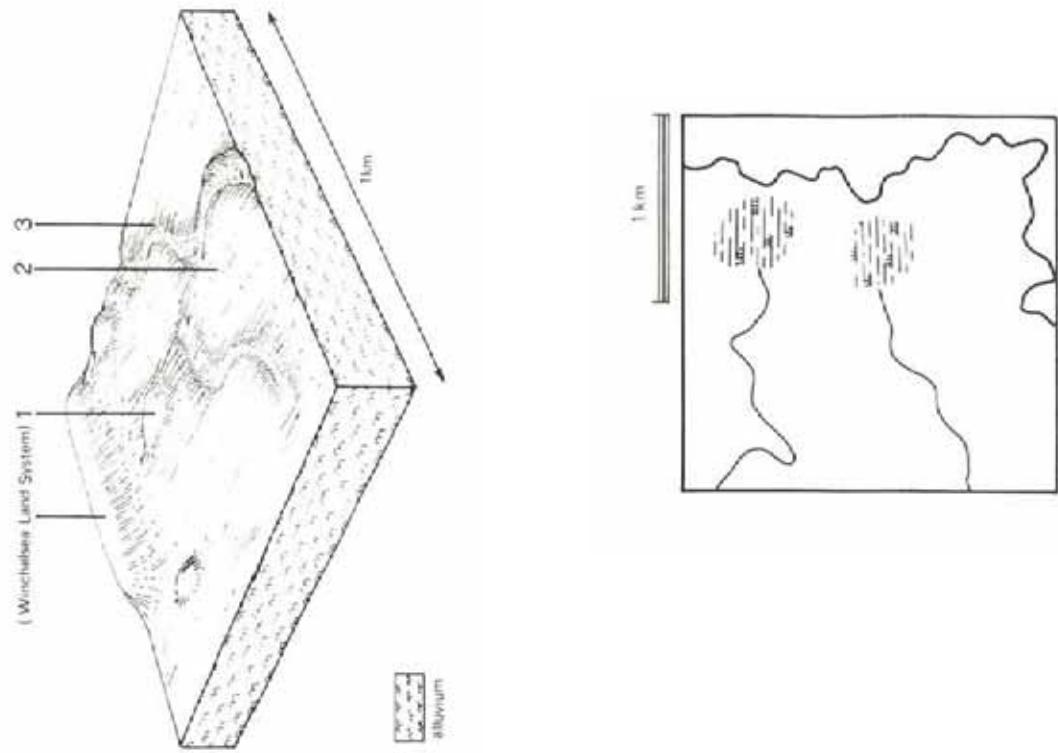
7.6 Barwon River Land System

The flood-plains of the Barwon River and its tributaries extend from the foothills of the northern side of the Range to the basalt plains near Winchelsea and encompass a comparatively wide climatic variation. The vegetation reflects these changes, with tall open forests of *Eucalyptus viminalis* and *E. ovata* occurring in the south and woodlands of *E. camaldulensis* dominating in the north. The soils also show a gradual transition from acid, freely drained profiles to heavier neutral soils as the influence of basalt-derived alluvium increases towards the north.

Flooding and siltation are common on these plains. Waterlogging of soils is a problem, particularly on low-lying areas such as cut-off meanders and infilled swamps. Gully erosion and stream-bank erosion are also common.



Gully erosion and stream-bank erosion are particularly common on these alluvial plains, where streams emerge from the foothills of the Otway Range.



BARWON RIVER

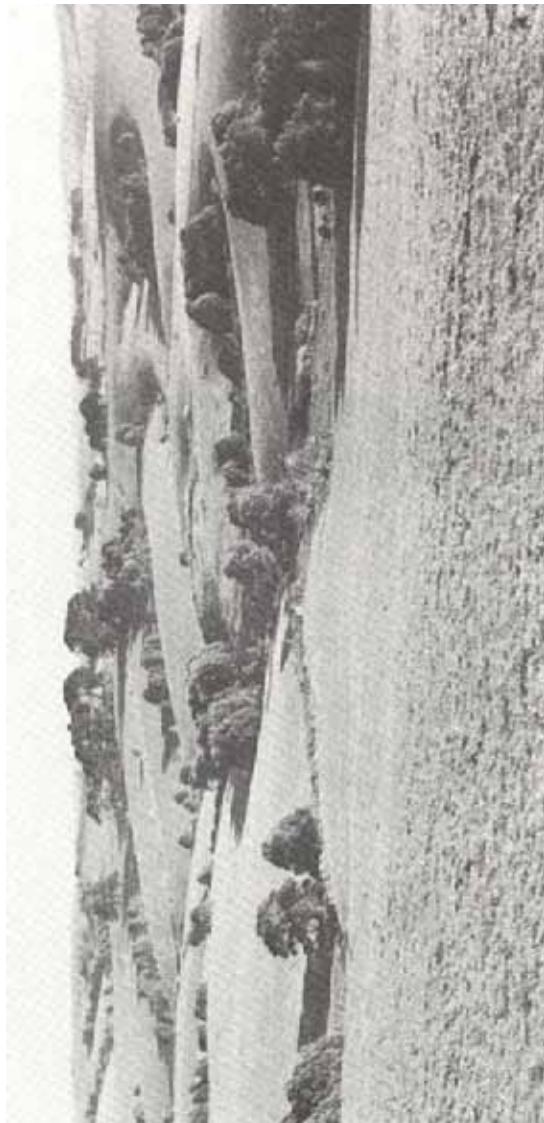
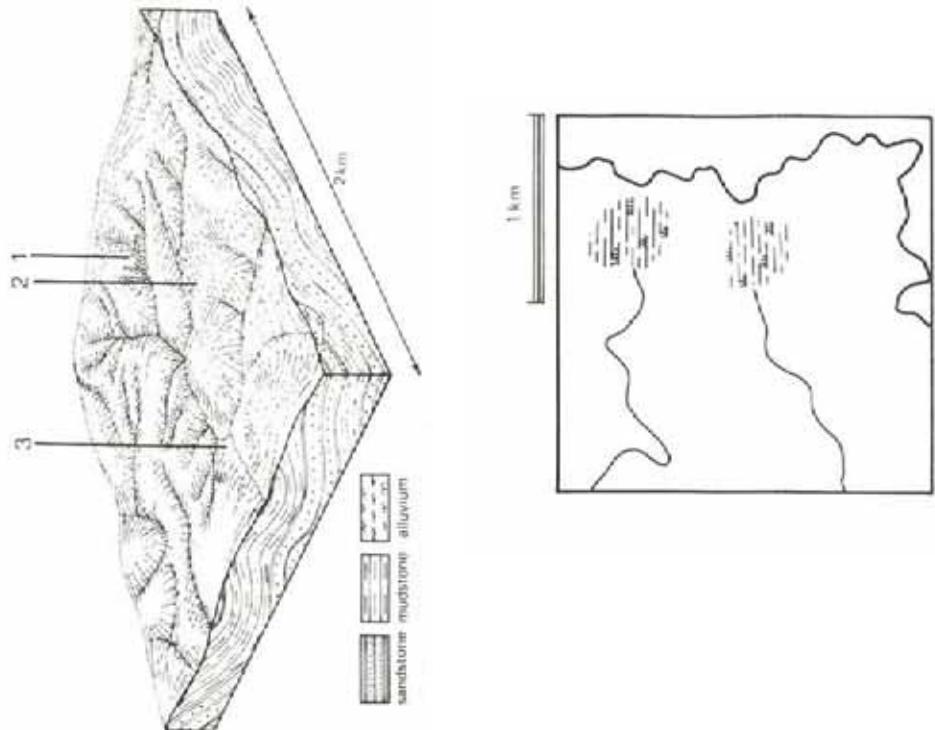
	Component and its proportion of land system	
CLIMATE	1 5%	2 85%
Rainfall, mm	Annual: 600 – 1,000, lowest January (30), highest August (80)	3 10%
Temperature, 0°C	Annual: 13, lowest July (8), highest February (9)	
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August (Also September in higher-rainfall areas) Precipitation: less than potential evapotranspiration October – April in lower-rainfall areas November – March in higher-rainfall areas	
GEOLOGY		Recent alluvium – sand, silt, clay and gravel
TOPOGRAPHY	Alluvial flood plain of the Barwon River and its tributaries with numerous cut-off meanders 90 - 150	
Landscape	Deranged with major meandering channel 3	
Elevation, m	1.6	
Local relief, m	Plain	
Drainage pattern	Plain	
Drainage density, km/km ²	1 (0-2)	
Land form	Straight	
Land form element		
Slope (and range), %		
Slope shape		
NATIVE VEGETATION		
Structure	Woodland	
Dominant species	<i>E. ovata</i> , <i>E. viminalis</i> , <i>Acacia melanoxylon</i> , in north <i>E. camaldulensis</i>	
SOIL		
Parent material	Sandy alluvium	Sandy alluvium
Description	Brown sandy loam soils, uniform texture	Brown sandy loam soils, uniform texture
Surface texture	Fine sandy loam	Fine sandy loam
Permeability	Very high	Very high
Depth, m	>2	>2
LAND USE	Dairy farming; cropping; sheep and beef cattle grazing	
SOIL DETERIORATION HAZARD	High permeability and leaching lead to nutrient decline.	High seasonal water table leads to waterlogging, soil compaction and salting. Dispersible clay subsoils are prone to gully and tunnel erosion. High discharge rates along some watercourses lead to flooding and siltation.
Critical land features, processes, forms		High discharge rates and weakly structured soils lead to streambank erosion and silation. High seasonal water tables lead to waterlogging.

7.7 Beech Forest Land System

Along the crest of the wetter parts of the Otway Range lies a rolling plain with rounded hills and shallow valleys. This area has one of the highest annual rainfalls in Victoria, averaging almost 2,000 mm at Woorapoinah.

Prior to settlement late last century, tall open forests of *Eucalyptus regnans* and associated species dominated the landscapes, but now most areas have been cleared for agriculture. Some stands of timber do remain and other areas are being regenerated to form climax communities of *E. regnans*. Agricultural uses are dairying, beef cattle grazing and cropping. The cool climate, remoteness and freely drained soils make the area suitable for seed-potato production.

The perennial nature of many of the creeks and drainage lines gives the areas high water catchment values. Conflict also arises between its high scenic appeal as a rural landscape and the conversion of farmland to softwood plantations.



The rolling hills of the Beech Forest land system comprise an agricultural landscape of high scenic value.

BEECH FOREST

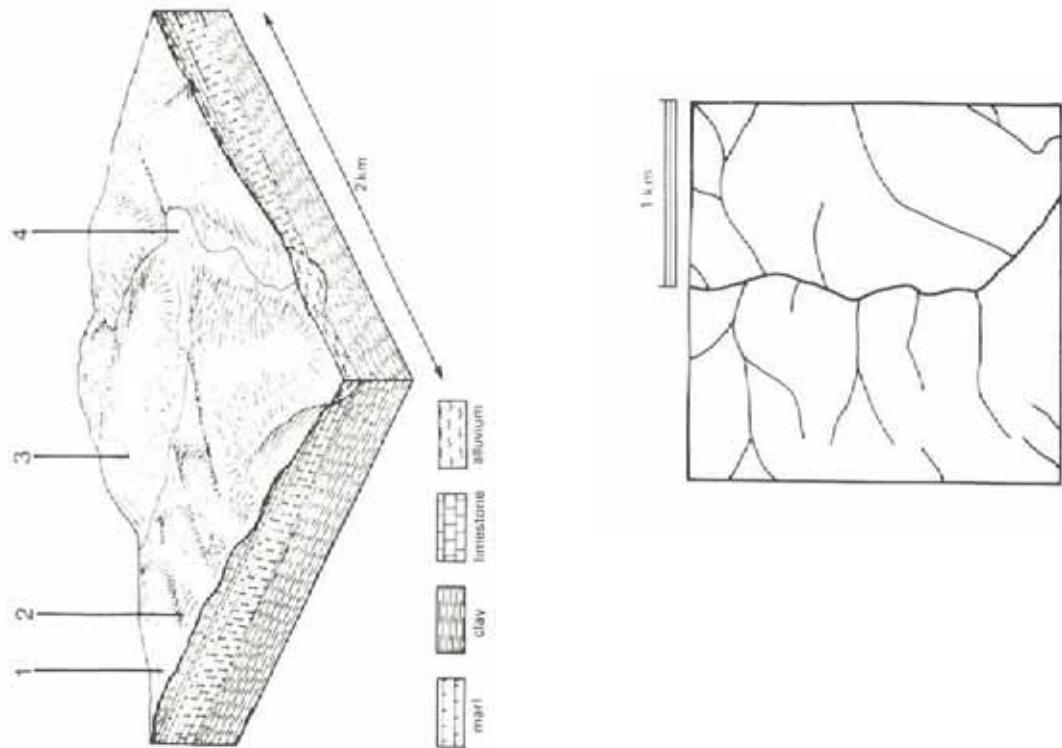
	Component and its proportion of land system	
CLIMATE	1 5%	2 85%
Annual: Rainfall, mm	1,550 – 1,950, lowest January (80), highest August (210)	3 10%
Temperature, °C	10, lowest July (6), highest February (15)	
Seasonal growth limitations	Temperature: less than 10°C (av.) May - October	
Precipitation: less than potential evapotranspiration late December – early February		
GEOLOGY		
Age, lithology	Lower Cretaceous feldspathic sandstone and mudstone	
TOPOGRAPHY		
Landscape	Rolling hills along the crest of the Otway Range	
Elevation, m	340 – 360	
Local relief, m	45	
Drainage pattern	Dendritic with some trellis and radial areas	
Drainage density, km/km ²		
Land form	5.8	
Slope (and range), %	12 (2-15)	
Slope shape	Convex	Hill
		Crest and slope 12 (1-20)
		Convex
NATIVE VEGETATION		
Structure	Tall open forest	Tall open forest
Dominant species	<i>E. regnans, E. obliqua, Acacia melanoxylon</i>	<i>E. regnans, E. obliqua, Acacia melanoxylon</i>
SOIL		
Parent material	In-situ weathered rock	
Description	Brown friable gradational soils	
Surface texture	Loam	
Permeability	Clay loam	
Depth, m	Moderate	
	1.6	
LAND USE		
Cleared areas:	Dairy farming; beef cattle grazing; row crops (seed potatoes); water supply	
Uncleared areas:	Softwood forestry; hardwood forestry for sawlogs and pulpwood; nature conservation; passive recreation; water supply	
SOIL DETERIORATION HAZARD		
Critical land features, processes, forms	High rainfall, high permeability and leaching plus loss of organic matter and soil structure upon disturbance lead to nutrient decline and soil compaction. Steeper slopes may be subsequently prone to sheet erosion.	
	High rainfall and moderate permeability lead to leaching of nutrients and losses in organic matter and soil structure. Steeper slopes are subsequently prone to sheet erosion. Clay subsoils on steeper slopes are subject to frequent saturation and are prone to landslips.	
	High seasonal water tables and run-off from surrounding slopes lead to waterlogging and soil compaction.	

7.8 Bellbrae Land System

Below the lateritized plateaux to the east of the Otway Range lie a series of rolling hills have formed by dissection along the valleys of Spring Creek and Jan Juc Creek. Weathering of limestone and marl exposed along these valleys has resulted in calcareous soils. Fertility is moderate, and thus contrasts with the surrounding impoverished soils of the lateritic plateaux and acid sands and clays.

The red soils, or those deeper profiles transitional to the red soils, are the most favoured for agriculture and are used or cropping as well as dairy-farming. Grazing of sheet and beef cattle is also common. Agricultural use is decreasing, however, as the township of Torquay extends its urban limits. Subdivision into small farmlets in other parts of the valleys also tends to decrease agricultural production.

Sheet erosion occurs on some of the cropped steeper slopes, while gully erosion and slumping are problems of the dispersible duplex soils.



Wide drainage lines and rounded hill sides typify this landscape, as it rises to the lateritic plateau in the distance

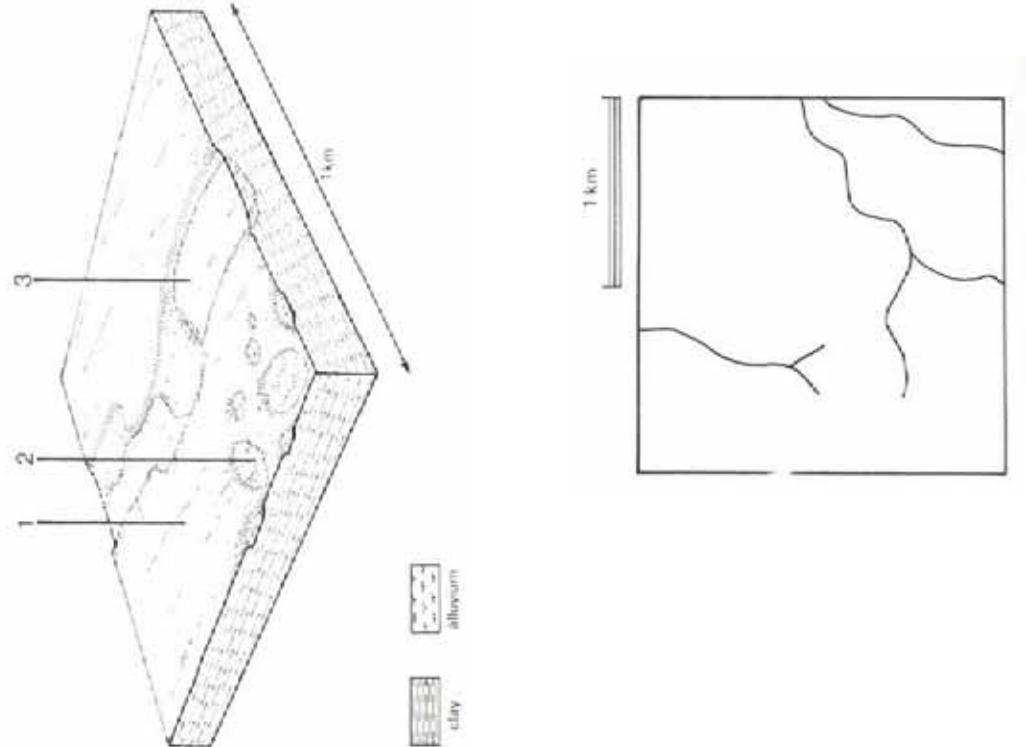
BELLBRAE		Component and its proportion of land system		
Area: 25 km ²		1 25%	2 40%	3 20%
CLIMATE				4 15%
Rainfall, mm				
Temperature, 0°C				
Seasonal growth limitations				
GEOLOGY				
Age, lithology				Miocene limestone and marl
TOPOGRAPHY				
Landscape				Rolling hills dissected out below the lateritic plateaux
Elevation, m		5 – 70		
Local relief, m		60		
Drainage pattern		Dendritic		
Drainage density, km/km ²		3.0		
Land form		Hill		
Slope (and range), %		Middle slope 11 (5-14)		
Slope shape		Linear		
NATIVE VEGETATION				
Structure		Open forest		Open forest
Dominant species		<i>E. viminalis</i> , <i>E. sideroxylon</i> , <i>E. obliqua</i>		<i>E. viminalis</i> , <i>E. ovata</i> , <i>Acacia melanoxylon</i>
SOIL				
Parent material		Calcareous clay and deeply weathered limestone		Colluvial limestone, clay, lateritic material
Description		Yellow-brown calcareous sodic duplex soils, coarse structure		Yellow sodic duplex soils
Surface texture		Fine sandy loam		Loamy sand
Permeability		Low		Moderate
Depth, m		>2		>2
LAND USE				
Cleared areas: Dairy farming; beef cattle grazing; residential; cropping				
Minor uncleared areas: Forest grazing; active and passive recreation; hardwood forestry for fuel, posts and poles				
SOIL DETERIORATION HAZARD				
Critical land features, processes, forms		Dispersible subsoils receiving seepage water are prone to gully erosion, slumping and rilling.		Highly dispersible subsoils are prone to sheet erosion. Steeper slopes are prone to gully erosion and tunnel erosion.

7.9 Birregurra Land System

Lying between the basalt plains to the north and dissected lateritized landscapes to the south, much, if not all, of this flat plain apparently marks the eastern extent of a large former lake in western Victoria. The landscape slopes very gently to the east with increasing dissection as the height above the Barwon River flood plain increases from 10 m to about 40 m.

The lacustrine deposits appear to be mainly calcareous and have formed soils with alkaline reaction trends. Dissolution of calcium carbonate has led to the development of sink holes in some areas, although levelling of paddocks has made these less apparent.

The native vegetation has been almost completely removed for agricultural use and its original structure and composition are difficult to determine. In the east there is some evidence of a former woodland, but further west the soils are less well drained and possibly the communities were more stunted.



The western parts of the land system show very little dissection and form a flat plain between the Tertiary sediments in the south and the basalt in the north.

BIRREGURRA

Area: 81 km²

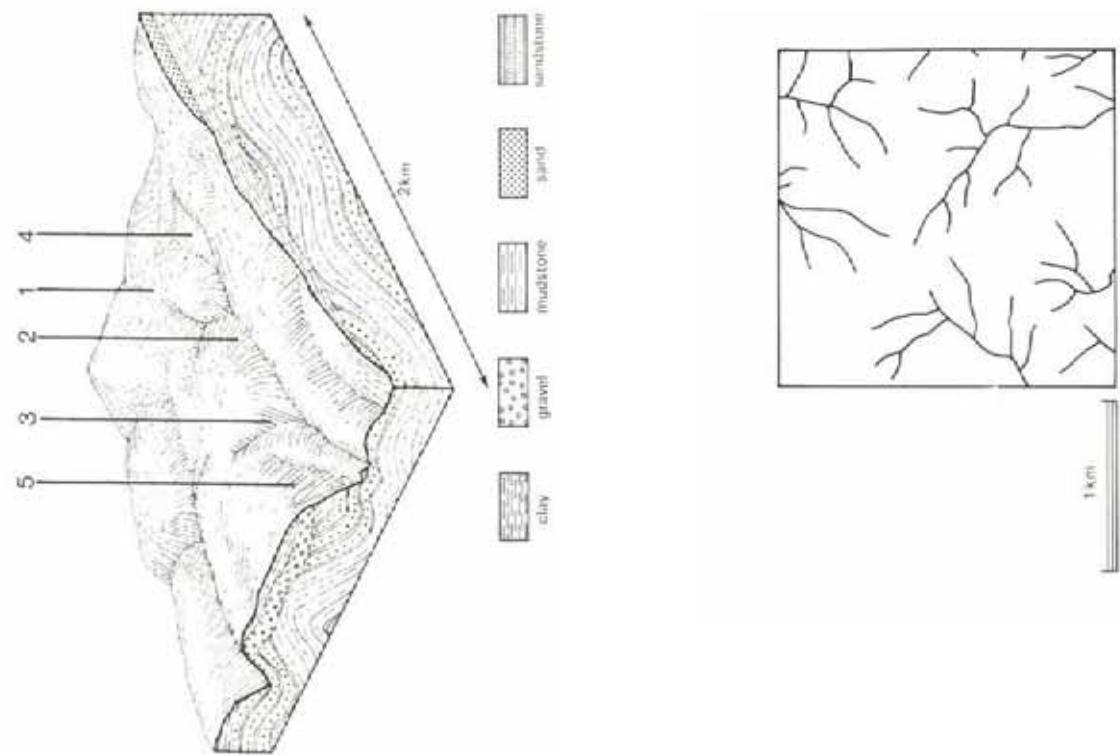
		Component and its proportion of land system	
		1 80%	2 10%
		3 10%	3 10%
CLIMATE			
Rainfall, mm	Annual: 600 – 650, lowest January (30), highest February (75)		
Temperature, 0°C	Annual: 13, lowest July (8), highest February (19)		
Seasonal growth limitations	Temperature: less than 10°C (av.) June - August		
Precipitation: less than potential evapotranspiration October – late April	Pleistocene clay, silt and some sand		
GEOLOGY			
Age, lithology			
TOPOGRAPHY			
Landscape	Flat plain bordering the present flood plain of the Barwon River		
Elevation, m	110 – 130		
Local relief, m	10		
Drainage pattern	Dendritic		
Drainage density, km/km ²	0.8		
Land form	Flat plain		
Slope (and range), %	Sinkhole		
Slope shape	0 (0-1)		
Linear	Concave		
Younger terrace	2 (1-3)		
Linear	Linear		
NATIVE VEGETATION			
Structure	Woodland		
Dominant species	<i>E. viminalis</i> , <i>E. ovata</i>		
SOIL			
Parent material	Calcareous clay		
Description	Yellow-brown calcareous duplex soils, coarse structure		
Surface texture	Fine sandy loam		
Permeability	Clay		
Depth, m	Very low		
	>2		
LAND USE			
SOIL DETERIORATION HAZARD			
Critical land features, processes, forms	Dispersible clay subsoils of low permeability and prone to gully and tunnel erosion. Seasonally high water tables lead to soil salting.		
	High water tables and low permeability lead to waterlogging, soil compaction and soil salting.		
	High seasonal water table, low permeability and saline groundwater lead to waterlogging, soil compactions and soil salting.		

7.10 Bunker Hill Land System

Deeply dissected hills north and west of Gellibrand possess Tertiary sands and clays on the higher parts of the landscape and outcrops of Cretaceous sediments on the steeper and lower parts. The soils become heavier and more fertile on the Cretaceous sediments and this is reflected in the occurrence of *Eucalyptus obliqua* and *E. viminalis* open forests with dense understoreys.

Most areas are too steep for agriculture, and remain forested with native hardwoods or pines. Clearing operations necessary for pine conversion and hardwood harvesting may result in severe scour gullying and landslips on the steep parts of the landscape.

Access tracks are difficult to site and prone to scouring. In general, careful management is required.



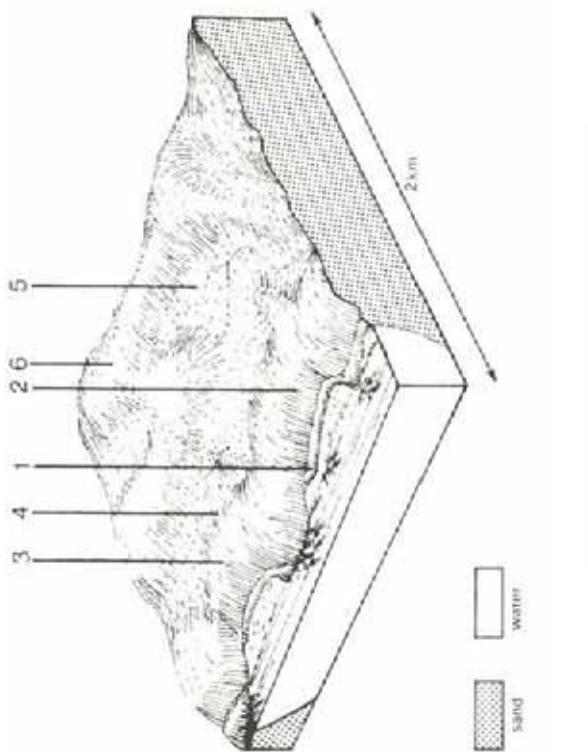
The steep land and irregular nature of the terrain makes these areas difficult to manage.

BUNKER HILL		Component and its proportion of land system		
	1 25%	2 20%	3 40%	
	4 9%	4 9%	5 6%	
CLIMATE				
Rainfall, mm	Annual: 900 – 1,050, lowest January (45), highest August (130)			
Temperature, °C	Annual: 12, lowest July (7), highest February (18)			
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August			
Precipitation: less than potential evapotranspiration early November – late March				
GEOLOGY				
Age, lithology	Palaeocene unconsolidated sand, silt and clay			
TOPOGRAPHY				
Landscape	Deeply dissected hills abutting the Gellibrand River to the west of Love Creek			
Elevation, m	60 – 290			
Local relief, m	95			
Drainage pattern	Dendritic with some radial areas			
Drainage density, km/km ²				
Land form				
Crests, upper slope				
20 (5–35)				
Convex				
Slope, upper slope				
20 (5–35)				
Convex				
Land form element				
Slope (and range), %				
Slope shape				
NATIVE VEGETATION				
Structure				
Dominant species				
SOIL				
Parent material				
Description				
Surface texture				
Permeability				
Depth, m				
LAND USE				
Cleared areas:	Hardwood forestry for posts and poles, some sawlogs on better soils; nature conservation; water supply; gravel extraction; softwood plantations			
Uncleared areas:	Beef cattle and sheep grazing on mainly unimproved pastures; water supply			
SOIL DETERIORATION				
HAZARD				
Critical land features, processes, forms				

7.11 Cape Otway Land System

In the vicinity of Cape Otway and extending discontinuously to the west is an elevated plain of coastal dunes. The coastal margins of the plain are generally fronted by 100 m cliffs of calcarenous with possibly small primary dunes at the base of the cliffs. Behind the cliffs, the plain has an irregular dune topography that may extend several kilometres inland. The demarcation to other land systems is very sharp and easily defined.

Woodlands of *Eucalyptus viminalis* with open grassy understoreys used to cover most areas, although shrubs resistant to salt- and salt-laden winds formerly colonized the coastal localities. Most areas have been cleared for grazing, but the establishment of improved pastures present difficulties. Overgrazing has resulted in severe wind erosion in some areas, and reclamation is difficult and expensive.



Large parts of the Cape Otway land system have been cleared and provide rough grazing for cattle on native grasses.

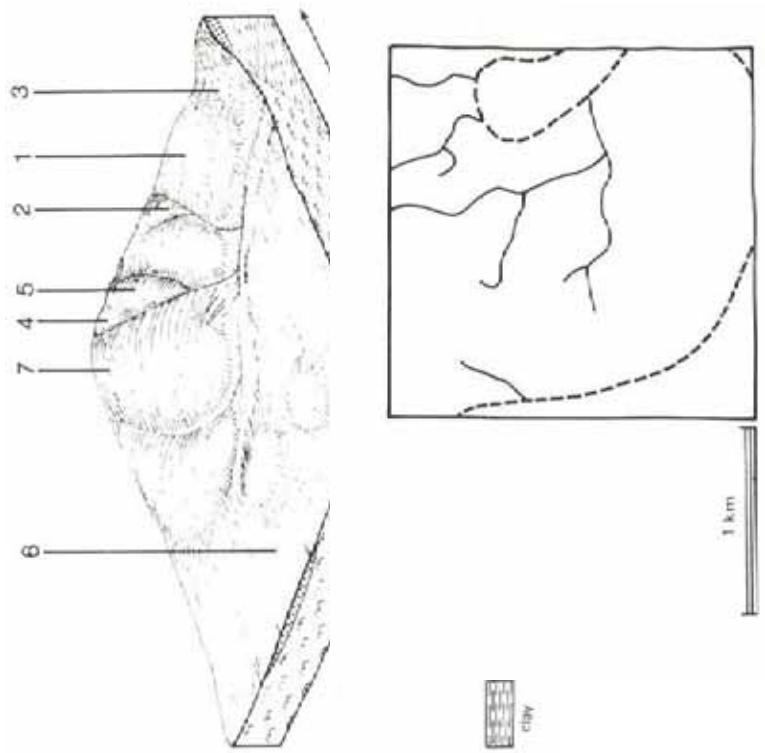
CAPE OTWAY		Component and its proportion of land system			
		1 6%	2 4%	3 20%	4 20%
		5 10%	6 40%		
CLIMATE	Area: 36 km ²				
Rainfall, mm	Annual: 900 – 1,100, lowest January (45), highest July (105)				
Temperature, °C	Annual: 14, lowest July (10), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) July				
Precipitation: less than potential evapotranspiration late November - February					
GEOLOGY		Recent sand and shell grit on a calcarenous basement			
TOPOGRAPHY		Elevated longitudinal coastal dunes at and to the west of Cape Otway			
Landscape		0 – 155			
Elevation, m		15			
Local relief, m					
Drainage pattern					
Drainage density, km/km ²					
Land form					
Land form element					
Slope (and range), %					
Slope shape					
NATIVE VEGETATION		Mainly absent; some dendritic areas			
Structure		0.7			
Dominant species					
Tussock grassland					
<i>Spinifex hirsutus</i> , <i>Scirpus nodosus</i> , <i>Calocephalus brownii</i>					
SOIL		Windward slopes			
Parent material		Cliff	Windward slopes	Leeward slopes	Interdune corridor
Description		-	25 (5-50)	20 (5-50)	-
Surface texture		65 (50-100)	Convex	Convex	Concave
Permeability		Linear			
Depth, m					
LAND USE		Inland dune			
Cleared areas: Beef cattle grazing on unimproved pastures; mining of calcarenite; residential; active recreation.					
Uncleared areas: Forest grazing of beef cattle; active and passive recreation; nature conservation; landscape conservation.					
SOIL DETERIORATION		Inland dune			
HAZARD					
Critical land features, processes, forms					
Dune inherently unstable due to cyclical marine erosion. Low fertility, low water-holding capacity on steep slopes with vegetation sensitive to disturbance lead to wind erosion and leaching of nutrients.					
Weakly structured sand soils with low water-holding capacities, subjected to strong on-shore winds are prone to wind erosion. Low inherent fertility, high alkalinity and rapid leaching lead to nutrient decline.					
Weakly structured sand soils with low water-holding capacities are prone to wind erosion. Low inherent fertility, high alkalinity and rapid leaching lead to nutrient decline.					

7.12 Carlisle Land System

High-level river terrace systems have developed along the Gellibrand River valley at Carlisle River, Gellibrand and Chapple Vale. Up to four different levels can be found, and mild dissection on the upper levels in quite complicated landscapes.

The alluvial material varies from coarse sands and gravels to silts and clays and a variety of soils is found at different levels. Redistribution of sand over some areas has resulted in polygenetic soils with hardpan development. This further complicates the soil and vegetation pattern.

Most of these terrace systems have been cleared, dairying being the major land use. Seasonal waterlogging is common and soil compaction may result from cattle grazing these areas in wet conditions.



Several levels can be found in this land system, with the highest levels being somewhat dissected.

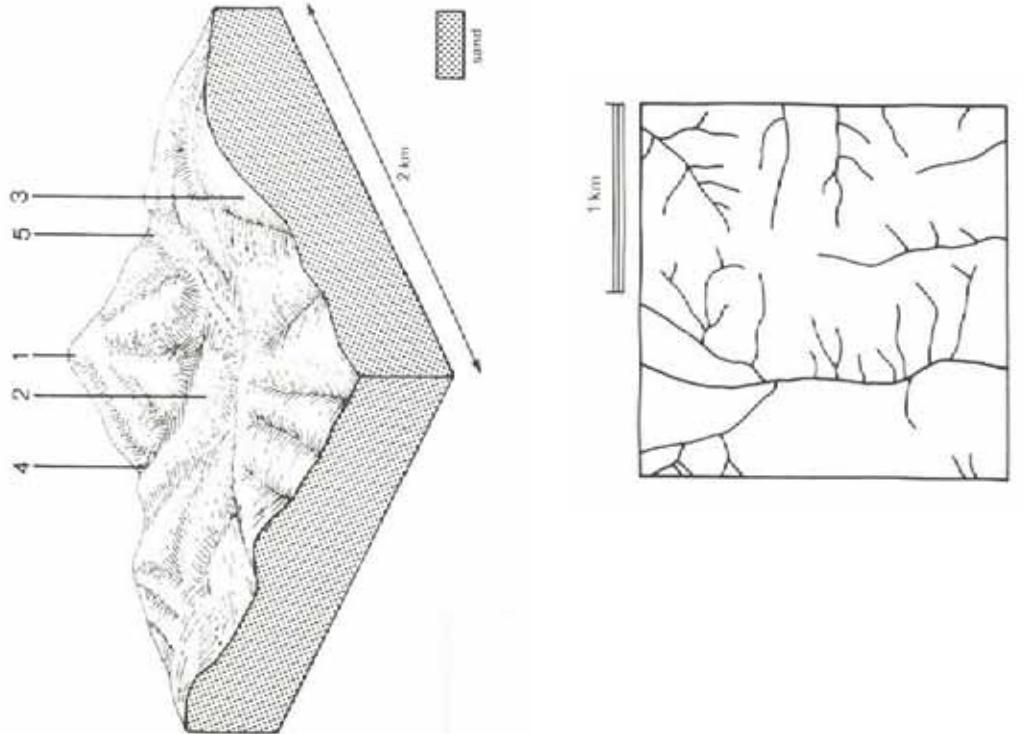
CARLISLE
Area: 19 km²

		Component and its proportion of land system			
	1 10%	2 10%	3 10%	4 10%	5 15%
CLIMATE					
Rainfall, mm	Annual: 1,000 – 1,150, lowest January (45), highest August (130)				
Temperature, °C	Annual: 13, lowest July (8), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September				
GEOLOGY	Precipitation: less than potential evapotranspiration mid November – late March				
TOPOGRAPHY					
Landscape	Recent alluvial clay, silt and sand shallowly overlying unconsolidated Palaeocene sand with some clay and silt.				
Elevation, m					
Local relief, m					
Drainage pattern					
Drainage density, km/km ²					
Land form	Alluvial terrace	Scarp	Valley floor	Mildly dissected alluvial terrace	
Land form element	Low level	–	–	Middle level	
Slope (and range), %	30 (0-8)	0 (0-1)	0 (0-1)	High level	
Slope shape	Linear	Linear	Linear	7 (1-10)	
NATIVE VEGETATION					
Structure					
Dominant species	Open forest <i>E. obliqua, E. ovata</i>	Open forest <i>E. obliqua, E. viminalis</i>	Tall open forest <i>E. viminalis, E. obliqua, Acacia melanoxylon, E. ovata</i>	Woodland <i>E. radiata, E. nitida, E. baxteri, E. viminalis</i>	Dendritic pattern in dissected areas; internal drainage elsewhere
SOIL					
Parent material	Alluvial clay, silt , some sand	Alluvial clay, silt and sand	Sand	Alluvial clay, silt with sand underlay	
Description	Yellow-brown gradational soils, coarse structure	Grey gradational soils	Grey sand soils with hardpans, uniform texture	Mottled yellow and red gradational soils	
Surface texture	Fine sandy loam	Sandy clay loam	Loamy sand	Structured clay underlay	
Permeability	Low	Low	Very high	Sandy loam	
Depth, m	>2	>2	>2	Low	
LAND USE					
Cleared areas:	Dairy farming; beef cattle grazing; open-range pig fattening; residential; water supply.				
Uncleared areas:	Sand and gravel extraction; water supply; minor forest produce				
SOIL DETERIORATION HAZARD	Low permeability and high rainfall lead to seasonally high water tables with resulting waterlogging and soil compaction.	Low inherent fertility and high permeability lead to leaching of nutrients. Weakly structured surface soils on the steepest slopes are prone to sheet erosion. Saturation of clay subsoils on steep slopes leads to landslips.	Flooding and seasonal water table development lead to waterlogging, soil compaction and siltation.	Very low inherent fertility with leaching of permeable acidic surfaces leads to nutrient decline. Steeper slopes with compacted soils of low water-holding capacity are prone to sheet erosion.	Low inherent fertility with leaching permeable acidic surfaces leads to nutrient decline. Hardpans restrict drainage, leading to seasonal waterlogging.
Critical land features, processes, forms					

7.13 Chapple Vale Land System

Low woodlands of Eucalyptus nitida with understoreys of *Lepidospernum juniperinum*, *L. myrsinoides* and *Xanthorrhoea australis* characterise these hills on the western periphery of the Otway Range. The soils are mainly deep, infertile and excessively drained sands, which contrast sharply with the adjacent gradational profiles of the Lower Cretaceous outcrops. Thus, although rainfall is high, moisture stress and soil infertility severely restrict plant growth.

Some attempts have been made to clear tracts of this land and establish pastures for cattle grazing. Trial plots of pine species have also been established. Given sufficient fertilizer and soil ameliorants such as lime, pastures or even intensive crops could be successfully grown. However, the rates of such chemicals needed to achieve satisfactory production are high and most of the land remains in its natural state. The main activity has been the opening up of numerous soil and gravel extraction pits, most of which have failed to regenerate naturally and now remain as scars on the landscape.



The components of this land system are well demarcated by the structure and species composition of the native vegetation.

CHAPPLE VALLE

Area: 115 km²

		Component and its proportion of land system			
		1 15%	2 15%	3 55%	4 10%
		5 5%			
CLIMATE					
Rainfall, mm	Annual: 1,000 – 1,350, lowest January (45), highest August (130)				
Temperature, °C	Annual: 12, lowest July (7), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June - September				
Precipitation: less than potential evapotranspiration mid November – late March					
GEOLOGY					
Age, lithology	Paleocene unconsolidated sand and gravel				
TOPOGRAPHY					
Landscape	Dissected hills in the western part of the Otway Range				
Elevation, m	30 - 270				
Local relief, m	60				
Drainage pattern	Dendritic with some radial areas				
Drainage density, km/km ²					
Land form	Hill				
Land form element	Steep lower slope				
Slope (and range), %					
Slope shape	Valley floor				
Convex					
Crest, slope	Crest, slope				
25 (10-35)	Impeded drainage				
Convex	15 (5-20)				
Linear	Broad, slightly depressed areas of				
	Hillside				
	20 (5-45)				
	Convex				
	8 (2-12)				
	Concave				
NATIVE VEGETATION					
Structure	Closed scrub				
Dominant species	<i>Melaleuca squarrosa</i> , <i>Lepospermum juniperinum</i> , <i>Castiarina littoralis</i> , <i>Grevillea myrsinoides</i> , <i>Aotus ericoides</i> , <i>Dillwynia floribunda</i> , <i>Eucalyptus impressa</i> , <i>Epacris lanigerosa</i>				
	<i>E. nitida</i> , <i>E. radiata</i> , <i>E. baxteri</i> , <i>E. viminalis</i> close to valley floor				
	<i>E. nitida</i> , <i>E. radiata</i> , <i>E. baxteri</i> , <i>E. viminalis</i> close to valley floor				
	<i>E. baxteri</i> , <i>E. radiata</i> , <i>E. nitida</i>				
	<i>Leptospermum juniperinum</i> , <i>Castiarina littoralis</i> , <i>Grevillea myrsinoides</i> , <i>Bauera rubioides</i> , <i>Sprengelia incarnata</i>				
SOIL					
Parent material	Alluvial sand, plant remains				
Description	Black sand soils, uniform texture				
Surface texture	Quartz sand				
Permeability	Grey sand soils, uniform texture				
Depth, m	Yellow sand soils, uniform texture				
>2	Loamy sand				
	Very high				
	>2				
	Very high				
	>2				
LAND USE					
SOIL DETERIORATION	Steeper slopes with weakly structured soils of low water-holding capacity are prone to sheet erosion. Low inherent fertility and high permeability lead to nutrient decline.				
HAZARD	High water tables lead to waterlogging and soil compaction. Rapid run-off from adjacent hills leads to flooding and siltation.				
Critical land features, processes, forms	Slopes with nutrient decline. Steeper slopes with compacted soils are prone to sheet, rill and scour gully erosion.				

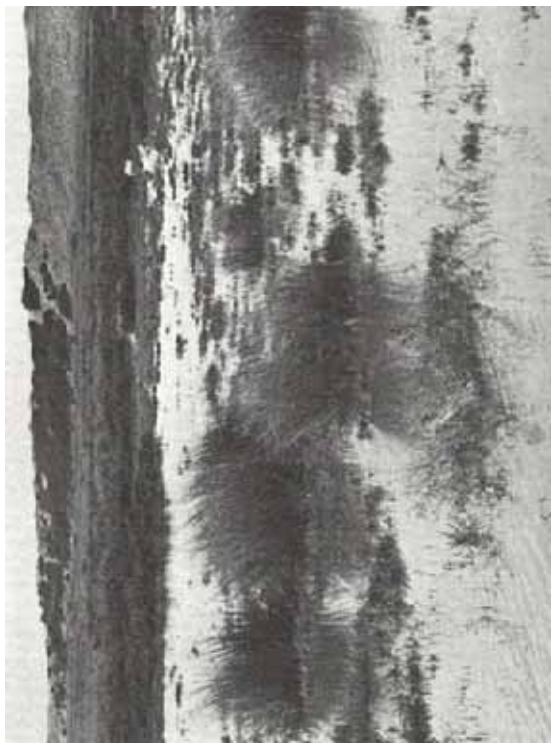
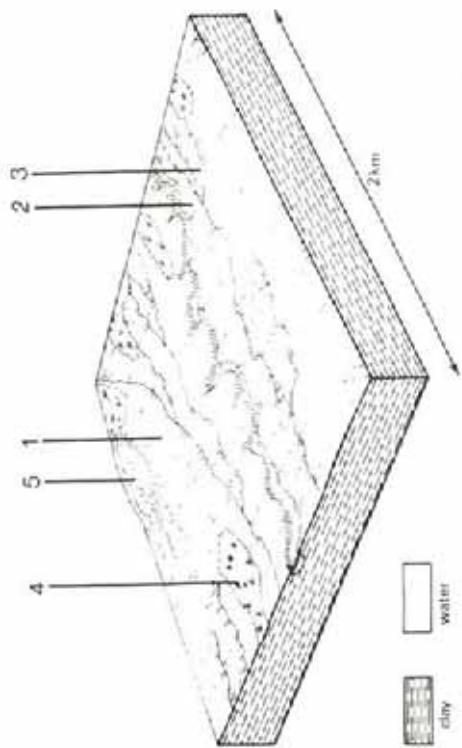
7.14 Connewarre Land System

Many of the outlets of creeks and rivers to the east of the Otway Range possess tidal swamps with braided channels and brackish lagoons. Thompson Creek and Painkalac Creek have such river mouths, although the most extensive swamp lies just outside the present study area, surrounding the mouth of the Barwon River.

Only minor differences in height above mean tide level determine the differences between the land components. The marine terraces escape inundation in all but extremely rare combinations of floods and high tide, while most other tracts of land are flooded either regularly or irregularly.

Halophytic shrubs and herbs colonize the grey and structureless silty clays found on these swamps. The structure and species of each community are strongly influenced by the height above mean tide level and the degree of salinity of the tidal water.

Some parts of these areas have been drained or filled to provide for agriculture or recreational facilities. However, most parts remain in their natural state.



These swamps lie just inland from the coastal dunes and provide valuable habitats for wildlife.

CONNEWARE		Component and its proportion of land system		
		1 30%	2 30%	3 10%
		4 15%	4 15%	5 15%
CLIMATE				
Rainfall, mm	Annual: 625, lowest January (30), highest August (60)			
Temperature, °C	Annual: 14, lowest July (10), highest February (18)			
Seasonal growth limitations	Temperature: less than 10°C (av.) July			
Precipitation: less than potential evapotranspiration October – early April				
GEOLOGY				
Age, lithology	Veneer of aeolian sand			
TOPOGRAPHY				
Landscape	Flat estuarine lowlands with braided channels			
Elevation, m	0-4			
Local relief, m	1			
Drainage pattern	Deranged			
Drainage density, km/km ²	-			
Land form	Marine terrace			
Land form element	Upper surface occasionally inundated			
Slope (and range), %	0 (0-2)			
Slope shape	Convex			
NATIVE VEGETATION				
Structure	Lower surface regularly inundated			
Dominant species	0 (0-1) Linear			
(Not known)	0 Linear			
SOIL				
Parent material	Marine terrace			
Description	Estuarine clay, silt and plant remains			
Surface texture	Saline soils			
Permeability	Estuarine clay, silt and plant remains			
Depth, m	Saline soils			
	Silicate soils			
	Sandy loam			
	Moderate			
	>2			
LAND USE				
Cleared areas:	Some of the higher areas cleared for grazing, cropping and recreational facilities.			
Uncleared areas:	Nature conservation; refuse disposal.			
SOIL DETERIORATION HAZARD				
Critical land features, processes, forms	Sodic subsoils with high saline groundwater tables are prone to soil salting, surface compaction and sheet erosion.	Regular influx of estuarine saline water on clays of low mechanical strength leads to soil salting and compaction.	Sodic subsoils with low permeability and high saline groundwater tables are prone to surface compaction and soil salting.	

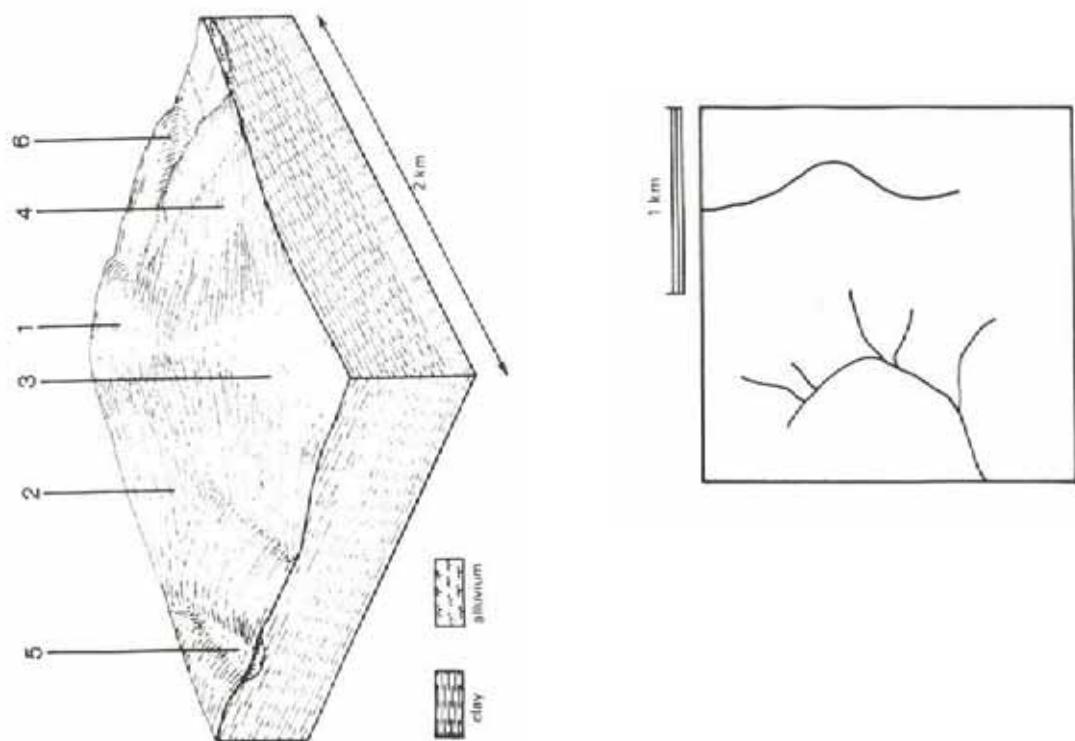
7.15 Deepdene Land System

An extensive lateritic plateau to the north of the Otway Range has been dissected by the Barwon River and its tributaries. There are several plateau remnants separated by alluvial plains of the Barwon River land system. In general, flat or gently undulating plains occupy the highest parts of the landscape, and these are surrounded by gentle slopes leading to slightly lower surfaces or by steep scarp falls away to the alluvial plains.

The areas to the west of the Barwon River is more dissected, with generally steeper slopes.

The soils on the highest levels have been strongly lateritized, with ironstone throughout the profile and concentrated in discontinuous layers at about 1.2 m depth. Similar soils without ironstone are found on lower levels, while the gentle slopes between these levels possess heavier-textured soils with coarse blocky structures in the subsoils.

Clearing has been widespread and the land is used for sheep and beef cattle grazing as well as some dairying. Soil salting has occurred in some areas, and major problems have arisen due to gully and tunnel erosion. The more dissected areas to the west of the Barwon are the most susceptible, and damage has been widespread.



Dispersible subsoils on the steeper slopes of this landscape are highly susceptible to gully erosion and landslips.

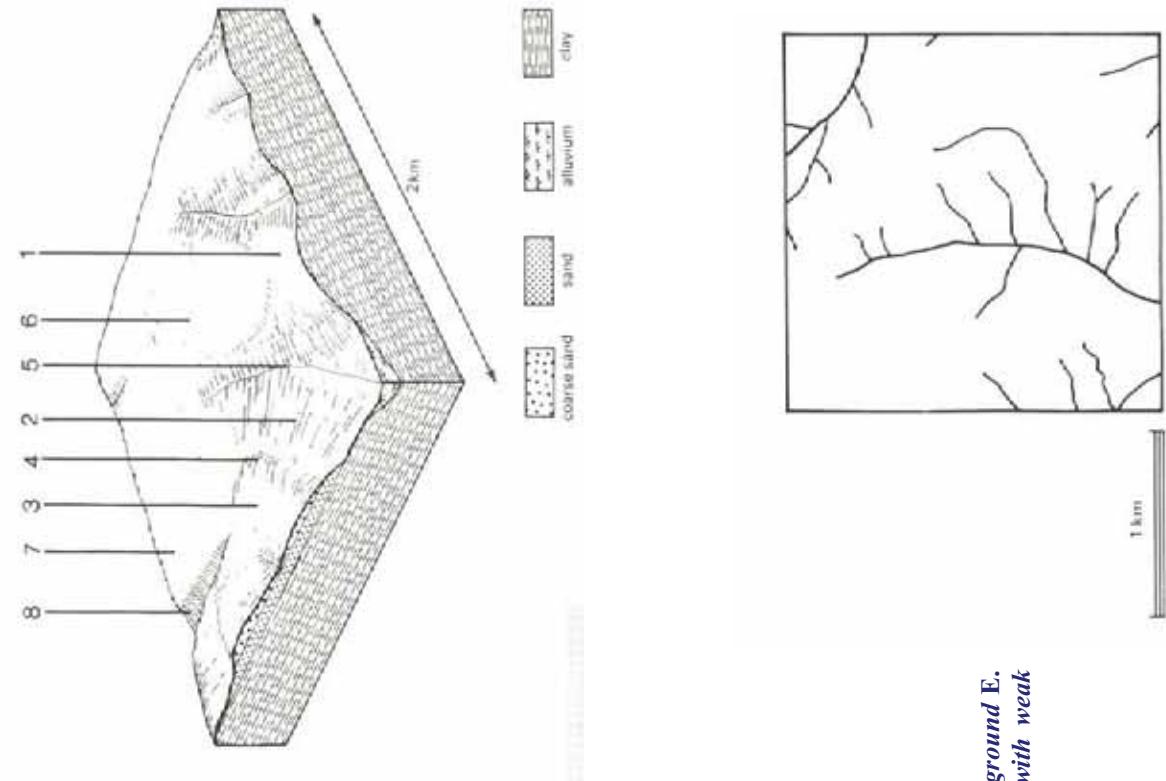
DEEPDENE		Components and its proportion of land system			
	1 40%	2 15%	3 20%	4 10%	5 7%
CLIMATE	Annual: 650 – 700, lowest January (30), highest August (85) Annual: 13, lowest July (8), highest February (9) Temperature: less than 10°C (av.) June – August Precipitation: less than potential evapotranspiration early October – late April	Undulating plain inland of the Otway Range 120 - 190 40	Gentle broad slope 3 (0-7) Convex	High level terrace 1 (0-2) Linear	Scarp - 35 (10-50) Linear, Convex
GEOLOGY	Age, lithology	Pliocene clay, silt and sand			
TOPOGRAPHY	Landscape	Undulating plain inland of the Otway Range			
	Elevation, m	120 - 190			
	Local relief, m	40			
	Drainage pattern	Dendritic			
	Drainage density, km/km ²				
	Land form				
	Land form element				
	Slope (and range), %				
	Slope shape				
NATIVE VEGETATION	Open forest <i>E. viminalis</i> , <i>E. obliqua</i> , <i>E. radiata</i>	Open forest <i>E. viminalis</i> , <i>E. ovata</i>	Open forest <i>E. obliqua</i> , <i>E. viminalis</i> , <i>E. ovata</i> , <i>E. radiata</i>	Woodland <i>E. viminalis</i> , <i>E. obliqua</i> , <i>E. ovata</i>	Closed scrub <i>Leptospermum juniperinum</i> <i>Melaleuca squarrosa</i>
SOIL	Lateritized sediments Mottled yellow and red duplex soils with ironstone Sandy loam Moderate 1.2	Clay, silt and sand Yellow-brown sodic duplex soils, coarse structure Fine sandy loam Low >2	Alluvial clay, silt and sand Yellow-brown calcareous sodic soils, coarse structure Fine sandy loam Low >2	Alluvial clay, silt and sand Grey gradational soils Fine sandy clay loam Very low >2	Clay, silt and sand Yellow sodic duplex soils Sandy loam Moderate >2
LAND USE	Cleared areas: Sheep and beef cattle grazing; cash and row cropping; dairy farming.	Dispersible clay subsoils of low inherent fertility, phosphate fixation and permeable surface soils lead to gully and tunnel erosion. Sodic subsoils of low permeability receiving saline seepage are prone to soil salting.	Low inherent fertility, phosphate fixation and permeable surface soils lead to nutrient decline.	Dispersible clay subsoils of low permeability are prone to gully and tunnel erosion and soil salting.	Dispersible soils on steep slopes subject to periodic saturation are prone to landslips and sheet erosion.
SOIL DETERIORATION	Low inherent fertility, phosphate fixation, and permeable surface soils lead to nutrient decline.				
HAZARD	Critical land features, processes, forms				

7.16 Ferguson Hill Land System

Most outcrops of Tertiary sediments to the west of the Otway Range are either deeply dissected or deeply weathered soils. However, some ridges and spurs are only mildly dissected and their soil profiles are only weakly developed. These areas are found at Ferguson Hill, just south of Simpson, along Pipeline Road and in an additional small area near Cape Otway.

The parent material is Tertiary sand, silt and clay, with some minor areas of lateritic ironstone. The soils vary according to the nature of the outcropping beds, but in general their structure is weak and often the A and B horizons are not clearly differentiated. Profile drainage is good on all but those areas with hardpans, and these are the only areas prone to waterlogging despite the high annual rainfall.

Eucalyptus obliqua and *E. baxteri* colonize most areas and often reach heights in excess of 30 m on the better-drained soils. However, these stands are decreasing in areas as much of the land is being cleared for agriculture. The soils are naturally quite stable and the major problems are likely to arise from nutrient decline.



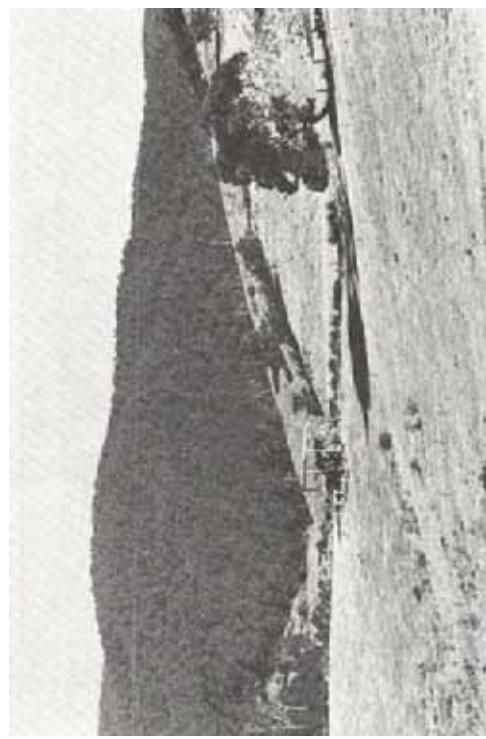
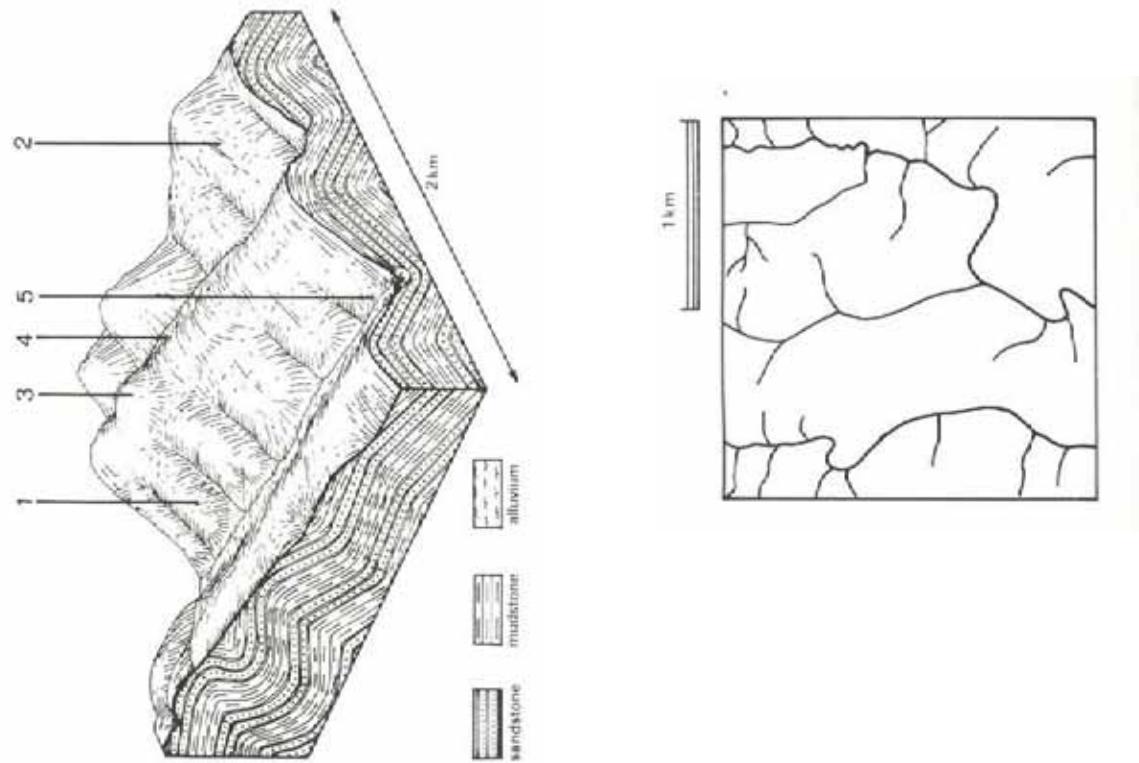
Along Pipeline Road the dissection is only mildly developed on these comparatively youthful soils. In the foreground *E. nitida* grown on grey sand soils, while in the distance tall open woodlands occur on red gradational soils with weak structures.

7.17 Forrest Land System

From Upper Gellibrand to Peters Hill, steep spurs and ridges with long straight slopes and narrow valleys form the rugged northern margin of the Otway Range. The climate is significantly drier than in other parts of the Range, with most areas receiving an annual rainfall of about 900 mm. The inland extent of the land system marks the northern boundary of continuous Cretaceous outcrop, although sporadic outcrops occur in the adjacent Pennyroyal land system.

The separation of these drier spurs and ridges from the rest of the Range is well reflected by changes in the structure and composition of the native vegetation. In particular, *Eucalyptus radiata* becomes a prominent member of the dominant stratum and the understorey changes from mesophytic species to drier sclerophyllous species such as *Acacia mucronata*, *A. verticillata*, *Cassinia longifolia* and *Eucrasis impressa*.

Most of this land system remains forested and is selectively logged for malleable timber. Some parts of the eastern areas have been cleared for grazing, but management is difficult due to rugged terrain. Softwood plantations have also been established. Landslips and sheet erosion have been severe in some areas, and rapid run-off from these hills creates problems of gully erosion in the Barwon River land system.



On the areas that have been cleared weeds such as blackberries and ragwort become a problem.

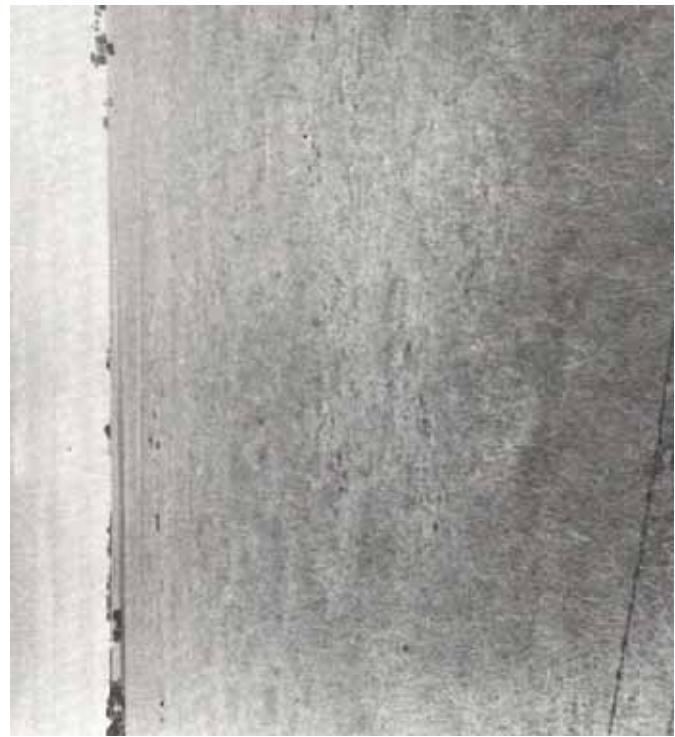
FORREST		Component and its proportion of land system		
	1 10%	2 50%	3 4%	4 35%
CLIMATE				5 1%
Rainfall, mm	Annual: 900 – 1,100, lowest January (45), highest August (130)			
Temperature, 0°C	Annual: 12, lowest July (7), highest February (17)			
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September			
Precipitation: less than potential evapotranspiration mid November – mid March				
GEOLOGY				
Age, lithology	Lower Cretaceous feldspathic sandstone and mudstone			
TOPOGRAPHY				
Landscape	Deeply dissected hills of the Otway Range			
Elevation, m	150 – 400			
Local relief, m	150			
Drainage pattern	Dendritic			
Drainage density, km/km ²	3.8			
Land form	Hill			
Slope (and range), %	North and west facing slopes 45 (25-65) Linear	Crest, upper slope 45 (25-65) Convex	South and east facing slopes 45 (25-65) Linear	Lower slope, drainage line 20 (1-35) Concave
Slope shape				
NATIVE VEGETATION				
Structure	Open forest	Tall open forest	Tall open forest	
Dominant species	<i>E. obliqua, E. radiata, E. cypellocarpa</i>	<i>E. obliqua, E. radiata, E. cypellocarpa</i>	<i>E. obliqua, E. radiata, E. cypellocarpa</i>	<i>E. cypellocarpa, E. obliqua</i>
SOIL				
Parent material	In-situ weathered rock	In-situ weathered rock	Tall open forest	Tall open forest
Description	Stony brown gradational soils	Brown duplex soils	Brown gradational soils	Brown gradational soils
Surface texture	Fine sandy loam	Loam	Loam	Loam
Permeability	Very high	Moderate	High	Silty loam
Depth, m	0.5	0.9	0.9	Loam >2
LAND USE				
Uncleared areas: Hardwood forestry for sawlogs, posts and poles; softwood forestry; nature conservation; active and passive recreation; water supply.				
Cleared areas: Beef cattle grazing on mainly unimproved pastures.				
SOIL DETERIORATION				
HAZARD				
Critical land features, processes, forms	Stony shallow soils with weak structure and low water holding capacity on steep slopes are prone to sheet erosion and landslips.	Dry aspect, steep slopes and weak structured surfaces lead to sheet erosion. Clay subsoils on steep slopes subject to periodic saturation are prone to landslips.	Steep slopes are prone to sheet erosion. Clay subsoils on steep slopes subject to periodic saturation are prone to landslips.	Weakly structured soils receiving run-off are prone to scour gullying, siltation and flooding.

7.18 Freshwater Creek Land System

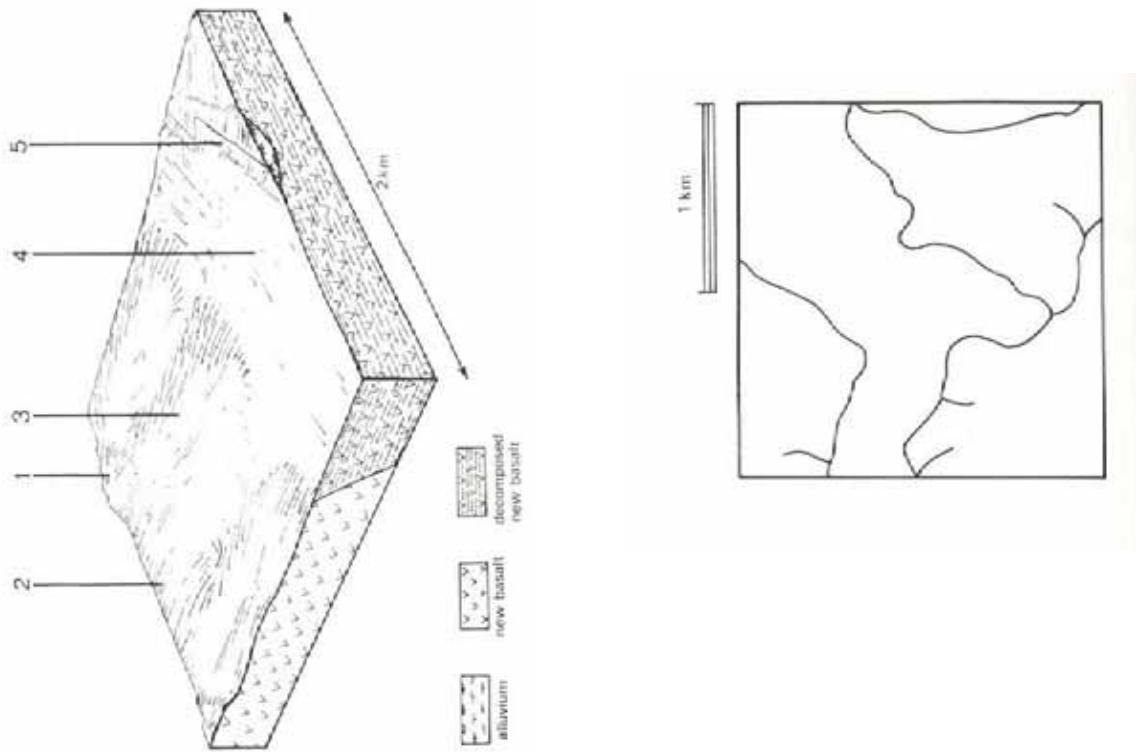
These gently sloping plains with heavy soils are similar to many areas on the basaltic plains of Western Victoria. Unlike most parts of the plains, this originally carried a woodland of *Eucalyptus viminalis* and *E. ovata*, which now exists mainly as roadside remnants.

These species tend to be replaced by *E. leucoxylon* in the east and *E. camaldulensis* in the north, the latter species being the most common tree on the basaltic plains in western Victoria. The presence of *E. viminalis* and *E. ovata* may reflect the climate, which is wetter than is normal for basaltic plains.

The main land use is sheep and beef cattle grazing. The low incidence of basaltic outcrops means that much of the area is arable, and cereal cropping is common. Minor soil salting and gully erosion occur.



Flat or very gently undulating plains are typical of much of the basalt outcrops in western Victoria. This area carries significantly more trees than is usual on these basalt plains.



FRESHWATER CREEK		Component and its proportion of land system		
	1 7%	2 10%	3 65%	
	4 15%	5 3%	5 3%	
CLIMATE				
Rainfall, mm				
Temperature, 0°C	Annual: 600 – 650, lowest January (30), highest August (60)			
Seasonal growth limitations	Annual: 14, lowest July (9), highest February (19)			
Temperature: less than 10°C (av.) June – July				
Precipitation: less than potential evapotranspiration October – mid April				
GEOLOGY				
Age, lithology	Pleistocene basalt with some areas of scoria and tuff			
TOPOGRAPHY				
Landscape	Gently undulating plains in the catchment of Thompson Creek			
Elevation, m	5 – 140			
Local relief, m	20			
Drainage pattern	Dendritic			
Drainage density, km/km ²				
Land form	Cone, scarp			
Slope (and range), %	8 (6-20)			
Slope shape	Convex			
NATIVE VEGETATION				
Structure	Open forest			
Dominant species	<i>E. viminalis</i> , <i>E. ovata</i> , <i>Casuarina stricta</i>			
SOIL				
Parent material	Scoria, freshly weathered basalt			
Description	Stony red-brown gradational soils			
Surface texture	Mottled yellow and red duplex soils			
Permeability	Gravelly loam			
Depth, m	High 0.3			
LAND USE				
SOIL DETERIORATION	Beef cattle grazing; dairy farming; cropping			
HAZARD	Stony shallow soils with low water holding capacity and impermeable rock layers are prone to sheet erosion.			
Critical land features, processes, forms	Minor hazards			

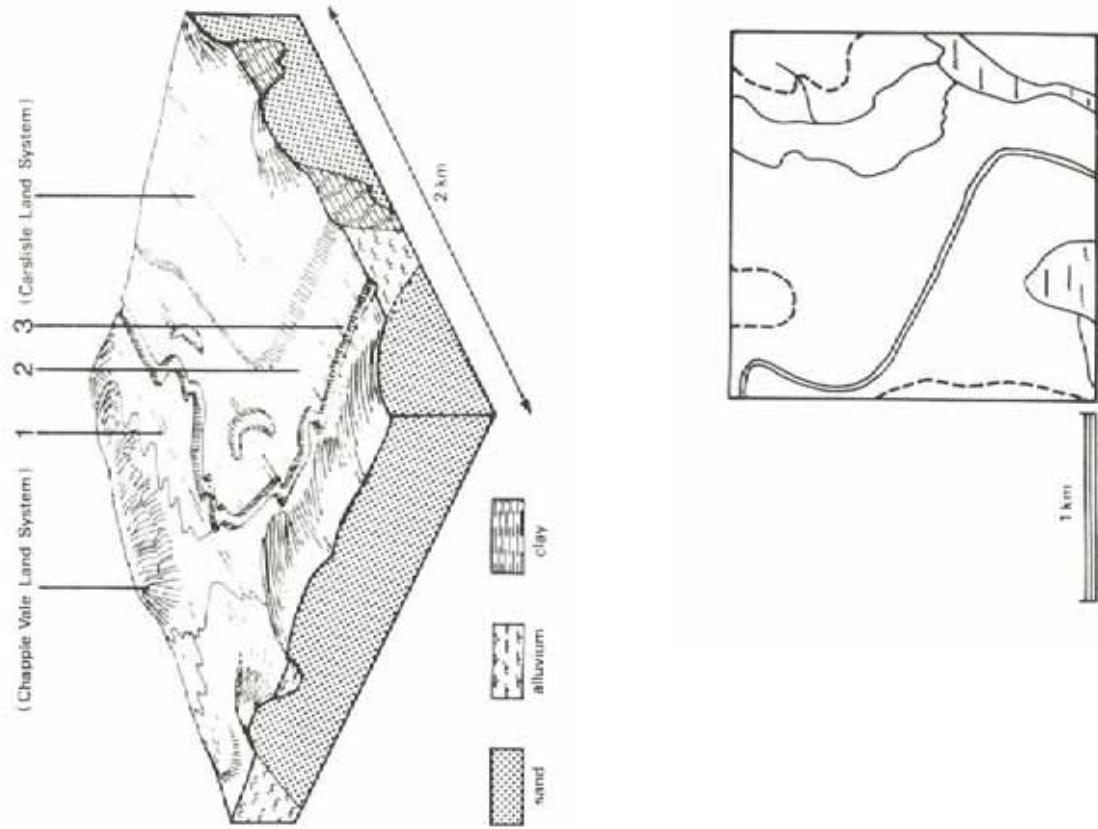
7.19 Gellibrand River Land System

Many of the larger rivers in the wetter parts of the study area have extensive flood plains. Areas large enough to map exist on the Barham, Aire and Johanna Rivers as well as the Gellibrand River and its tributaries.

The landscape is generally flat, but irregular areas occur in the form of infilled meanders and minor terraces. In general, most areas are poorly drained, with stunted vegetation. However, closer to the drainage lines, the improved drainage often results in conditions more favourable for plant growth.

Most of these alluvial flats have been cleared and provide valuable summer grazing for dairy farms along the valleys.

Areas prone to waterlogging have been drained and improved pastures established. However, the remoteness of the valleys, set among very infertile surrounding land, has hampered agricultural development.



The Aire River has an extensive floodplain with many swamps and lakes where it emerges from the Otway Range near Hordern Vale.

GELLIBRAND RIVER

	Component and its proportion of land system		
	1 60%	2 30%	3 10%
CLIMATE			
Rainfall, mm	Annual: 950 – 1,100, lowest January (45), highest August (135)		
Temperature, °C	Annual: 13, lowest July (8), highest February (18)		
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September; July only near the coast		
Precipitation: less than potential evapotranspiration early November – late March; December – January near coast			
GEOLOGY			
Age, lithology			
TOPOGRAPHY			
Landscape	Recent alluvium derived from the Otway Range and surrounding foothills.		
Elevation, m	Alluvial flood plain of the Gellibrand, Aire and Barham Rivers		
Local relief, m	0 – 100		
Drainage pattern	Major meandering stream with deranged tributaries		
Drainage density, km/km ²	1.3		
Land form			
Poorly drained lower reaches	Alluvial terrace		
1 (0-2)	Well-drained upper reaches		
Linear	0 (0-1)		
Slope shape	Linear		
NATIVE VEGETATION			
Structure	Tall open forest		
Dominant species	<i>E. viminalis</i> , <i>E. obliqua</i> , <i>E. ovata</i> , <i>Acacia melanoxylon</i>		
SOIL			
Parent material	Alluvial clay, silt and sand		
Description	Grey gradational soils		
Surface texture	Fine sandy loam		
Permeability	Very low		
Depth, m	>2		
LAND USE			
Cleared areas:	Dairy farming and beef cattle grazing on improved pastures; row and fodder cropping; water supply		
Uncleared areas:	Water supply; nature conservation; hardwood forestry for sawlogs		
SOIL DETERIORATION HAZARD			
Critical land features, processes, forms	High discharge rates along watercourses lead to flooding and siltation. High seasonal water table and low permeabilities lead to seasonal waterlogging and soil compaction.		

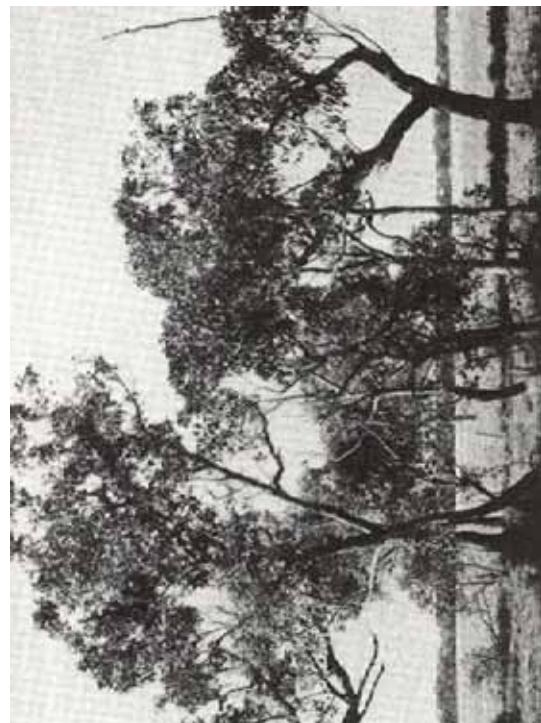
7.20 Gherang Gherang Land System

Inland from Point Addis and extending west as far as Wormbete Creek, flat-topped hills represent the remnants of an extensive former lateritic plateau. Small remnants are also found further north towards Moriac.

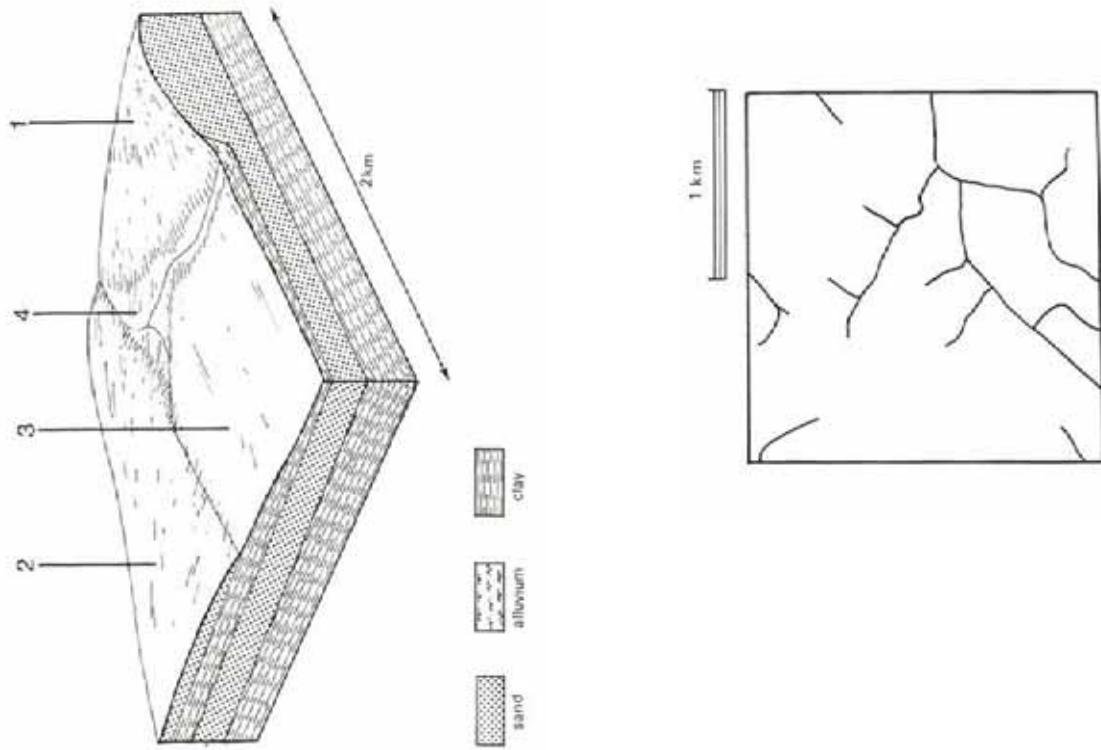
Over most of this landscape lateritic profiles are present, indicating former climatic conditions different from those experienced today. Where the Tertiary sediments contain excessive amounts of gravel, lateritic profiles are absent, but there is still evidence of deep weathering and leaching.

The soils are generally infertile, carrying a vegetation of stunted woodlands of *Eucalyptus obliqua* and *E. radiata*. The cinnamon fungus, *Phytophthora cinnamomi*, is very common on these plateau remnants and large areas of dead and dying native vegetation can be found.

Many of these remnants remain uncleared and are used for flora and fauna reserves and some minor forestry operations. Gravel extraction pits have been established on suitable areas of Crown land. These pits will not revegetate quickly without the appropriate management and have become popular with trail-bike-riders.



The flat lateritic plateaux carry woodland of E. obliqua and E. radiata, but the timber is generally unsuitable for milling.



GHERANG GHERANG

Area: 52 km²

		Component and its proportion of land system		
		1 20%	2 7%	3 65%
		4 8%		
CLIMATE				
Rainfall, mm	Annual: 600 – 850, lowest January (35), highest August (80)			
Temperature, 0°C	Annual: 14, lowest July (9), highest February (17)			
Seasonal growth limitations	Temperature: less than 10°C (av.) July			
Precipitation: less than potential evapotranspiration mid October - April	Lateritized Tertiary clay, gravel and clayey silt			
GEOLOGY				
Age, lithology	Recent aeolian siliceous sand			
TOPOGRAPHY				
Landscape	Flat or gently dissected plateau remnants			
Elevation, m	50 - 230			
Local relief, m	10			
Drainage pattern	Rectangular			
Drainage density, km/km ²				
Land form	Gently undulating plateau			
Slope (and range), %	1.6			
Slope shape	Broad flat crest, slope 2 (0-3) Irregular			
NATIVE VEGETATION				
Structure	Open forest			
Dominant species	<i>E. obliqua, E. radiata, E. ovata</i>	<i>E. obliqua, E. baxteri, E. radiata, E. aromaphloia</i>	<i>E. ovata, E. viminalis</i>	
SOIL				
Parent material	Siliceous sand	Lateritized sediments	Alluvial sand, clay, silt and plant remains	
Description	Grey sand soils, uniform texture	Mottled yellow and red duplex soils with ironstone	Yellow-brown duplex soils, coarse structure	
Surface texture	Loamy sand	Loamy sand	Fine loamy sand	
Permeability	Very high	Moderate	Very low	
Depth, m	>2	1.2	>2	
LAND USE				
	Uncleared areas: Hardwood forestry for posts, poles and firewood; nature conservation; passive and active recreation; gravel extraction.			
	Cleared areas: Beef cattle grazing on unimproved pastures; residential			
SOIL DETERIORATION HAZARD	Low inherent fertility and high permeability lead to leaching of nutrients.	Low inherent fertility phosphate fixation and leaching of permeable upper horizons	High seasonal water table and weak surface	
Critical land features, processes, forms	Weakly structured sands with low water holding capacities are prone to wind erosion.	lead to nutrient decline.	structured lead to surface compaction.	

7.21 Hordern Vale Land System

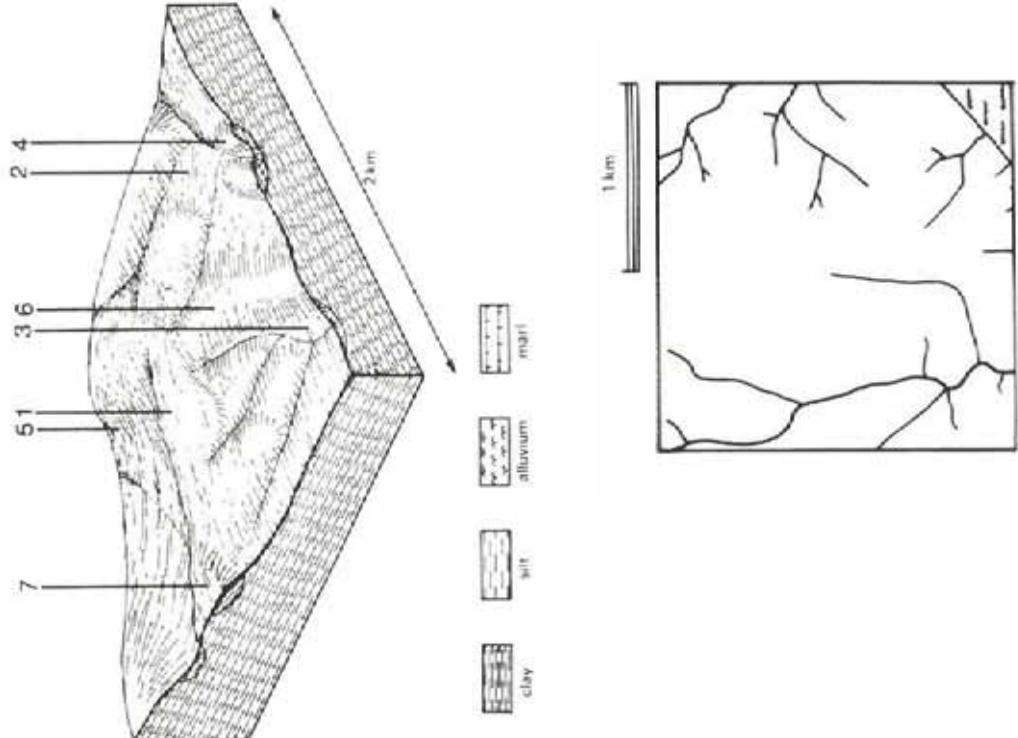
In the vicinity of Cape Otway, Tertiary clay, silt, sand, limestone and marl all outcrop. Three separate areas exist – at Johanna, Hordern Vale and inland from Point Franklin and Blanket Bay. All areas are generally similar, but possess distinct differences in specific features. The limestone and marl outcrops are confined to marine terraces at Hordern Vale. The Johanna area is distinguished by its dominance of red sands. The area east of Cape Otway includes hilltops of kaolinitic clay and silt and these carry rare low woodlands of *Eucalyptus kitsonia*.

In general, these landscapes are old with areas of lateritized soils on the highest parts. Recent dissection has often been superimposed on the more undulating areas, resulting in straight slopes with youthful soil profiles.

Land uses are very diverse. Areas that have been cleared are used for dairy farming, grazing of sheep and beef cattle and a small amount of potato growing. Those areas that remain uncleared are selectively logged, and also have nature conservation values. Sheet erosion and landslips have been quite severe on some of the steeper areas, and some gully erosion occurs on the slopes coming away from the lateritized areas.



Youthful dissection with steep straight slopes and young soils is encroaching on many of the more gently undulating higher parts of the landscape.



HORDERN VALE		Component and its proportion of land system			
		1 20%	2 8%	3 7%	4 4%
CLIMATE				5 25%	6 30%
Rainfall, mm	Annual: 900 – 1,250, lowest January (50), highest July (130)				
Temperature, °C	Annual: 13, lowest July (9), highest February (17)				
Seasonal growth limitations	Temperature: less than 10°C (av.) July				
Precipitation: less than potential evapotranspiration late November - February	Paleocene unconsolidated sand, clay and silt				
GEOLOGY	Limestone, marl				
TOPOGRAPHY	Undulating coastal plains surrounding Cape Otway				
Landscape	0 - 200				
Elevation, m	0 - 60				
Local relief, m	Dendritic				
Drainage pattern	2.1				
Drainage density, km/km ²	Rise				
Land form	Upper slope, crest				
Slope (and range), %	5 (1-15)				
Slope shape	Convex				
NATIVE VEGETATION	Valley floor				
Structure	Slope, river terrace				
Dominant species	7 (1-15)				
	Linear				
	Concave				
	Marine terrace				
	25 (10-55)				
	Convex				
SOIL	Rise				
Parent material	Valley floor				
Description	Slope, river terrace				
Dominant species	7 (1-15)				
	Linear				
	Concave				
	Marine terrace				
	25 (10-55)				
	Convex				
LAND USE	Rise				
Cleared areas:	Beef cattle grazing; dairy farming; sheep grazing; tow crops				
Uncleared areas:	Hardwood forestry for sawlogs and pulpwood; sand extraction; nature conservation; passive recreation				
	Clay subsoils on steep slopes subject to periodic saturation are prone to landslips				
SOIL	Steep slopes with weakly structured soils are prone to some sheet erosion.				
DETERIORATION	High rainfall, high permeability and leaching lead to nutrient decline and surface compaction upon disturbance.				
HAZARD	High rainfall and high permeability lead to nutrient decline.				
Critical land features, processes, forms	Low permeability and high annual rainfall lead to waterlogging and soil compaction.				

7.22 Junction Track Land System

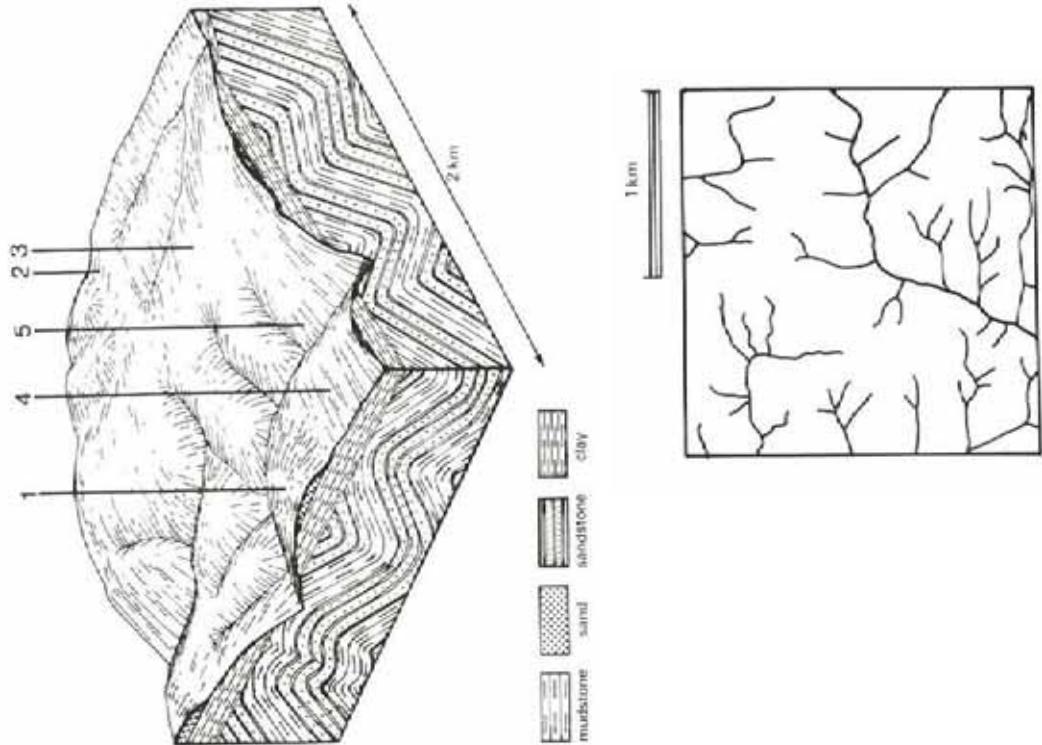
The junction between Cretaceous and Tertiary sediments on the western periphery of the Otway Range is clearly reflected in vegetation changes. However, the junction is discontinuous and there is a belt of land where the higher parts of the landscape are capped by Tertiary sands with only occasional areas of silts and clays derived from Cretaceous sediments. The lower slopes are often steeper, with outcrops of Cretaceous sandstones and mudstones. Thus, the higher areas carry low woodlands of *Eucalyptus nitida* and *E. baxteri*, while the lower slopes support open forests or even tall open forests of *E. obliqua* and *E. cypellocarpa*.

This landscape pattern is somewhat similar to the Redwater Creek land system. The major distinguishing feature is that the position in the landscape at which the Cretaceous sediments outcrop is very variable. The deposit of sand above the Cretaceous sediments varies in thickness, but is usually deep enough for the native vegetation to be dependent upon the sand for its nutrient supply.

Most parts of this land system remain uncleared and unused. Some sand and gravel extraction pits have been established in the past. Pines have been established on small areas adjoining privately held land.



Most slopes support low woodlands of E. nitida, but outcrops of Cretaceous sediments can be recognised by the increases soil fertility and the accompanying change to open forests or tall open forests of E. obliqua and E. cypellocarpa.



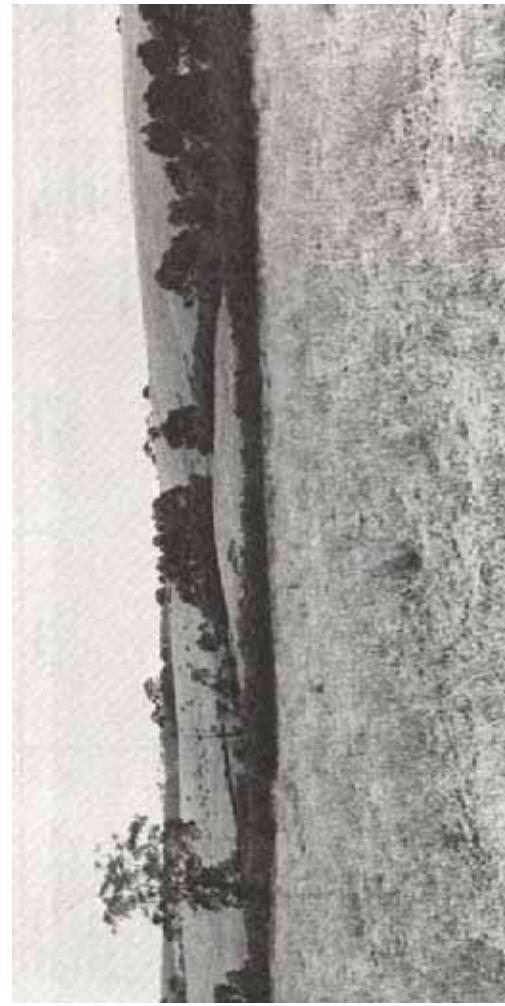
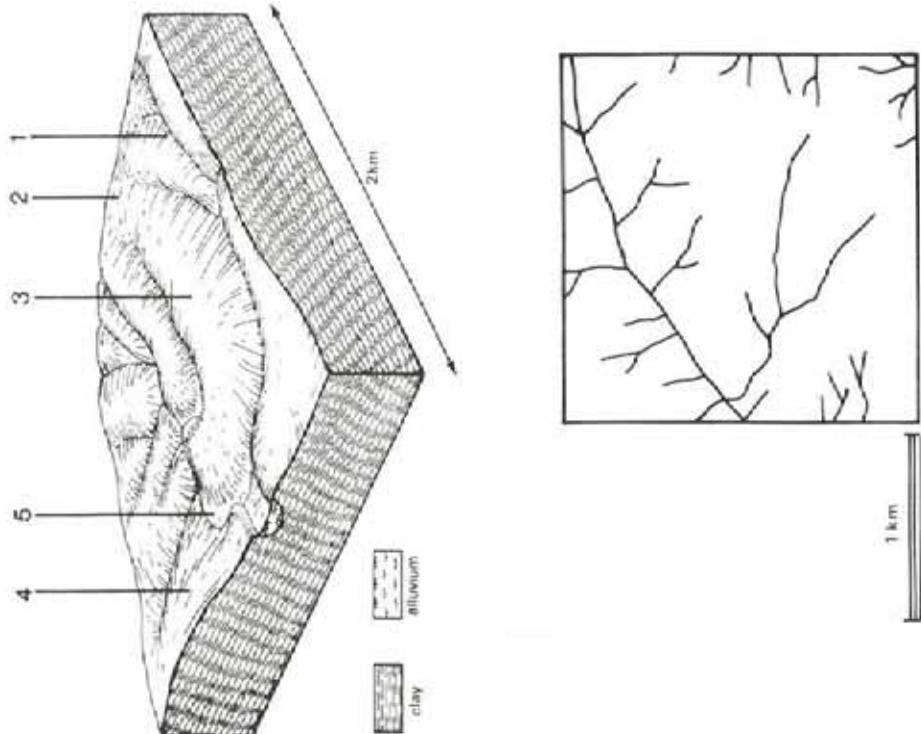
JUNCTION TRACK		Component and its proportion of land system	
		1 30%	2 5%
		3 20%	4 30%
CLIMATE			5 15%
Rainfall, mm			
Temperature, 0°C			
Seasonal growth limitations			
GEOLOGY			
Age, lithology	Paleocene unconsolidated sand, gravel, silt and clay		Lower Cretaceous sandstone and mudstone
TOPOGRAPHY			
Landscape	Dissected hills with broad gentle hill cappings on western periphery of the Otway Range		
Elevation, m	30 - 270		
Local relief, m	75		
Drainage pattern			
Land form	Crest, slope 15 (2-35) Convex	Drainage line 3 (0.5) Concave	3.5 Hill
Slope (and range), %			
Slope shape		Lower slope 9 (3-12) Linear	Steep slope 12 (2-25) Convex
NATIVE VEGETATION			
Structure	Low woodland	Open woodland	Tall open forest
Dominant species	<i>E. nitida, E. baxteri</i>	<i>E. baxteri, E. nitida</i>	<i>E. obliqua, E. cypellocarpa</i>
SOIL			
Parent material	Quartz sand and gravel	Quartz sand and gravel	In-situ weathered rock
Description	Grey sand soils, uniform texture	Grey sand soils with hardpans, uniform texture	Brown gradational soils
Surface texture	Alluvial sand, plant remains	Loamy sand	
Permeability	Black sand soils, uniform texture	Very low	
Depth, m	Loamy sand Very high >2	1.1	Moderate High 1.5
LAND USE			
SOIL DETERIORATION	Uncleared areas: Sand and gravel extraction; hardwood forestry for posts, poles, fuel and some sawlogs on more fertile soils; nature conservation; water supply protection	High water tables lead to waterlogging.	Clay subsoils on steeper slopes subject to periodic saturation are prone to landslips. Soils of moderate permeability on steep slopes are prone to sheet erosion.
HAZARD	Very low inherent fertility and high permeability lead to nutrient decline. Steeper slopes with compacted soils are prone to sheet, rill and scour gully erosion.	Hardpans restrict vertical drainage leading to seasonal waterlogging. Very low inherent fertility, with some leaching of permeable high acidic surfaces, leads to nutrient decline.	Low inherent fertility and high permeability lead to nutrient decline. Weakly structured soils on steeper slopes are prone to sheet erosion.

7.23 Kawarren Land System

Rolling hills with occasional steep slopes and broad drainage lines are found in the vicinity of Kawarren. The landscape has several components, including some areas of red stony brown gradational soils developed on outcrops of basalt. However, old soils on deeply weathered Tertiary clay and sand tend to dominate the landscape.

Other land systems with similar soils and parent material are found to the east and west of this land system. However, the Kawarren land system is a rolling landscape whereas the others are gently undulating to flat. The Barongarook land system to the east has a slightly lower rainfall and *Eucalyptus baxteri* has not been observed in this area.

Clearing has been common and the main land uses are dairy farming and grazing of beef cattle and sheep. Some forested areas, such as the old Beech Forest railway escarpment, are popular for bushwalking. Pine establishment is common on private land. Sheet erosion and landslips have occurred on the steeper slopes.



Most of the cleared areas are used for dairy farming

KAWAREN		Component and its proportion of land system			
		1 15%	2 10%	3 60%	4 10%
CLIMATE					
Rainfall, mm	Annual: 850 – 1,100, lowest January (40), highest August (120)				
Temperature, °C	Annual: 12, lowest July (8), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September				
Precipitation: less than potential evapotranspiration	Precipitation: less than potential evapotranspiration November - March				
GEOLOGY					
Age, lithology	Paleocene unconsolidated clay, silt and sand				
TOPOGRAPHY					
Landscape	Rolling hills in the northern upper reaches of the Gellibrand River catchment				
Elevation, m	75 - 210				
Local relief, m	60				
Drainage pattern	Dendritic with some radial areas				
Drainage density, km/km ²	2.6				
Land form	Hill				
Land form element	Crest, slope				
Slope (and range), %	9 (1-15)				
Slope shape	Convex				
NATIVE VEGETATION					
Structure	Open forest				
Dominant species	<i>E. obliqua</i> , <i>E. radiata</i> , <i>E. viminalis</i>				
	<i>E. radiata</i> , <i>E. obliqua</i> , <i>E. nitida</i> , <i>E. ovata</i>				
	<i>E. viminalis</i> ; occasionally <i>E. ovata</i>				
SOIL					
Parent material	Colluvial sand on unconsolidated clay				
Description	Yellow gradational soils, weak structure				
Surface texture	Sandy loam				
Permeability	High				
Depth, m	>2				
LAND USE					
SOIL DETERIORATION HAZARD	Uncleared areas: Hardwood forestry for sawlogs, posts and poles; softwood plantations; nature conservation; passive recreation; water supply; forest grazing Cleared areas: Beef cattle and sheep grazing; dairy farming; water supply				
Critical land features, processes, forms	Clay subsoils on steep slopes subject to periodic saturation are prone to landslips. Steep slopes are prone to sheet and rill erosion.				
SOIL DETERIORATION HAZARD	Clay subsoils on steep slopes subject to periodic saturation are prone to landslips. Steep slopes are prone to sheet and rill erosion.	Low subsoil permeabilities leads to seasonal waterlogging. Low permeability and inherent fertility and permeable surface horizons lead to nutrient decline.	Low inherent fertility and phosphorus fixation lead to nutrient decline.	Dispersible clay subsoils of low permeability are prone to gully erosion. Clay subsoils on steeper slopes subject to periodic saturation are prone to landslips.	Low permeabilities and high water tables lead to gully erosion. Clay subsoils on steeper slopes subject to periodic saturation flooding and gully erosion.

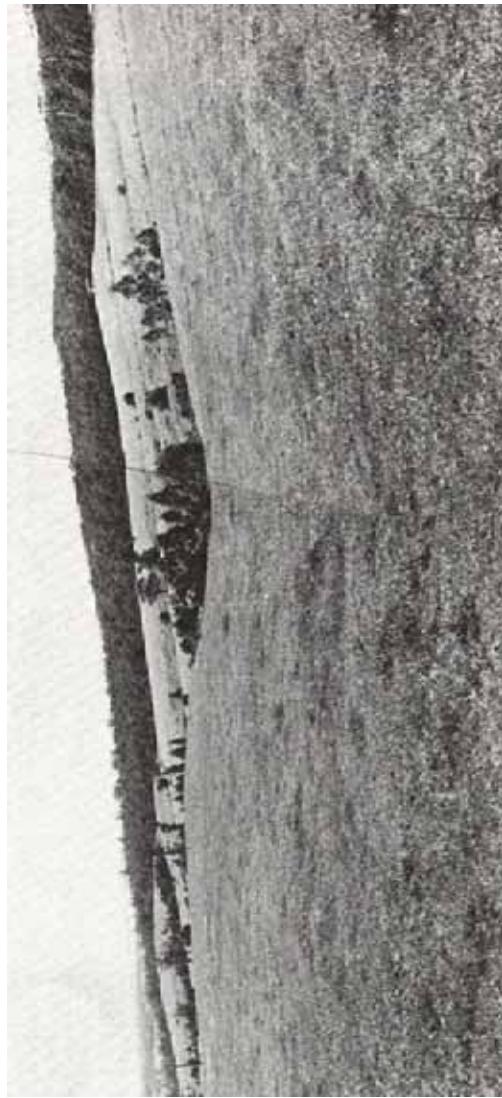
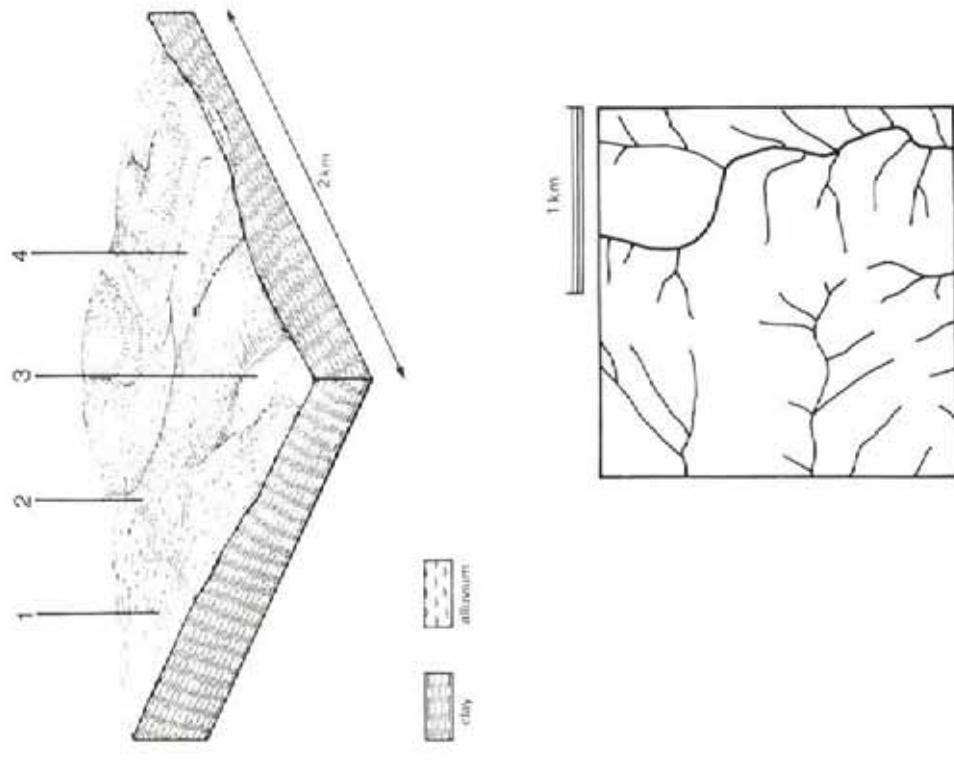
7.24 Kennedys Creek Land System

From Princetown, stretching northwards, an undulating plain can be found extending up into the catchment of Kennedys Creek. The southern parts consist of a series of north-nor'-west and south-sou'-east-oriented ridges, but the major part of the land system is a plain with dendritic drainage pattern.

The higher parts of the landscape have deeply weathered soils with yellow and red mottled. Most slopes, however, carry heavier-textured soils with dark-coloured and coarsely structured subsoils. They extend up to the crests and ridges in many areas; less weathered profiles occupy the lower parts of the landscape.

This pattern resembles that found in many other land systems on Tertiary sediments. The distinguishing features here are the dominance of the coarsely structured soils in the landscape, and the absence of lateritic cappings.

Dairy farming is the main land use, and only small areas still remain under native forest. The coarsely structured subsoils are dispersible and gully and tunnel erosion have occurred. On recently cleared areas, particular care is needed to prevent gullies being initiated. Landslips also occur on these soils.



Only a few forested areas remain, dairy farming being the main land use

KENNEDYS CREEK

Area: 95 km²

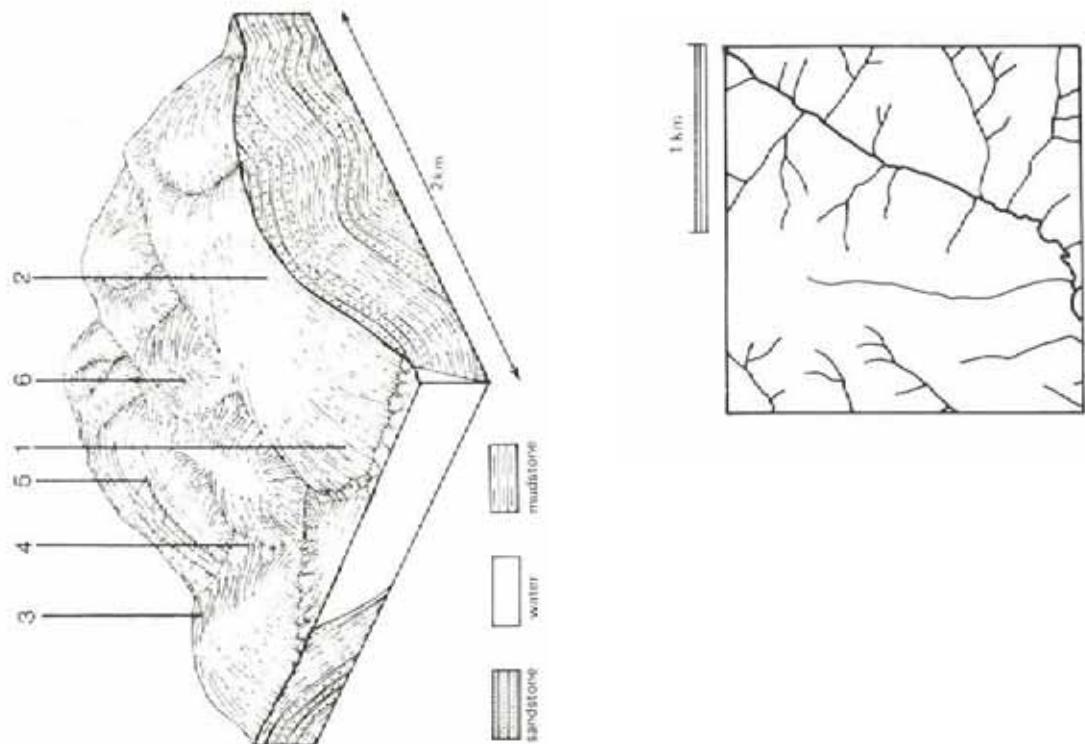
		Component and its proportion of land system		
	1 20%	2 65%	3 6%	4 9%
CLIMATE				
Rainfall, mm				
Temperature, 0°C				
Seasonal growth limitations				
GEOLOGY				
Age, lithology	Miocene unconsolidated marine clay, silt and sand			
TOPOGRAPHY				
Landscape	Undulating plain			
Elevation, m	15 – 150			
Local relief, m	70			
Drainage pattern	Predominantly dendritic with some trellis			
Drainage density, km/km ²	4.0			
Land form				
Land form element				
Slope (and range), %				
Slope shape				
NATIVE VEGETATION				
Structure				
Dominant species	Open forest <i>E. obliqua</i> , <i>E. viminalis</i> , occasionally <i>E. ovata</i>	Open forest <i>E. aromaphloia</i> , <i>E. viminalis</i> , <i>E. obliqua</i> , <i>E. radiata</i> , <i>E. ovata</i>	Open forest <i>E. obliqua</i> , <i>E. radiata</i> , occasionally <i>E. viminalis</i>	Woodland <i>E. ovata</i> , <i>E. obliqua</i> , <i>E. viminalis</i>
SOIL				
Parent material				
Description	Clay and silt Mottled yellow and red gradational soils	Clay and silt Yellow-brown gradational soils, coarse structure	Clay and silt Grey-brown gradational soils	Alluvial clay, silt and sand Mottled yellow and grey gradational soils
Surface texture				
Permeability				
Depth, m	Fine sandy loam Moderate >2	Fine sandy loam Low >2	Fine sandy loam Moderate >2	Sandy loam Low >2
LAND USE				
Cleared areas:	Dairy farming; beef cattle and sheep grazing; water supply			
Uncleared areas:	Water supply; hardwood forestry; nature conservation	High dispersible clay subsoils are prone to sheet erosion.	Steeper slopes are prone to sheet erosion.	Dispersible clay subsoils of low permeability are prone to gully erosion.
SOIL DETERIORATION HAZARD	Low inherent fertility, phosphorus fixation and steep slopes lead to sheet erosion and nutrient decline.	High dispersible clay subsoils on moderate steep gully and tunnel erosion. Periodic saturation leads to landslips. Steeper slopes are prone to sheet erosion of nutrient-rich surface horizons.	Dispersible clay subsoils on moderate steep slopes are prone to gully erosion.	High water tables lead to seasonal waterlogging and soil compaction.

7.25 Lorne Land System

From Cinema Point to Moonlight Head, much of the coastline consists of steep slopes, coastal cliffs and rocky shore platforms. These coastal margins of the Range have a milder maritime climate than those areas further inland, and receive a lower rainfall. Inland from the coast the topography consists of steeply dissected spurs and ridges with cliffs and waterfalls.

The steepest slopes have shallow stony soils with areas of rock outcrop. Most slopes, however, have moderately deep duplex soils. On inland slopes with a southerly aspect, no strong profile differentiation has occurred and profiles are gradational. Tall open forests, with understorey species such as *Betfordia salicina*, *Olearia* spp. and *Pomaderis* spp., occupy these sites. On the duplex soils the trees are lower with a more open understorey.

Large tracts of this land system have been cleared and dairy farming is a major land use. The steep slopes and deep valleys create severe management problems. The coastal areas between Cinema Point and Apollo Bay have been popular for residential development. Landslips are very common and sheet erosion has been widespread.



Siting of roads, fences and access tracks in this rugged terrain creates many problems, and management is difficult

LORNE		Component and its proportion of land system			
		1 7%	2 8%	3 35%	4 5%
		5 35%	5 35%	5 35%	6 10%
CLIMATE					
Rainfall, mm	Annual: 850 – 1,200, lowest January (45), highest August (120)				
Temperature, °C	Annual: 13, lowest July (9), highest February (17)				
Seasonal growth limitations	Temperature: less than 10°C (av.) July				
Precipitation: less than potential evapotranspiration mid November – mid March					
GEOLOGY					
Age, lithology	Lower Cretaceous feldspathic sandstone and mudstone				
TOPOGRAPHY					
Landscape	Deeply dissected hills of the Otway Range				
Elevation, m	0 – 400				
Local relief, m	150				
Drainage pattern	Dendritic with some radial areas				
Drainage density, km/km ²	4.0				
Land form	Coastal cliff				
Land form element	Upper gentler slope				
Steep lower slope	North- and west-facing slopes; upper slope				
60 (30–75)	45 (5–55)				
Linear	Linear				
Slope (and range), %	20 (1–35)				
Slope shape	Concave				
Land form element	Hill				
Steep lower slope	South- and east-facing slopes				
60 (30–75)	45 (5–65)				
Linear	Linear				
NATIVE VEGETATION					
Structure	Deeply dissected hills of the Otway Range				
Dominant species	0 – 400				
<i>E. obliqua, E. globulus, E. radiata, E. cypellocarpa, Acacia melanoxylon</i>	150				
SOIL					
Parent material	Woodland				
Description	<i>E. obliqua, E. globulus, E. radiata, E. cypellocarpa, E. globulus</i>				
Structure	Tall open forest				
Dominant species	<i>E. obliqua, E. globulus, E. cypellocarpa, Acacia melanoxylon</i>				
<i>Casuarina stricta, Cassinia aculeata, E. obliqua, Alyxia buxifolia, Leucopogon parviflorus</i>	Tall open forest				
LAND USE					
Minor cleared areas: Hardwood forestry for sawlogs, posts and poles; softwood plantations; nature conservation; active and passive recreation; landscape conservation; water supply.	Stony brown gradational soils				
Uncleared areas: Dairy farming and beef cattle grazing on mainly unimproved pastures; residential.	In-situ weathered rock				
Native vegetation is sensitive to salt pruning and disturbance. Dispersible soils on steep slopes are prone to sheet erosion. Marine undercutting and saturation of soils lead to landslips.	Alluvium				
Native vegetation is sensitive to disturbance and to salt pruning. Dispersible soils on moderate slopes are prone to sheet erosion. Periodic saturation of dispersible clay subsoils leads to landslips and slumping of road batters.	Brown gradational soils, weak structure				
	In-situ weathered rock				
	Brown duplex soils				
	Fine sandy clay loam				
Surface texture	Moderate				
Permeability	Silty loam				
Depth, m	High				
0.3	0.9				
Very high	>2				
0.3	0.9				
SOIL DEGRADATION					
HAZARD					
Critical land features, processes, forms	Stony shallow soils of weak structure, and low water-holding capacity on steep slopes are prone to sheet erosion and landslides.				

7.26 Moggs Creek Land System

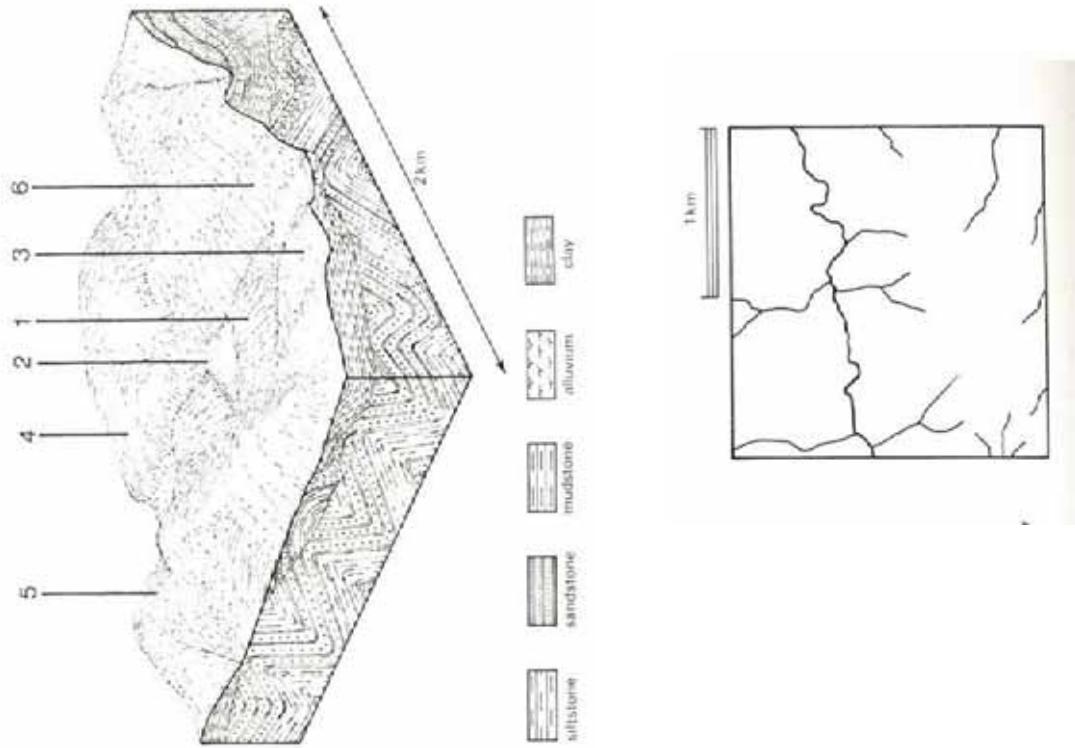
The terrain inland from Eastern View and Aireys Inlet consists of spurs and ridges with steep slopes and deep valleys. The outcropping Tertiary sediments are partly unconsolidated, but many beds are composed of quartzitic sandstones and siltstone. The lower parts of the landscape often possess outcrops of Cretaceous sediments.

Open forests of *Eucalyptus obliqua*, *E. sideroxylon* and *E. radiata* occur over most of the landscape on duplex soils. The drier north- and west-facing slopes and steep slopes carry woodlands on shallow stony soils. The Cretaceous outcrops can be recognized by the increase in understorey cover and the occurrence of species such as *Acacia mucronata* and *Cassinia longifolia*.

Some selective logging of these hills is undertaken, but the main use is for recreation such as bushwalking and picnicking. The steep slopes are popular with trail-bike-riders, and this often results in severe damage to the vegetation and soils.



The valley of Painkalac Creek remains virtually uncleared, and is popular with bushwalkers and picnickers from nearby coastal resorts.



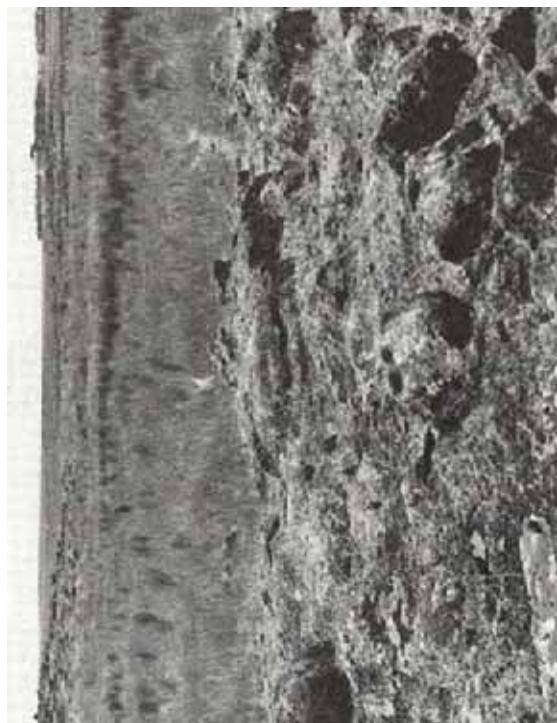
MOGGS CREEK		Component and its proportion of land system			
		1 30%	2 20%	3 7%	4 25%
CLIMATE					5 8%
Rainfall, mm	Annual: 800 – 1,050, lowest January (40), highest August (110)				6 10%
Temperature, °C	Annual: 13, lowest July (8), highest February (17)				
Seasonal growth limitations	Temperature: less than 10°C (av.) mid June – mid August				
Precipitation:	less than potential evapotranspiration mid November – mid March				
GEOLOGY	Paleocene unconsolidated clay, silt and sand; some silica cemented quartz sandstone and siltstone		Lower Cretaceous sandstone and mudstone		
TOPOGRAPHY					
Landscape	Deeply dissected hills				
Elevation, m	0–240				
Local relief, m	100				
Drainage pattern	Dendritic				
Drainage density, km/km ²	2.1				
Land form	Hill				
Land form element	Crest, north and west slopes				
Drainage density, km/km ²	18 (6–45)				
Slope (and range), %	Convex				
Slope shape	Concave				
NATIVE VEGETATION					
Structure	Valley floor				
Dominant species	Alluvial terrace				
	1 (0–2)				
	Linear				
	Hill				
	Steep lower slope				
	55 (40–65)				
	Linear				
SOIL					
Parent material	Alluvial terrace				
Description	Alluvial terrace				
Surface texture	Alluvial clay, silt and sand				
Permeability	Yellow gradational soils, weak structure				
Depth, m	Yellow-brown sodic duplex soils, coarse structure				
	Fine sandy loam				
	High				
	Low				
	>2				
LAND USE	Uncleared areas: Nature conservation; hardwood forestry; active and passive recreation.				
SOIL DETERIORATION	Cleared areas: Residential; active recreation				
HAZARD					
Critical land features, processes, forms	Weakly structured soils on steep slopes are prone to sheet erosion and compaction. Clay subsoils on steep slopes are prone to flooding.		Weak surface structure is prone to compaction leading to reduced permeability and increased overland flow.		
	Receiving surface run-off from adjacent areas are prone to scour gullying, silting and flooding.		Weakly structured surface soils on steep slopes are prone to sheet erosion and compaction. Clay subsoils on steep slopes are prone to landslips.		

7.27 Moleric Land System

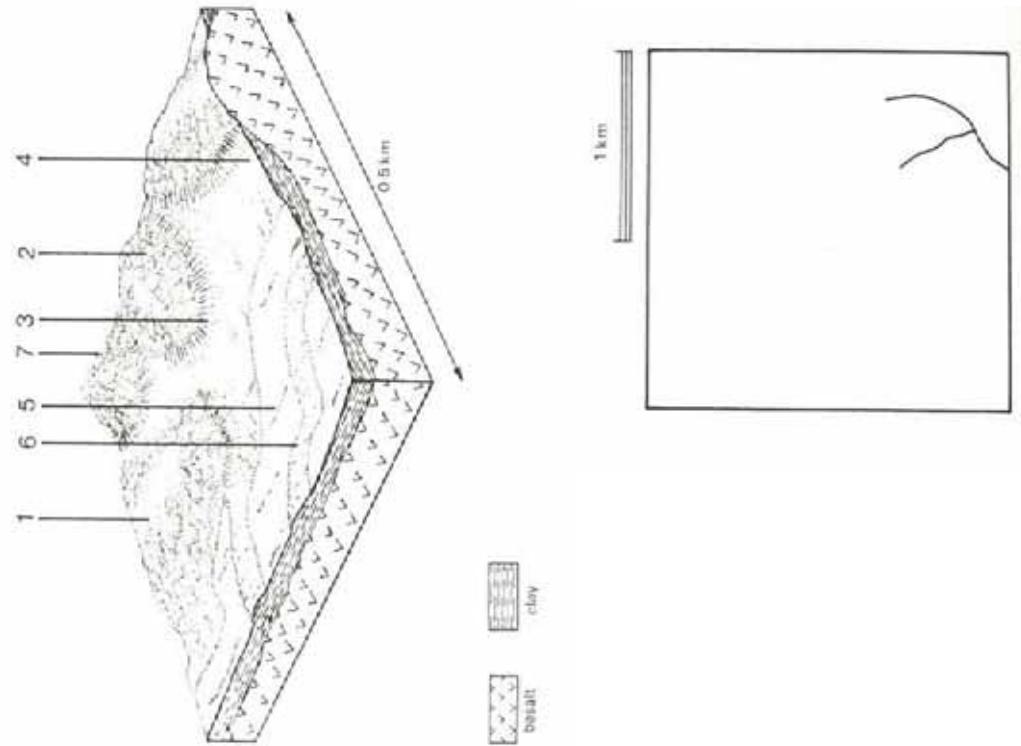
The stony rises between Mount Gellibrand and the Baron River were among the first areas grazed in this part of Victoria. The stony rises are both interconnected and solitary and they slope southwards away from Mount Gellibrand. The major areas is found north of the Princes Highway, but occasional vents or old cones also occur further south.

The nature of the native vegetation is difficult to determine. Many early reports describe the area as a treeless plain, but there are occasional specimens of *Acacia melanoxylon*, *A. implexa* and even *Eucalyptus viminalis* in roadside reserves. Thus, there may have originally been a low open woodland prior to settlement, which has disappeared following grazing and burning. Stony rise landscapes in other parts of Victoria possess woodland or low woodland communities.

Soil nutrient levels are high on these basalt outcrops, especially in the less weathered soils. The abundance of rock floaters and outcrops makes cultivation difficult even on infilled swamps between the rises. Thus grazing, often on unimproved pastures, is the main land use.



Depressions between the stony rises are infilled with basaltic clay and organic clay, both of which have low permeability, leading to waterlogging.



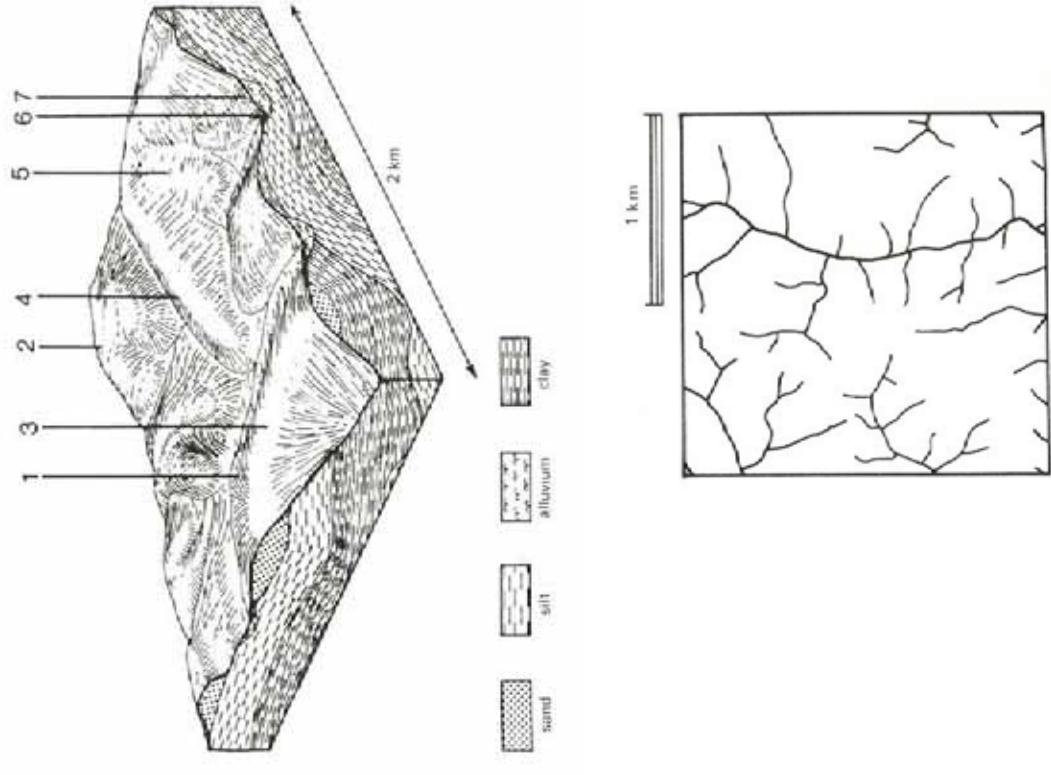
MOOLERIC		Component and its proportion of land system			
		1 5%	2 9%	3 7%	4 45%
		5 25%	4 45%	5 25%	6 5%
CLIMATE					
Rainfall, mm	Annual: 550 – 600, lowest January (25), highest August (60)				
Temperature, °C	Annual: 13, lowest July (8), highest February (19)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June - August				
Precipitation: less than potential evapotranspiration late September – April	Pleistocene basalt, scoria and tuff				
GEOLOGY					
Age, lithology					
TOPOGRAPHY					
Landscape	Stony rise, undulating plain with occasional steep hills (volcanic cones)				
Elevation, m	120 – 250				
Local relief, m	5				
Drainage pattern	Dendritic				
Drainage density, km/km ²	0.2				
Land form					
Land form element	Stony rise	Plain			
Slope (and range), %	Steep slopes, narrow crest	Depression			
Slope shape	5 (3-9)	0 (0-3)			
Broad crest	Apron	Bank			
2 (0-3)	5 (3-9)	1 (0-2)			
Linear	Concave	Convex			
	Concave	Linear			
NATIVE VEGETATION					
Structure	Possibly low woodland	Possibly sedgeland			
Dominant species	<i>Acacia melanoxylon, A. implexa, E. viminalis</i>	<i>Juncus</i> spp., <i>Ranunculus</i> spp., <i>Carex</i> spp., <i>Scirpus calocarpus, Schoenus apogon</i>			
			Possibly low woodland		
SOIL					
Parent material					
Description	Basalt	Colluvium, mainly clay	Basalt	Alluvium, plant remains	Scoria, tuff, basalt
	Grey calcareous sodic duplex soils, coarse structure	Black calcareous clay soils, uniform texture	Grey calcareous sodic duplex soils, coarse structure	Grey calcareous sodic duplex soils, coarse structure	Stony red-brown gradational soils
Surface texture	Loam	Fine sandy loam	Fine sandy loam	Fine sandy loam	
Permeability	High	Very low	Clay	Very low	Clay loam
Depth, m	0.2	1.2	>2	>2	High
		1.9			0.9
LAND USE					
Cleared areas:	Sheep and beef cattle grazing; some minor cropping between stony rises.				
Soils of low permeability	Stony shallow soils with low water-holding capacity, over rock layers on steep slopes, are prone to sheet erosion.	Soils of low permeability are prone to waterlogging.	Sodic clay subsoils of low permeability with seasonally high water tables are prone to soil salting.	Soils of low permeability and with sodic clay subsoils are prone to waterlogging, soil compaction and soil salting.	Stony shallow soils with low water-holding capacity, over rock layers on steep slopes, are prone to sheet erosion.
SOIL DETERIORATION HAZARD					
Critical land features, processes, forms					

7.28 Mount Mackenzie Land System

Steeply dissected hills abut either side of the middle and lower reaches of the Gellibrand River. Dissection into Tertiary clay, silt and sand has resulted in steep slopes and narrow drainage lines.

The finely textured Tertiary sediments outcropping in these areas has resulted in heavier-textured soils than those found in the neighbouring Chapple Vale land system. Moisture stress and fertility are not as limiting to plant growth, so open forests of *Eucalyptus obliqua* and *E. baxteri* have developed on most sites. Included in the land system are dissected river terraces along the valley of the Gellibrand River and these possess well-developed soils with coarse-structured subsoils. The higher parts of the landscape may also possess such soils where Kennedy's Creek land system is adjacent, or sand soils where the Chapple Vale land system is nearby.

Most areas remain forested but areas abutting the flood plains have been cleared to provide winter pastures for dairy cattle. Pines have been established on previously forested land. Sheet erosion and landslips have occurred on many of the steeper slopes where the native vegetation has been removed and the rugged nature of the terrain make most land uses difficult.



The steep dissected hills of the Mount Mackenzie land system originally supported open forest communities, but many areas have been extensively cleared for pine conversion and grazing.

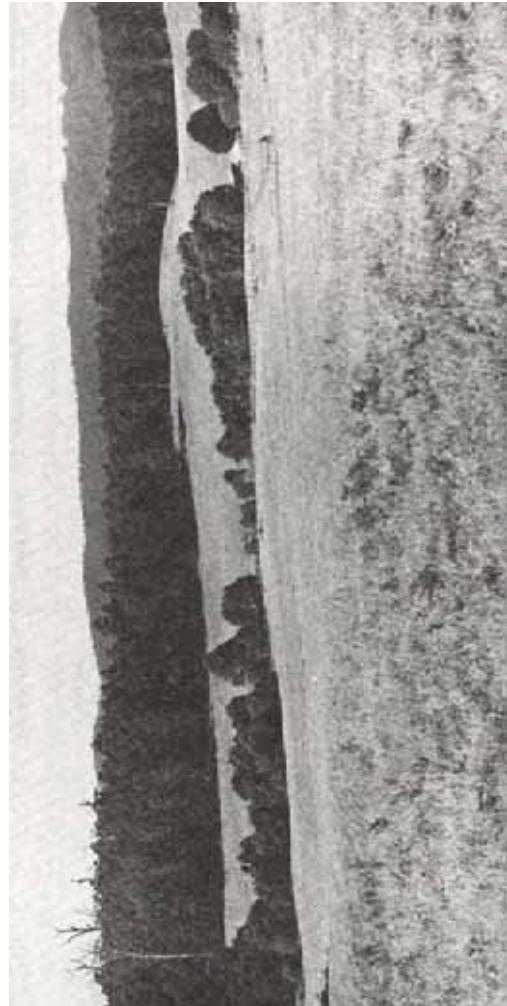
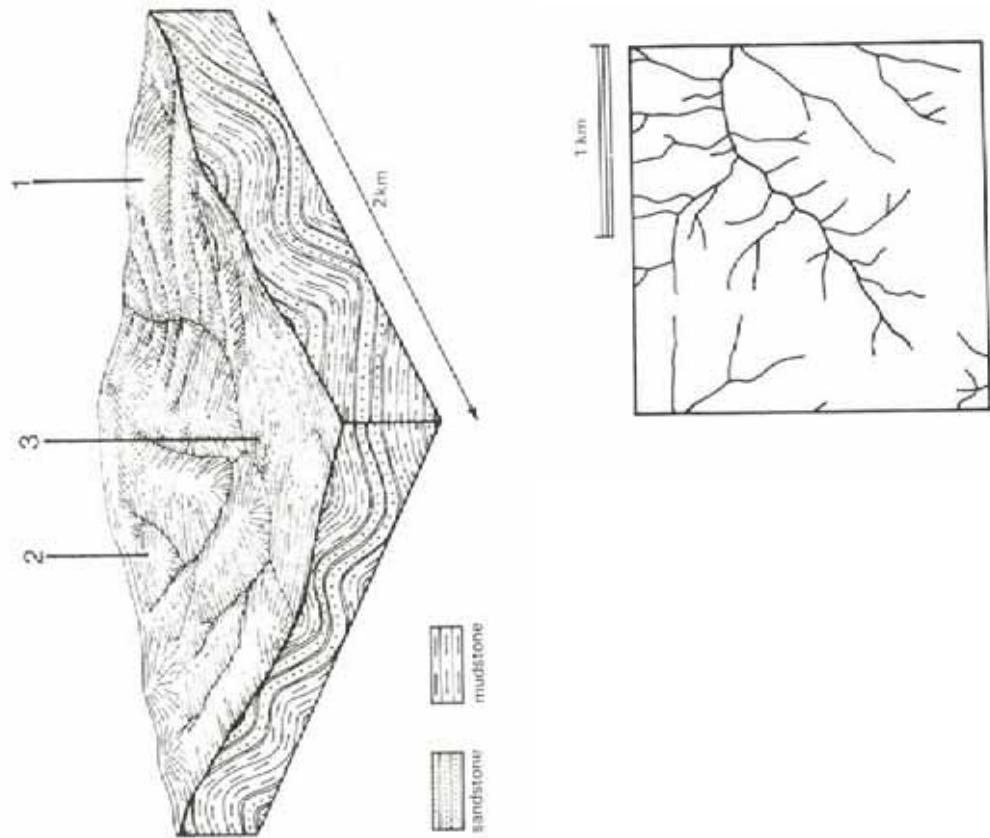
MOUNT MACKENZIE		Component and its proportion of land system			
		1 40%	2 8%	3 9%	4 25% 8%
CLIMATE					5 8%
Rainfall, mm	Annual: 950 – 1,100, lowest January (45), highest August (120)				
Temperature, °C	Annual: 13, lowest July (8), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August				
Precipitation: less than potential evapotranspiration mid November – March	Paleocene unconsolidated marine sand, clay and silt				
GEOLOGY					
Age, lithology					
TOPOGRAPHY					
Landscape	Deeply dissected hills in the middle and lower reaches of the Gellibrand River catchment				
Elevation, m	15 – 180				
Local relief, m	100				
Drainage pattern	Dendritic with some radial				
Drainage density, km/km ²	3.3				
Land form	Hill			Valley floor	Terrace
Land form element	Slope, crest	Crest, spur, mainly in south	Crest, slope	Slope, crest	Broad slight depression
Slope (and range), %	33 (4–63)	14 (4–19)	32 (22–45)	37 (31–49)	14 (2–21)
Slope shape	Convex	Convex	Convex	Concave	Concave
NATIVE VEGETATION					
Structure	Open forest	Low woodland	Open forest	Low woodland	Woodland
Dominant species	<i>E. baxteri</i> , <i>E. nitida</i> , <i>E. obliqua</i> , <i>E. ovata</i>	<i>E. baxteri</i> , <i>E. nitida</i>	<i>E. baxteri</i> , <i>E. obliqua</i>	<i>E. nitida</i> , <i>E. baxteri</i>	<i>E. obliqua</i> , <i>E. baxteri</i>
SOIL					
Parent material	Clay, silt and sand	Sand	Clay, silt and sand	Sand, colluvial sand	Plant remains, alluvial sand and clay
Description	Yellow gradational soils, weak structure	Yellow-brown gradational soils, coarse structure	Grey sand soils, uniform texture	Red gradational soils, weak structure	Grey sand soils, with hardpans, uniform texture
Surface texture	Sandy loam	Fine sandy loam	Loamy sand	Sandy loam	Loamy sand
Permeability	High	Low	Very high	High	Very low
Depth, m	>2	>2	>2	>2	0.6
LAND USE	Uncleared areas: Hardwood forestry for sawlogs, posts and poles; water supply; nature conservation; quarrying of ironstone; softwood forestry				
Minor cleared areas: Dairy farming; beef cattle grazing.					
SOIL DETERIORATION HAZARD					
Critical land features, processes, forms	Weakly structured soils on steep slopes are prone to sheet, rill, scour gully erosion and landslips. Low inherent fertility and high permeability lead to nutrient decline.	Dispersible clay subsoils of low permeability are prone to gully erosion.	Very low inherent fertility and high permeability are prone to sheet, rill and scour gully erosion.	Weakly structured soils on steep slopes are prone to sheet and rill erosion and landslips. Low inherent fertility and high permeability lead to nutrient decline.	High water tables lead to waterlogging and soil compaction. Rapid runoff from adjacent hills lead to flooding and silting.
				Hardpans restrict vertical drainage leading to seasonal waterlogging.	High water tables lead to waterlogging and soil compaction. Rapid runoff from adjacent hills lead to flooding and silting.
				Very low inherent fertility with leaching of permeable highly acidic surface soils lead to nutrient decline.	Low permeabilities and high water tables lead to waterlogging and soil compaction.

7.29 Mount Sabine Land System

Disconnected remnants of an undulating plain are found on the high parts of the Otway Range from near the Parker river to Gentle Annie Hill. The wettest and most extensive part of this undulating plain comprises the Beech Forest land system. All other areas receive an annual rainfall of 1,700 mm or less and the tall open forests, although they reach impressive heights, do not approach the 100 m stands reported for the Beech Forest land system prior to clearing.

Most slopes and crests have moderate deep and fertile soils. The occurrence of extremely deep and friable soils in some areas seems to be related to a change in the nature of the Cretaceous beds. The depth to weathering parent material is often in excess of 2 m in these profiles.

The remote nature of most of these plateau remnants has hindered their development for agriculture. Many of the areas originally cleared by early settlers have reverted to dense scrub while others have been regenerated to Eucalyptus regnans or other hardwood species. Landslips and loss of soil nutrients in such a wet climate are the main hazards to land use.



Only small areas of farmland still remain, the remoteness from areas of substantial settlements being one of the major problems.

MOUNT SABINE
Area: 95 km²

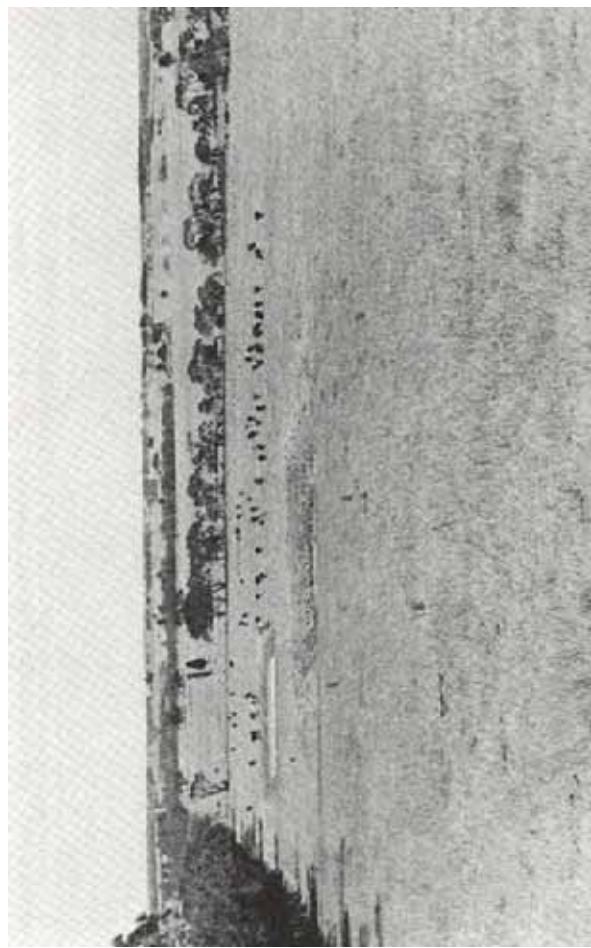
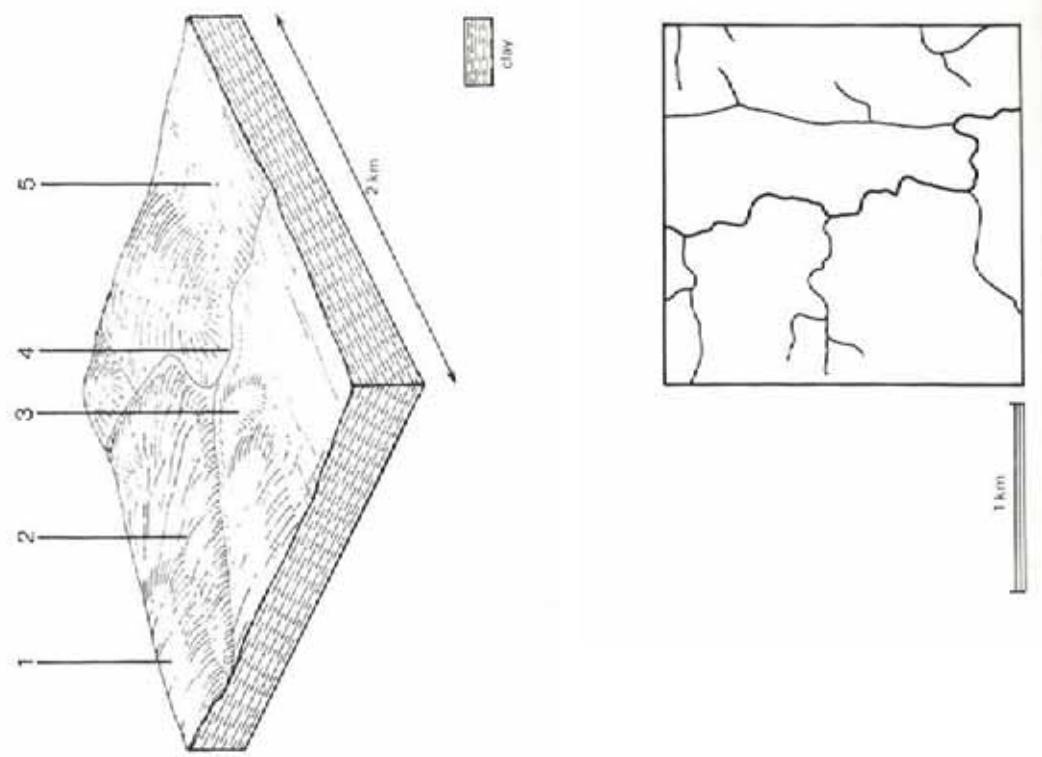
		Component and its proportion of land system			
		1 25%	2 70%	3 5%	3 5%
CLIMATE					
Rainfall, mm	Annual: 1,200 – 1,700, lowest February (65), highest June (170)				
Temperature, 0°C	Annual: 10, lowest July (6), highest February (15)				
Seasonal growth limitations	Temperature: less than 10°C (av.) May – October				
Precipitation: less than potential evapotranspiration early December - February	Precipitation: less than potential evapotranspiration early December - February				
GEOLOGY					
Age, lithology	Lower Cretaceous feldspathic sandstone and mudstone				
TOPOGRAPHY					
Landscape	Rolling hills along the top of the Otway Range				
Elevation, m	400 – 670				
Local relief, m	60				
Drainage pattern	Dendritic pattern with some radial areas				
Land form					
Drainage density, km/km ²					
Upper slope 15 (1-25)	General slope 15 (1-25)	3.6			
Convex	Convex				
Slope (and range), %	Hill				
Slope shape	Concave				
NATIVE VEGETATION					
Structure	Tall open forest				
Dominant species	<i>E. obliqua</i> , <i>E. cypellocarpa</i> , <i>E. regnans</i> , <i>Acacia melanoxylon</i> , occasional <i>E. ovata</i>				
SOIL					
Parent material	In-situ weathered rock				
Description	Brown friable gradational soils				
Surface texture	Clay loam				
Permeability	High				
Depth, m	1.8				
LAND USE					
Minor cleared areas:	Hardwood forestry for sawlogs and pulpwood; softwood plantations; nature conservation; passive recreation; water supply.				
Major cleared areas:	Some beef cattle grazing on unimproved pastures; most reverting to native forest or converted to pine plantations.				
SOIL DETERIORATION HAZARD					
Critical land features, processes, forms	High rainfall and high permeability lead to leaching of nutrients and losses in organic matter and soil structure. Steeper slopes may be subsequently prone to sheet erosion.	High rainfall and moderate permeability lead to leaching of nutrients and losses in organic matter and soil structure. Steeper slopes are subsequently prone to sheet erosion. Clay subsoils on steeper slopes subject to frequent saturation are prone to landslips.	High seasonal water table leads to waterlogging and compaction.	High seasonal water table leads to waterlogging and compaction.	High seasonal water table leads to waterlogging and compaction.

7.30 Paraparap Land System

Between the lateritic plateaux of the Gherang land system and the basaltic plains of the Freshwater Creek land system, a long narrow plain extends from the Barwon River near Winchelsea to the middle reaches of Thompson Creek.

Deeply weathered duplex soils are found on most of this land system, with occasional areas of aeolian sand. Remnants of woodlands and open forests are found along many reserves with the unusual occurrence of *Eucalyptus pauciflora* on many of the better-drained and less fertile sites.

Most areas have been cleared for agriculture and, despite the fairly low rainfall, dairy farming is common. Other uses include sheep and beef cattle grazing and cereal cropping. Soil salting is a problem in many areas and some minor gully erosion has also occurred.



Clearing has been widespread, but an abundance of vegetation in the road reserve adds an appealing dimension to the landscape.

PARAPARAPAI		Component and its proportion of land system			
		1 35%	2 30%	3 10	4 15%
CLIMATE					
Rainfall, mm	Annual: 600 – 650, lowest January (30), highest August (65)				
Temperature, °C	Annual: 13, lowest July (9), highest February (19)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – July				
Precipitation: less than potential evapotranspiration	Precipitation: less than potential evapotranspiration				
GEOLOGY					
Age, lithology	Plio-Pleistocene sediments consisting of clayey sand, sandy clay and lateritic detritus				
	Recent aeolian sand				
TOPOGRAPHY					
Landscape	Gently undulating plain lying between basalt to the north and lateritic plateaux to the south				
Elevation, m	40 – 130				
Local relief, m	20				
Drainage pattern	Dendritic				
Drainage density, km/km ²	2.5				
Land form					
Land form element					
Slope (and range), %					
Slope shape					
NATIVE VEGETATION					
Structure	Middle slope				
Dominant species	4 (1-7)				
	Linear				
Crest, upper slope	Gentle rise				
3 (0-11)	Crest, slope				
Convex	5 (2-10)				
	Irregular				
SOIL					
Parent material	Lower slope				
Description	2.5				
Surface texture	Valley floor				
Permeability	-				
Depth, m	1 (0-2)				
	Concave				
LAND USE					
SOIL DETERIORATION	Dairy and beef cattle grazing on mainly improved pastures; some sand extraction.				
HAZARD	Dispersible subsoils are prone to gully erosion and slumping of road batters.				
Critical land features, processes, forms	Low inherent fertility, phosphorus fixation and leaching of permeable A horizons leads to nutrient decline.				

7.31 Pennroyal Land System'

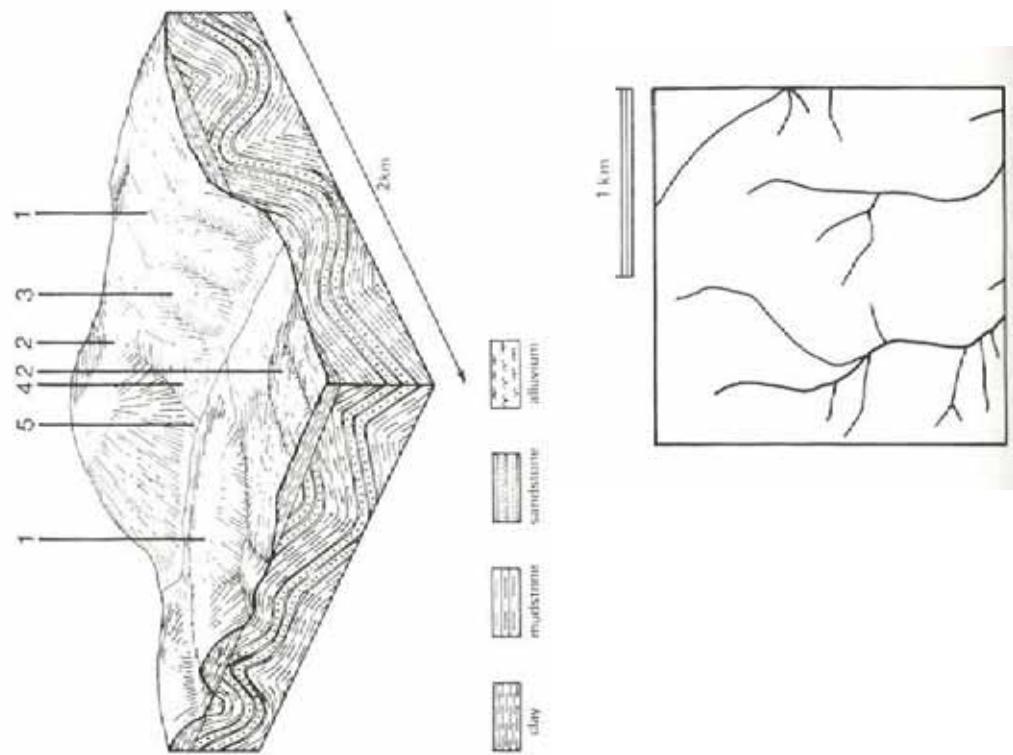
Along the northern periphery of the Range, flat-topped spurs and ridges form an irregular band of foothills from Wormbete Creek to Barwon Downs. The terrain is variable, with steep slopes leading away from these gentle hill crests to wide valley floors. The ridge slopes upwards towards the Range and becomes narrower as the local relief increases.

The gentle parts of the landscape are formed on Tertiary clay, silt and sand. These sediments overlie Cretaceous sandstones and mudstones, which outcrop on steep slopes on the valley sides. Soil and vegetation reflect changes in the parent material, with the soils on the upper parts of the landscape being somewhat deeply weathered with sandy surface horizons in contrast to loam or clay loam soils on the Cretaceous outcrops.

Clearing has been widespread and sheep and beef cattle grazing as well as dairy farming are the main land uses. Some hardwood is logged from forested areas, and softwood plantations have been established in the east. Poor management of these hills can lead to rapid surface run-off along the valleys creating problems of gully erosion, siltation and flooding further downstream.



Upper gentle slopes are formed on Tertiary clay, silt and sand, while Cretaceous sandstones and mudstones outcrop on steep slopes along the valley sides and Recent alluvium is found in the valley floor.



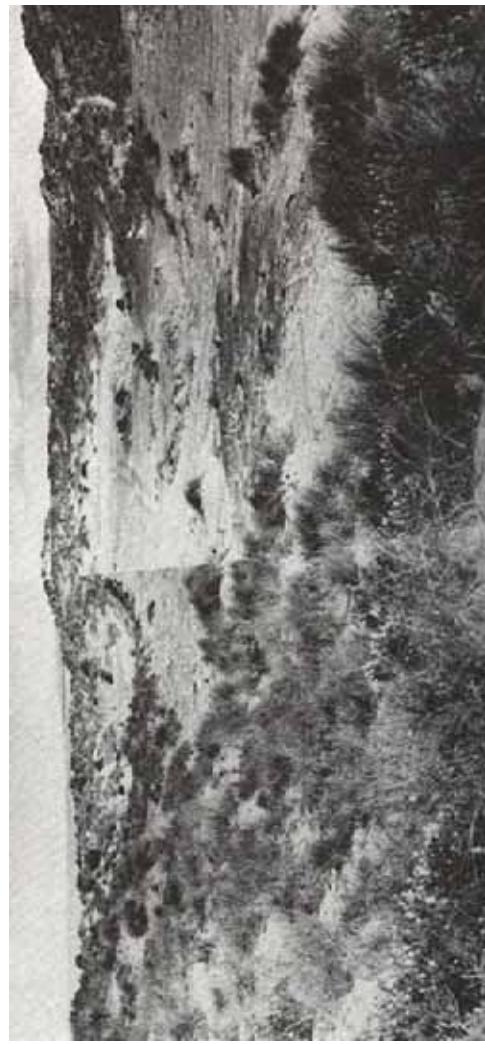
PENNYROYAL		Component and its proportion of land system		
		1 35%	2 15%	3 35%
CLIMATE				
Rainfall, mm	Annual: 700 – 1,050, lowest January (35), highest August (80)			
Temperature, 0°C	Annual: 12, lowest July (8), highest February (18)			
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September			
Precipitation: less than potential evapotranspiration November - March	Precipitation: less than potential evapotranspiration November - March			
GEOLOGY				
Age, lithology	Tertiary unconsolidated clay, silt and sand. Minor remnants of lateritization			
		Lower Cretaceous sandstone and mudstone		Recent alluvial clay, silt and sand
TOPOGRAPHY				
Landscape	Steep rolling hills on the northern periphery of the Otway Range			
Elevation, m	135 - 300			
Local relief, m	65			
Drainage pattern	Dendritic			
Land form	Hill			
Drainage density, km/km ²	1.9			
Land form element	Gentle upper slope			
Slope (and range), %	Upper slope, crest 7 (0-25) Convex			
Slope shape	15 (3-25) Linear			
NATIVE VEGETATION				
Structure	Open forest			
Dominant species	<i>E. obliqua</i> , <i>E. ovata</i> , <i>E. radiata</i> , <i>E. viminalis</i>			
SOIL				
Parent material	Sand and clay			
Description	Yellow gradational soils, weak structure Loamy sand High >2			
Surface texture	Yellow-brown duplex soils, coarse structure Fine sandy loam Low >2			
Permeability	Clay, silt and sand			
Depth, m	Brown duplex soils Loam Moderate 0.8			
LAND USE				
Cleared areas: sheep and beef cattle grazing; dairy farming; water supply.	In-situ weathered rock			
Uncleared areas: Hardwood forestry for some sawlogs, posts and poles; softwood plantations; nature conservation; water supply, gravel extraction; passive recreation	Alluvium			
SOIL DETERIORATION HAZARD				
Critical land features, processes, forms	High seasonal water table and low permeability lead to sheet erosion, particularly on dry aspects. Clay subsoils on steep slopes subject to periodic saturation are prone to landslips.			
	Dispersible clay subsoils on steep slopes are prone to gully erosion. Soils of low permeability on steep slopes are prone to sheet erosion.			
	Low inherent fertility and high phosphorus fixation lead to nutrient decline. Weakly structured soils on steeper slopes are prone to sheet erosion.			

7.32 Point Roadknight Land System

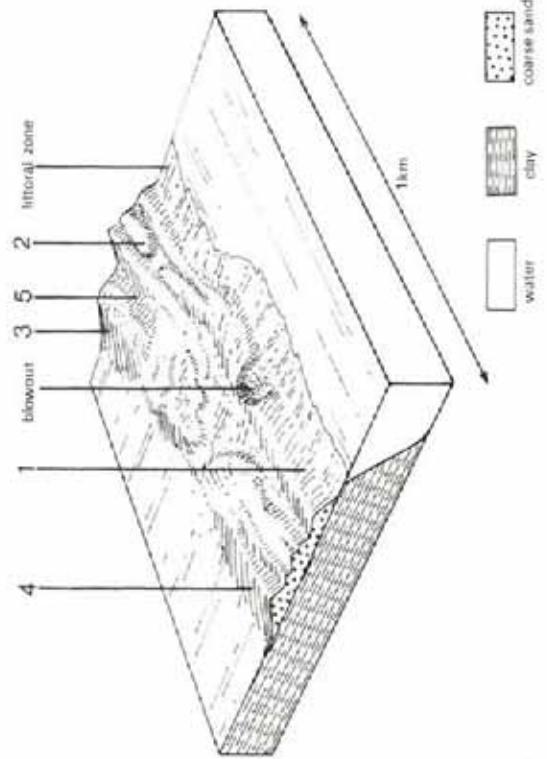
Along the coast from Breamlea to Eastern View, coastal dunes occur discontinuously. In some localities a primary and a secondary dune form a thin barrier between the sea and the Tertiary sediments, but in the locality of Point Impossible the dune system is more complex and extensive.

The foredune and secondary dune material is aeolian sand and shell grit. On older dunes, mobilization of calcium carbonate has resulted in the formation of calcarenite, which may outcrop on blowouts or steep slopes. Away from these calcarenite pavements, the soils are freely drained calcareous sands. The exposed calcarenite pavements may support red calcareous gradational soils, but extensive sheet erosion has removed most of this material.

Recreation and access to the foreshore are the main land uses. Some buildings have been sited in these dunes at Breamlea and Fairhaven. Native grasses and shrubs that colonize these dunes are very sensitive to disturbance and, once devoid of vegetative cover, wind erosion is likely to occur. Hand planting of *Ammophila arenaria* has been necessary to stabilize many areas.



Sections of coastline in the drier eastern parts of the study area often have extensive calcareous dune systems. On many of these dunes the native vegetation has been trampled and destroyed and the hand planting of Ammophila arenaria has been necessary to restabilize the dune system.



No drainage pattern. Land system has complete internal drainage.

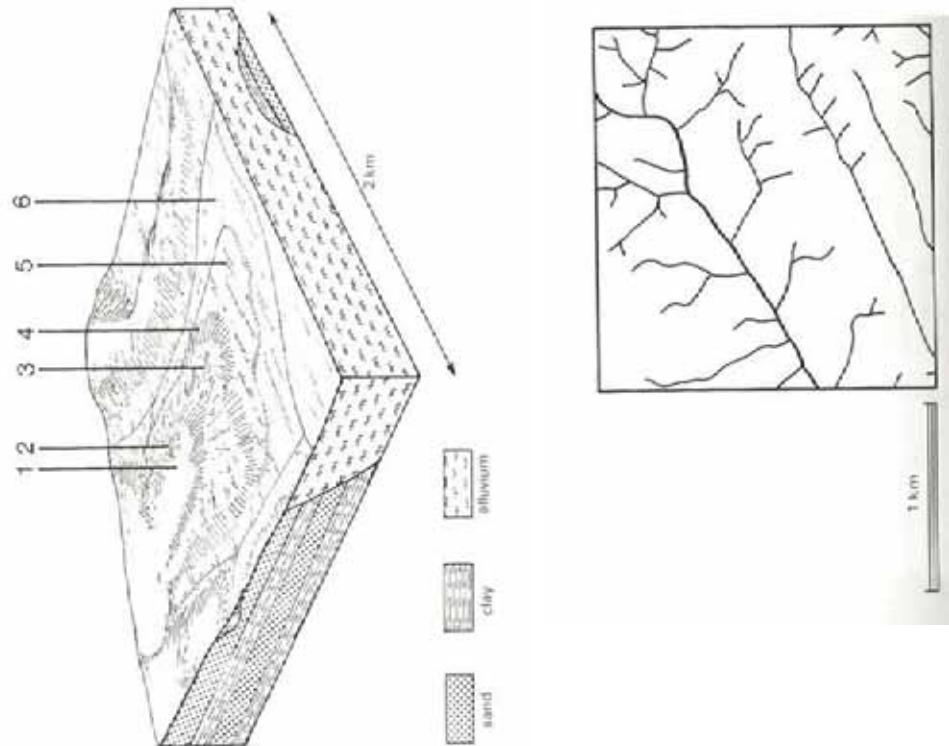
POINT ROADKNIGHT		Component and its proportion of land system	
	1 20%	2 50%	3 25%
	4 2%	4 2%	5 3%
CLIMATE			
Rainfall, mm	Annual: 600 – 750, lowest January (30), highest August (75)		
Temperature, 0°C	Annual: 14, lowest July (10), highest February (18)		
Seasonal growth limitations	Temperature: less than 10°C (av.) July Precipitation: less than potential evapotranspiration mid October - early April		
GEOLOGY			Cemented deposits (calcareous and travertine)
Age, lithology			
TOPOGRAPHY			
Landscape	Longitudinal coastal dunes to the east of the Otway Range		
Elevation, m	0 – 25		
Local relief, m	1.5		
Drainage pattern	Absent		
Drainage density, km/km ²			
Land form			
Land form element			
Slope (and range), %			
Slope shape			
NATIVE VEGETATION			
Structure			
Dominant species			
SOIL			
Parent material			
Description			
Surface texture			
Permeability			
Depth, m			
LAND USE			
Minor cleared areas: Recreational facilities; residential			
Marine erosion and accretion occur seasonally. Native vegetation is sensitive to trampling and disturbance. Weakly structured sands are prone to wind erosion. Low inherent fertility and high permeability lead to nutrient decline.			
SOIL DETERIORATION			
HAZARD			
Critical land features, processes, forms			

7.33 Porcupine Creek Land System

Tertiary quartzitic sands outcrop in many areas north and west of the Range. Widespread surface redistribution of this sand has resulted in a gentle landscape with sands overlying more clayey material at four localities. The largest area is east of Kawarren in the catchment of Porcupine Creek, and another extensive area is found in the upper reaches of Tomahawk Creek. Somewhat steeper slopes with a predominance of deep relatively uniform sands occur to the east of Forrest, while the area near Princetown has broader crests and narrower drainage lines.

Hardpans are a feature of the soils and the impeded drainage leads to waterlogging on many sites. The native vegetation consists of woodlands of *Eucalyptus nitida* and *E. radiata*, with closed scrubs of shrub species in the drainage lines.

Clearing of these areas for agriculture has been attempted in many areas, but impeded drained on sites with hardpans and excessive drainage on sites without them create management difficulties. Deep ripping of the hardpans may improve site drainage, but low soil pH and low fertility also have to be contended with for successful pasture establishment. Most areas remain as wildlife habitats, with the exception of one near Princetown and part of the area near Tomahawk Creek, which border the Heytesbury Settlement Scheme.



Drainage of these landscapes is poor, and the waterlogged soils carry woodlands of E. nitida and E. radiata with closed scrubs in the drainage lines.

PORCUPINE CREEK		Component and its proportion of land system			
		1 30%	2 25%	3 15%	4 15%
CLIMATE					
Rainfall, mm	Annual: 800 – 1,000, lowest January (40), highest August (120)				
Temperature, °C	Annual: 13, lowest July (8), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August				
Precipitation: less than potential evapotranspiration late October – March					
GEOLOGY		Paleocene unconsolidated marine sand			
Age, lithology	Paleocene unconsolidated marine sand	Paleocene unconsolidated marine clay, sand and silt			
TOPOGRAPHY					
Landscape	Undulating plains				
Elevation, m	60 – 230				
Local relief, m	45				
Drainage pattern	Trellis				
Drainage density, km/km ²	3.8				
Land form	Rise				
Land form element	Crest, slope	Upper slope	Mid slope	Lower slope	Drainage line
Slope (and range), %	21 (9-38)	9 (2-21)	5 (2-11)	16 (5-33)	-
Slope shape	Convex	Convex	Linear	2 (0-5)	0 (0-1)
NATIVE VEGETATION					
Structure	Woodland	Low woodland	Open woodland	Woodland	Linear
Dominant species	<i>E. radiata</i> , <i>E. nitida</i>	<i>E. radiata</i> , <i>E. nitida</i>	<i>E. radiata</i> , <i>E. nitida</i>	<i>E. radiata</i> , <i>E. nitida</i> , <i>E. ovata</i>	Linear
SOIL					
Parent material	Sand	Sand	Colluvial sand on clay	Colluvial sand on alluvial clay, silt and sand	Closed scrub
Description	Grey sand soils, uniform texture	Grey sand soils, with hardpans, uniform texture	Grey sand soils, structured clay underlay	Grey sand soils, structured clay underlay	Open forest
Surface texture	Loamy sand	Loamy sand	Sandy loam	Sandy loam	<i>Meteleuca squarrosa</i> , <i>Casuarina littoralis</i> , <i>Aotus ericoideas</i>
Permeability	Very high	Very low	Very low	Very low	<i>Meteleuca squarrosa</i> , <i>Casuarina littoralis</i> , <i>Aotus ericoideas</i>
Depth, m	>2	0.8	>2	>2	Plant remains alluvial sand, silt and clay
LAND USE		Undeveloped areas: Nature conservation; water supply; sand and gravel extraction; hardwood forestry for posts, poles and fuel			
Minor cleared areas	Beef cattle grazing; water supply				
HAZARD	Hardpans restrict drainage, leading to seasonal waterlogging. Very low inherent fertility and leaching slopes with compacted soils are prone to sheet, rill and scour gully erosion.	Low permeability and seasonal perched water tables lead to waterlogging and soil compaction.	Weakly structured soils of low permeability on steeper slopes are prone to sheet erosion.	High water tables lead to waterlogging and soil compaction. Run-off from adjacent hills lead to flooding and siltation.	High water tables lead to waterlogging and soil compaction. Run-off from adjacent hills lead to flooding and siltation.
Critical land features, processes, forms					

7.34 Redwater Creek Land System

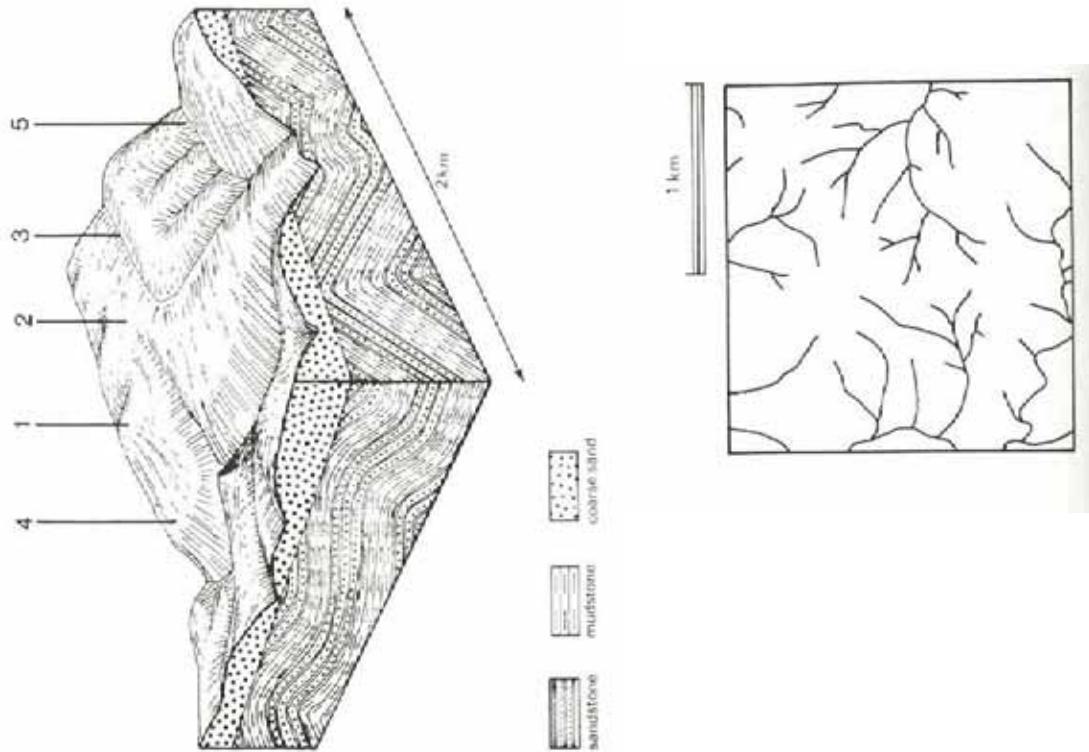
In the southern parts of the Otway Range, gentle hill cappings of Tertiary quartzitic sands occur as remnants on the high parts of the landscape. Most creeks and rivers have dissected through these sands, exposing Cretaceous sandstone and mudstone on steep slopes leading down to the drainage lines.

The capping of sand overlies Cretaceous sediments at a fairly shallow and uniform depth. The native vegetation on the sands is not dissimilar from that on the surrounding brown gradational soils, consisting of tall open forests of *Eucalyptus obliqua*, *E. cypellocarpa* and *E. regnans* on the better sites. These tall trees apparently extract nutrients from underlying weathering Cretaceous rocks. Nutrient cycling by leaf fall and decay has built up the fertility of the sands, far above that normally encountered on such parent material.

Only minor parts of this land system have been cleared and it appears that a marked decline in soil fertility has resulted. Hardwood forestry is the main land use, together with a small industry in the cutting of tea-tree stakes.



The higher parts of the landscape form undulating hills, with E. regnans successfully competing with other trees on sand soils.



REDWATER CREEK		1 5%	2 40%	3 5%	4 25%	5 25%
CLIMATE						
Rainfall, mm	Annual: 1,150 – 1,60, lowest January (60), highest August (160)					
Temperature, °C	Annual: 12, lowest July (7), highest February (16)					
Seasonal growth limitations	Temperature: less than 10°C (av.) June – September					
GEOLOGY	Precipitation: less than potential evapotranspiration December – mid February					
Age, lithology	Paleocene unconsolidated quartz sand and gravel shallowly underlain by Lower Cretaceous sandstone and mudstone					
TOPOGRAPHY						
Landscape	Deeply dissected hills with broad gently hill cappings in the southern parts of the Otway Range.					
Elevation, m	15 – 370					
Local relief, m	90					
Drainage pattern	Dendritic with some radial areas					
Drainage density, km/km ²	3.7					
Land form						
Land form element	Rise					
Slope (and range), %	Crest, upper slope					
Linear	20 (3-35)	Scarp	Crest, upper slope			
Slope shape	Convex	Swale	8 (3-15)	35 (10-60)		
NATIVE VEGETATION	Concave	3 (1-5)				
Structure	Tall open forest	Irregular				
Dominant species	Closed forest	Linear				
Woodland	<i>E. nitida</i> , <i>E. baxteri</i>	Tall open forest				
	<i>E. obliqua</i> , <i>E. cypellocarpa</i> , <i>E. regnans</i> , <i>E. viminalis</i>	<i>Leptospermum juniperinum</i>				
SOIL						
Parent material	Shallow deposits of quartz sand	Alluvial sand and gravel, organic matter	Shallow deposits of quartz sand and gravel	White sand soils, uniform texture	Brown gradational soils	In-situ weathered rock
Description	Deep deposits of quartz sand	Black sand soils, uniform texture	Black sand soils, uniform texture			
Surface texture	Grey sand soils with hardpans, uniform texture					
Permeability	Loamy sand	Sandy loam	Silty loam	(Gravelly) loamy sand	Sandy clay loam	
Depth, m	Low	High	Moderate	Very high	Moderate	
	1.2	>2	>2	>2	1.4	
LAND USE						
Minor cleared areas:	Hardwood forestry for sawlogs and pulpwood; tea-tree stake harvesting; nature conservation; sand and gravel extraction.					
Uncleared areas:	Beef cattle grazing on unimproved pastures.					
SOIL DETERIORATION						
HAZARD	Hardpans restrict vertical drainage, leading to seasonal waterlogging. Very low inherent fertility with decline. Steeper slopes with compacted soils (tracks, clear-felled areas) are prone to nutrient decline.	Soils of high permeability in high rainfall areas are prone to nutrient leaching of permeable highly acidic surfaces leads to nutrient decline.	High water tables lead to waterlogging. Run-off from adjacent hills lead to flooding and siltation.	Soils of very low inherent fertility, low nutrient – holding capacity and high permeability in high-rainfall areas are prone to nutrient decline.	Clay subsoils on steeper slopes are subject to periodic saturation and are prone to landslips. Steeper slopes are prone to sheet erosion.	
Critical land features, processes, forms						

7.35 Rivernook Land System

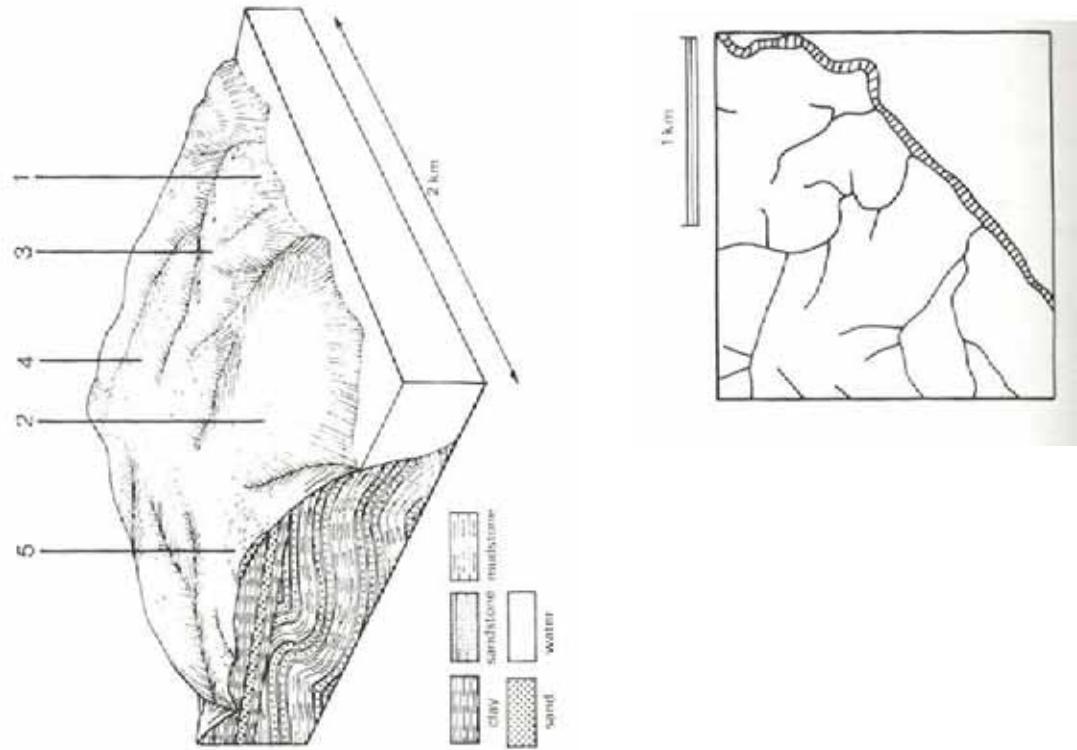
Tertiary sediments outcrop along the coast at Moonlight Head, Rotten Point and Apollo Bay. The terrain is a deeply dissected plain fronted by steep coastal cliffs. The rainfall is high.

The soils vary, ranging from old profiles with evidence of lateritization to young soils with little horizon development. The native vegetation appears to be more dependent on exposure to salt- and sand-laden coastal winds than on the soil type. *Casuarina luehmannii* at Rotten Point is an unusual member of the vegetative community, but most species are well adapted to the harsh environment.

Clearing is confined to an area near Apollo Bay used for grazing. The area has high landscape and nature conservation values, but disused sand and gravel extraction pits at Moonlight Head and Rotten Point detract from these attributes. Once the vegetation is disturbed, re-establishment is slow and difficult and sheet, rill and gully erosion are likely to occur.



These rugged coastal cliffs provide some of the most spectacular coastal scenery in the study area.



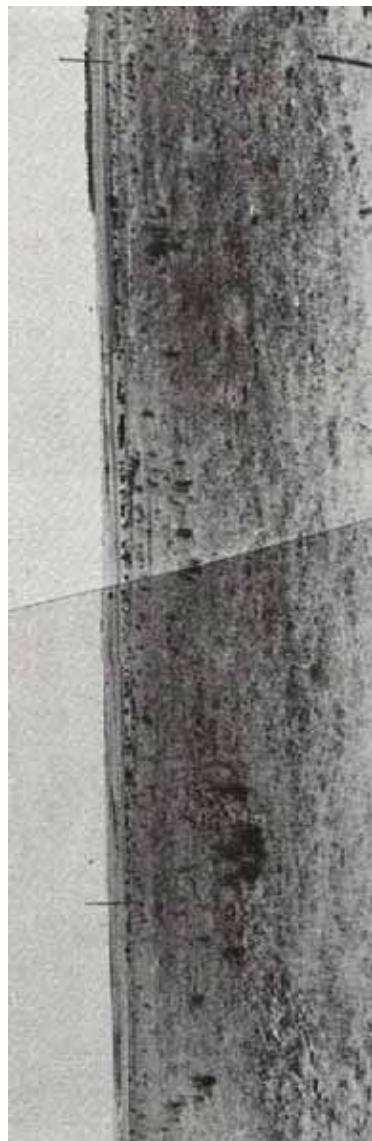
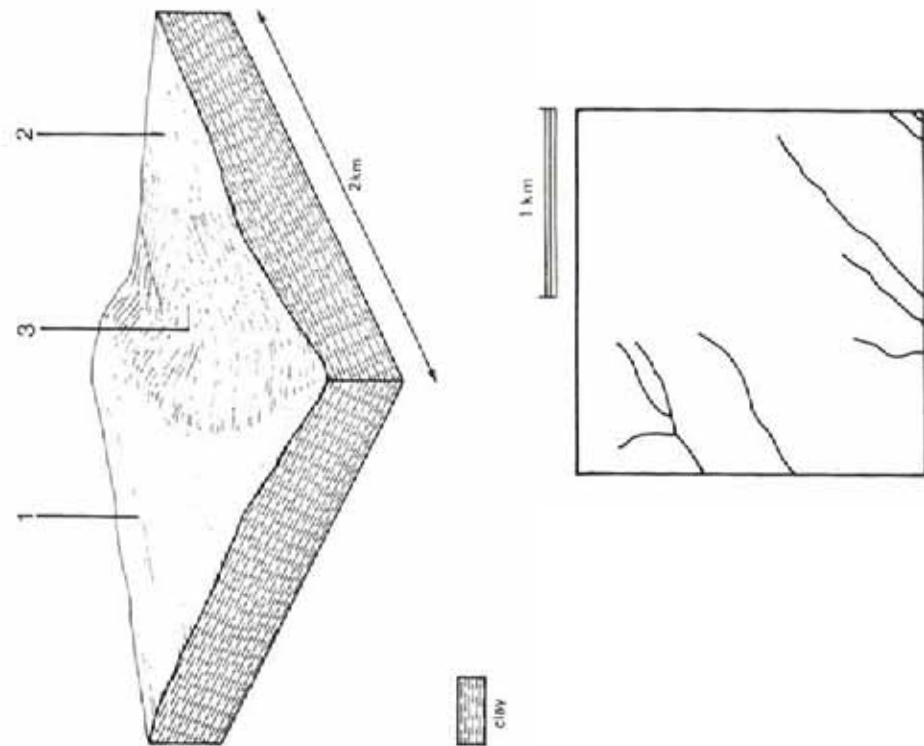
RIVERNOOK				Component and proportion of its land system			
		1 10%	2 20%	3 30%	4 30%	5 10%	
CLIMATE							
Rainfall, mm	Annual: 850 – 1,000, lowest January (40), highest July (110)						
Temperature, °C	Annual: 14, lowest July (10), highest February (18)						
Seasonal growth limitations	Temperature: No month less than 10°C (av.)						
GEOLOGY	Precipitation: Exceeds potential evapotranspiration all months.						
Age, lithology							
	Lower Cretaceous sandstone and mudstone						
TOPOGRAPHY							
Landscape							
Elevation, m							
Local relief, m							
Drainage pattern							
Drainage density, km/km ²							
Land form							
Land form element							
Slope (and range), %							
Slope shape							
NATIVE VEGETATION							
Structure							
Dominant species							
	Open heath to tall shrubland						
	<i>Casuarina stricta, Cassinia longifolia, Helichrysum parvulum, Casuarina luehmannii, Calocephalus brownii</i>						
SOIL							
Parent material							
Description							
	Beach sand, some cliff detritus						
	<i>Stony brown gradational soils</i>						
Surface texture							
Permeability							
Depth, m							
LAND USE							
	Uncleared areas: Nature conservation; landscape conservation; sand and gravel extraction; forest grazing.						
	Minor cleared areas: Residential; dairy farming; beef cattle grazing, often on unimproved pastures.						
SOIL DETERIORATION							
HAZARD							
Critical land features, processes, forms							

7.36 Simpson Land System

Small remnants of flat lateritic plateaux near Simpson and extending towards Irrewillipe are evidence of former widespread lateritization. Most lateritic hill capping have been removed by dissection, and this set of north-nor'-west- and south-sou'-east-orientated ridges is the only significant remnant to the west of the Range.

The most common soils have gradational profiles containing lateritic ironstone. However, some profiles possess sand veneers in the surface horizons, with hardpans overlying mottled clays. Drainage of the landscape is poor, particularly where hardpans occur, and seasonal waterlogging is a problem.

The ridges have been extensively cleared as part of the Heytesbury Settlement Scheme and dairy farming is the main land use. There are problems arising from low soil fertility and exposure to wind. Only one small area of native vegetation remains in the study area.



Clearing of these flat lateritic plateau has been very thorough, and little evidence remains of the former hardwood forests that covered them.

SIMPSON		Components and its proportion of land system			
	Area: 33 km ²	1 65%	2 25%		
CLIMATE		3 10%			
Rainfall, mm	Annual: 800 – 950, lowest January (35), highest August (110)				
Temperature, 0°C	Annual: 13, lowest July (8), highest February (18)				
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August				
Precipitation: less than potential evapotranspiration late October – early April					
GEOLOGY					
Age, lithology		Pliocene latitized sand and clay Veneer of Quaternary sand			
TOPOGRAPHY					
Landscape	Very gently undulating plateau with north-west and south-east dissection				
Elevation, m	150 – 170				
Local relief, m	10				
Drainage pattern	Parallel				
Drainage density, km/km ²	1.0				
Land form	Plateau				
Land form element	Middle slope				
Slope (and range), %	0 (0-3)				
Slope shape	Straight (some convex)				
NATIVE VEGETATION					
Structure	Middle and upper slopes, crest				
Dominant species	4 (0-14) Straight (some convex)				
SOIL					
Parent material	Leptospermum juniperinum Melaleuca squarrosa, <i>E. nitida</i> , <i>Casuarina littoralis</i>				
Description	Closed scrub				
Surface texture	<i>E. obliqua</i> , <i>E. baxteri</i>				
Permeability					
Depth, m					
LAND USE					
Cleared areas:	Dairy farming; some beef cattle grazing				
Minor cleared areas:	Hardwood forestry production				
SOIL DETERIORATION HAZARD	Low inherent fertility and phosphorus fixation lead to nutrient decline. Leaching of salts lead to increased salinity to drainage waters.	Low permeabilities and high seasonal watertables lead to seasonal waterlogging and soil compaction. Leaching of salts from landscape leads to increased salinity of drainage waters.			
Critical land features, processes, forms					

7.37 Thompson Creek Land System

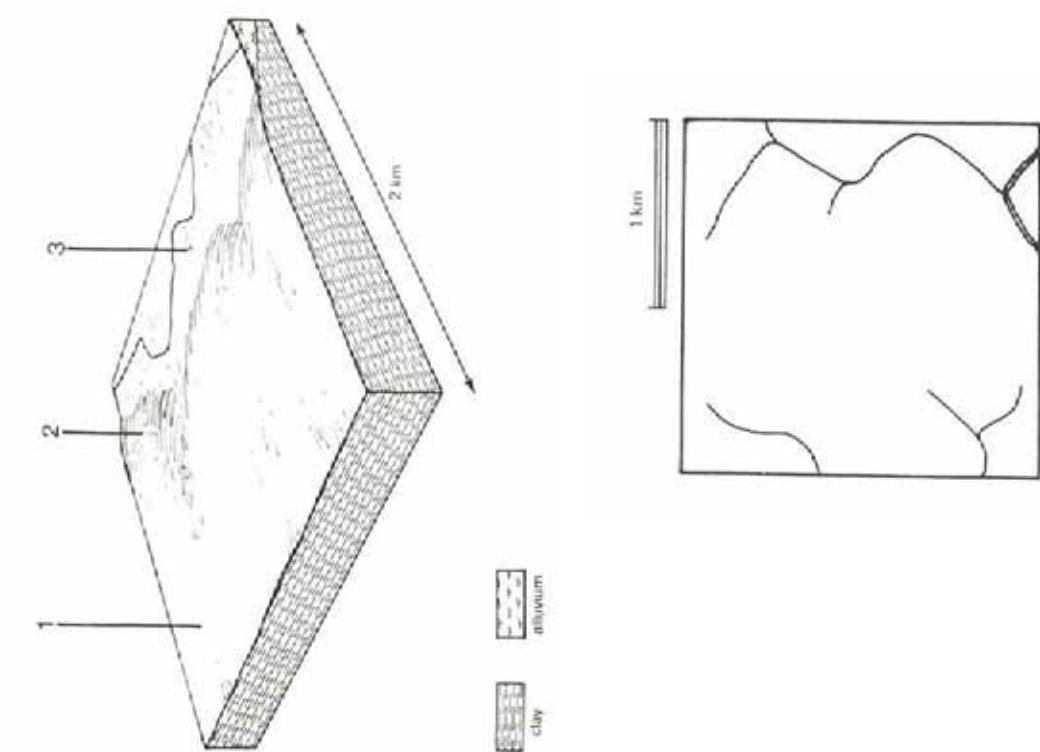
The lower reaches of the Thompson Creek catchment spread out into a wide alluvial plain. The plain appears almost flat, but it slopes towards the sea. The highest inland parts are some 20 m above the present valley floor of Thompson Creek, and some mild dissection into the plain occur along the sides of this valley.

Road reserves and small shelter belts for stock contain the only remnants of the native vegetation. Low woodlands of *Eucalyptus leucoxylon* and *Casuarina stricta* appear to have been common, with *Acacia pycnantha* dominating the understorey. *E. leucoxylon* shows evidence of severe salt pruning several kilometres from the coast. Soils are duplex and sodic with dispersible subsoils.

These plains are used for grazing and cropping. Minor problems are encountered from gully erosion along the margins of Thomson Creek, and soil salting occurs in the lowest areas close to the Connewarre land system.



These flat plains are used mainly for grazing and cropping



THOMPSON CREEK

Area: 29 km²

		Component and its proportion of land system	
	1 70%	2 20%	3 10%
CLIMATE			
Rainfall, mm	Annual: 600, lowest January (30), highest August (60)		
Temperature, 0°C	Annual: 14, lowest July (9), highest February (19)		
Seasonal growth limitations	Temperature: less than 10°C (av.) July		
Precipitation: less than potential evapotranspiration October – mid April	Deeply weathered Plio-Pleistocene fluvialite sand and clay		
GEOLOGY			
Age, lithology			
TOPOGRAPHY			
Landscape	Flat to gently undulating plain near the south of Thompson Creek		
Elevation, m	0 – 50	5	
Local relief, m			
Drainage pattern	Weak dendritic pattern with some deranged areas		
Drainage density, km/km ²	1.2		
Land form			
Middle and upper slope	Plain		
0 (0-2)	Lower slope	–	
Linear	4 (2-10)	1 (0-2)	
Slope shape	Convex	Linear	
NATIVE VEGETATION			
Structure	Low woodland	Open forest	Woodland
Dominant species	<i>E. leucoxylon, Casuarina stricta, E. ovata</i>	<i>E. leucoxylon</i>	<i>E. leucoxylon, E. viminalis</i>
SOIL			
Parent material	Sandy clay	Sandy clay	Sand, silt and clay
Description	Yellow-brown sodic duplex soils, coarse structure	Yellow sodic duplex soils	Brown sandy loam soils, uniform texture
Surface texture	Sandy loam	Sandy loam	Sandy loam
Permeability	Low	Moderate	High
Depth, m	>2	>2	>2
LAND USE	Cleared areas: Dairy farming and beef cattle grazing on mainly improved pastures; some cereal cropping		
SOIL DETERIORATION HAZARD	Dispersible soils are prone to gully erosion. Sodic subsoils and high water tables lead to soil salting, Critical land features, processes, forms	Sodic subsoils and high water tables lead to soil salting.	Shallow saline water tables lead to soil salting, waterlogging and soil compaction. High discharge rates along watercourses lead to streambank erosion.

7.38 Tomahawk Creek Land System

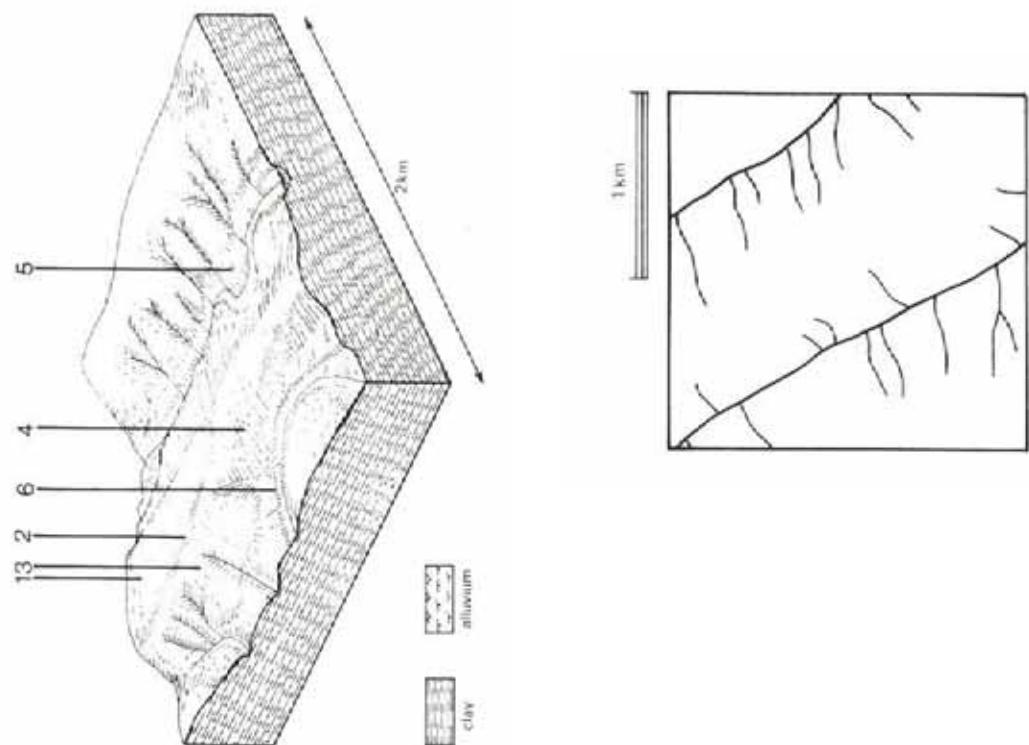
Tomahawk Creek and its tributaries have dissected out deep valleys with characteristic north-not-west- and south-sou'-east-oriented parallel ridges and spurs. Small remnants of lateritic plateaux on the high parts of the landscape are bounded by scarpson which ironstone outcrops. Tertiary sand is often exposed in a narrow band below these scarpss, and springs are often present at this level. Silt and clay are the more common parent materials on long straight slopes leading down to the valley floor. Small dissected terraces are found along the wider valleys.

The terrain to the south and east of Tomahawk Creek shows a lower local relief than the area to the north and west. Areas of lateritic plateaux are often wider and surrounding slopes are shorter and more gentle. Site drainage is affected by the more subdued relief. Woodlands and lowlands appear to have been more common in this area, with open forests to the north and west.

Most of this land system has been cleared as part of the Heytesbury Settlement Scheme, and dairy farming is the main land use. Subsoils on many slopes are dispersible and gully and tunnel erosion are quite active. Some landslips have occurred, particularly below springs at the base of scarpss.



Cattle graze the undulating plateau country.



TOMAHAWK CREEK

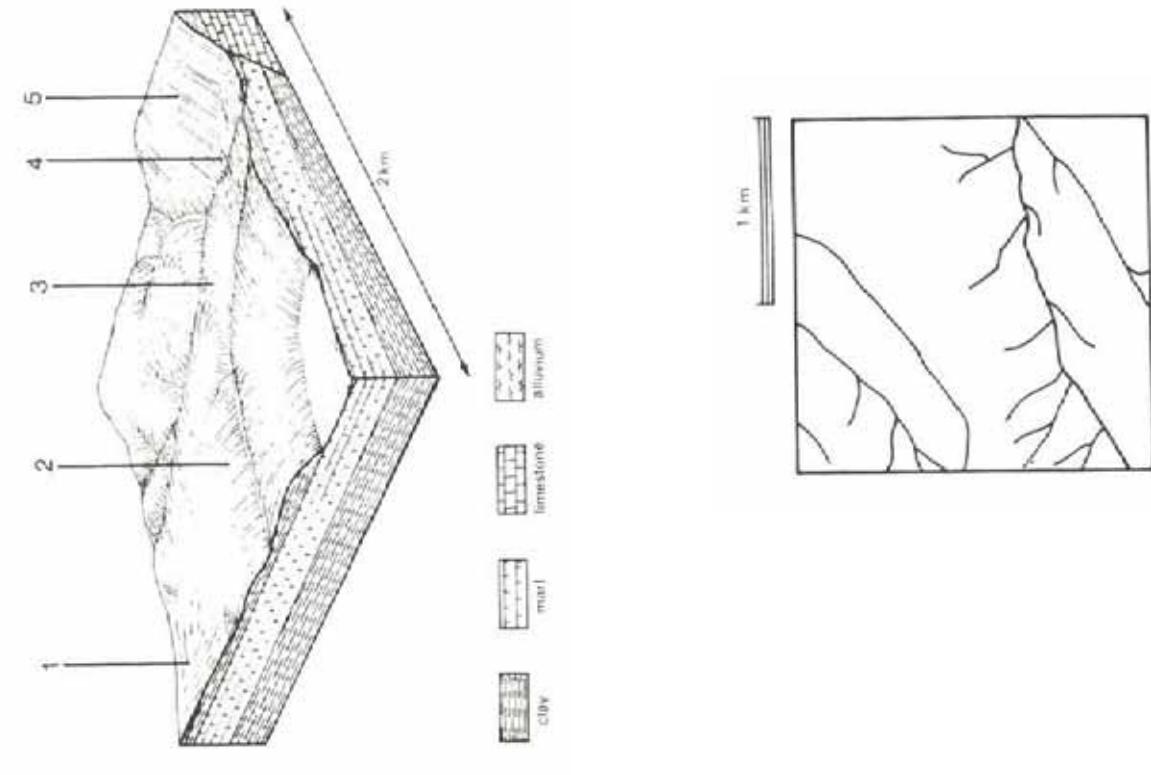
	Component and its proportion of land system			
	1 15%	2 6%	3 10%	
	4 50%	5 9%	6 10%	
CLIMATE				
Rainfall, mm	Annual: 850 – 1,050, lowest January (40), highest August (125)			
Temperature, °C	Annual: 13, lowest July (8), highest February (19)			
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August			
Precipitation: less than potential evapotranspiration November – March				
GEOLOGY				
Age, lithology	Pliocene lateritized sand and clay			Miocene unconsolidated sand, silt and clay
TOPOGRAPHY				
Landscape				Deep valleys dissected out from lateritic plateaux
Elevation, m				50 – 160
Local relief, m				70
Drainage pattern				Trellis predominantly, some dendritic areas
Drainage density, km/km ²				2.9
Land form				
Land form element				
Slope (and range), %				
Slope shape				
Plateau remnants				
	Upper slope 12 (8–18) Straight			Upper slope 5 (1–8) Straight
	Concave			Mid slope 12 (8–20) Straight
				Scarp
				Lower slope 5 (1–8) Straight
				Concave
				Valley floor
NATIVE VEGETATION				
Structure				
Dominant species				
Open forest				
<i>E. obliqua, E. baxteri</i>				
Open forest				Woodland
<i>E. obliqua, occasionally E. viminalis</i>				<i>E. radia, E. baxteri</i>
				<i>E. ovata, E. obliqua, E. radia, E. baxteri</i>
SOIL				
Parent material				
Description				
Lateritic remains				Siliceous sand
Mottled yellow and red gradational soils with ironstone				Grey sand soils, uniform texture
Sandy loam				Yellow-brown gradational soils, coarse structure
Moderate				Sandy clay (in-situ)
Surface texture				Grey sand soils, structured clay underlay
Permeability				Colluvial/alluvial sand over sandy clay
Depth, m				Grey gradational soils
1.6				Sand and clay alluvium
1.6				
LAND USE				
Cleared areas:	Manly dairy farming; some beef cattle grazing.			
Uncleared areas:	Hardwood forestry for sawlogs, some posts and poles, gravel extraction; nature conservation.			
SOIL DEGENERATION HAZARD				
Critical land features, processes, forms	Low inherent fertility and phosphorus fixation lead to nutrient decline. Leaching of salts leads to increased salinity of drainage waters.			
	Steep slopes with weakly structured surfaces of low water-holding capacity are prone to sheet erosion. Low inherent fertility and high permeability lead to nutrient decline.			
	Emergence of springs from these permeable aquifers leads to seasonal waterlogging and soil compaction. Permeable soils of low inherent fertility are prone to nutrient decline.			
	Highly dispersible clay subsoils of low permeability receiving seepage water are prone to gully and tunnel erosion, waterlogging and surface compaction. Permeable surfaces of low inherent fertility are prone to nutrient decline.			
	Dispersible soils of low permeability receiving seepage water are prone to gully and tunnel erosion, waterlogging and surface compaction. Permeable surfaces of low inherent fertility are prone to nutrient decline.			
	Dispersible clay subsoils of low permeability receiving rapid run-off from surrounding hills are prone to gully erosion. Rising water tables and low permeabilities lead to seasonal watchlogging and soil compaction.			

7.39 Waarre Land System

Undulating plains to the north and west of Princetown are formed on Tertiary limestone, marl and calcareous clay. Only a small tract of this land lies within the study area, but the landscape is extensive in the neighbouring catchments of Scotts Creek and Cooriemungle Creek. Some faulting has led to occasional steep scarp, but most slopes are gentle and straight, separated by broad drainage lines.

The gradational soils on these calcareous sediments are heavier-textured and significantly more fertile than soils formed on Tertiary sediments in adjacent land systems. Free lime is often present in the soil profile. Remnants of the native vegetation indicate that it was somewhat stunted, possibly as a result of the proximity of the coast.

A large part of this land system lies within the Heytesbury Settlement Scheme and clearing has been widespread. Dairy farming is the main land use, although some of the earlier established areas close to the coast are used for sheep and beef cattle grazing. Subsoils are dispersible and gully erosion has occurred along some drainage lines. Landslip and slumping of road batters cause problems with road construction and access on the more undulating areas. Drainage lines remain waterlogged for most of the year and are prone to soil compaction by stock.



Long straight slopes with broad drainage lines typify the landscape formed on these calcareous sediments, but occasional fault scarp are found close to the coast.

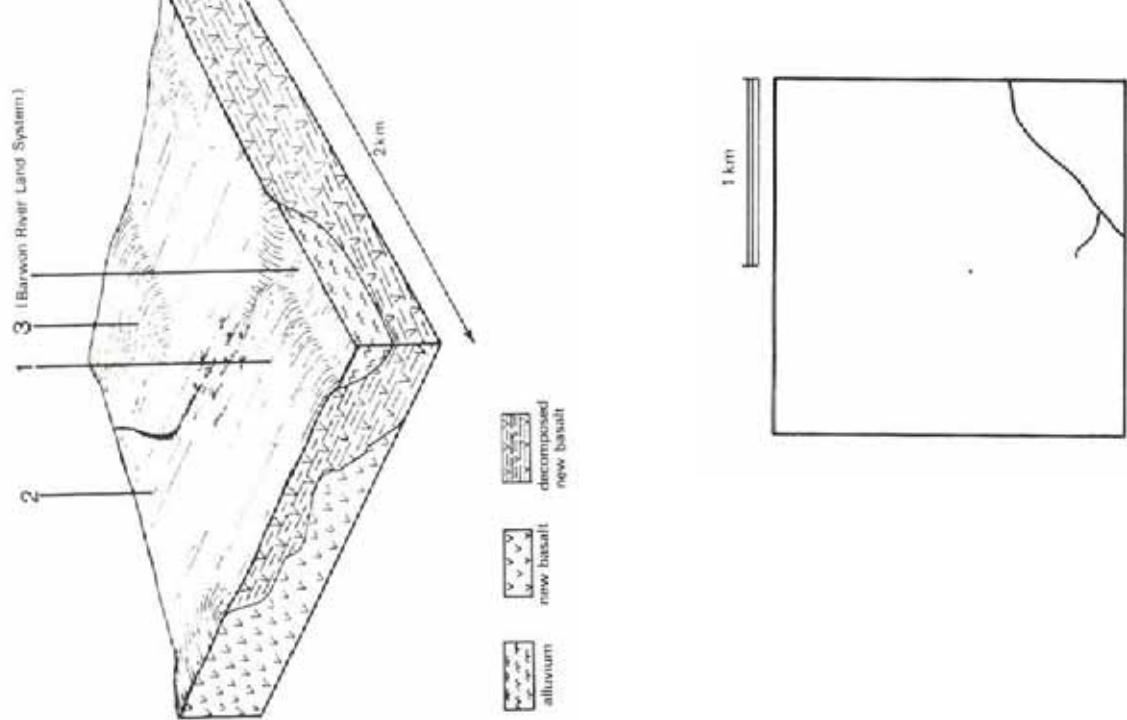
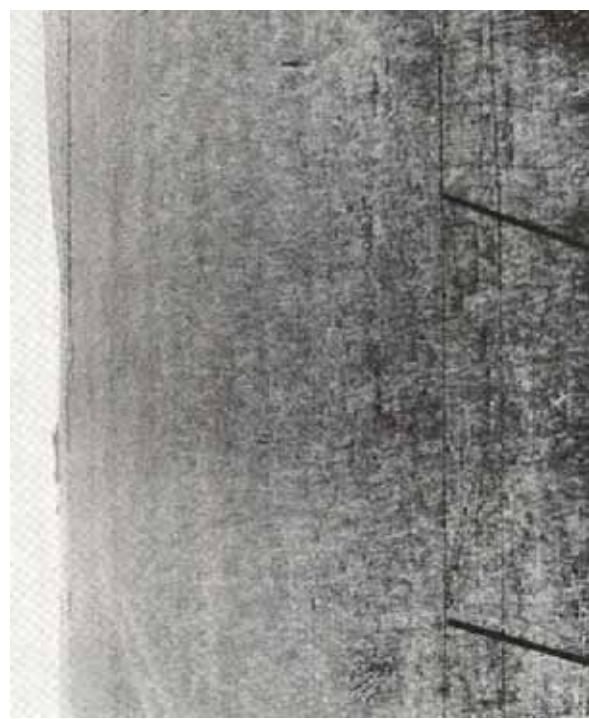
W^ARE	Area: 28 km ²	Component and its proportion of land system
	1 4%	2 65%
		3 20%
		4 8%
		5 3%
CLIMATE		
Rainfall, mm	Annual: 900 – 1,000, lowest January (40), highest August (120)	
Temperature, 0°C	Annual: 14, lowest July (9), highest February (18)	
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August	
Precipitation: less than potential evapotranspiration November – March	Miocene marine clay, marl and limestone in the lower reaches of the Gellibrand River catchment	
GEOLOGY		
Age, lithology		
TOPOGRAPHY		
Landscape	Undulating plain with some fault scarps	
Elevation, m	0 – 165	
Local relief, m	45	
Drainage pattern	Dendritic	
Drainage density, km/km ²	2.9	
Land form	Rise	Fault scarp
Slope (and range), %	Mid slope, crest 11 (4-21)	Lower slope 0 (0-1)
Slope shape	Convex	Linear
Upper slope, crest 5 (2-9)	Concave	33
Linear		Linear
NATIVE VEGETATION		
Structure	Rise	
Dominant species	Mid slope, crest 11 (4-21)	Lower slope 0 (0-1)
<i>E. ovata, E. radiata</i>	Concave	Linear
<i>E. obliqua, E. ovata</i>		
<i>E. aromaphloia</i>		
SOIL		
Parent material	Woodland	Woodland
Description	<i>E. ovata, E. radiata</i>	<i>E. obliqua, E. ovata</i>
Surface texture	In-situ marl, limestone	Closed scrub
Permeability	Brown duplex soils, coarse structure	<i>Melaleuca squarrosa,</i> <i>Leptospermum lanigerum</i>
Depth, m	Loam Low 1.7	
LAND USE		
SOIL DETERIORATION		
HAZARD		
Critical land features, processes, forms	Highly dispersible soils of low permeability are prone to gully and sheet erosion. Low inherent fertility and leaching of permeable surfaces lead to nutrient decline.	Dispersible subsoils on steeper slopes subject to periodic saturation are prone to landslips, slumping of road batters and gully erosion.
Minor uncleared areas: Nature conservation; includes the rugged coastline of the Port Campbell National Park	Clay subsoils on steeper slopes subject to periodic saturation are prone to landslips and sheet erosion.	Dispersible subsoils of low permeability receiving run-off from surrounding hills are prone to gully erosion, waterlogging and soil compaction.

7.40 Winchelsea Land System

Basaltic plains north of the Barwon River are typical of those found in much of western Victoria. These plains are relatively featureless, although there are occasional outcrops of basalt in the form of stony rises or scarpas.

The soils are duplex with heavy clay subsoils. Permeability is very low and waterlogging occurs during the wetter months. Gilgais are a feature of the landscape.

Grazing of sheet and beef cattle is the main land use, and there is some cereal and oilseed cropping. The climate is relatively dry, but suitable for agriculture, and improved pastures have normally been established. Soil salting occurs in many parts of the landscape, particularly close to the Barwon River.



These flat basalt plains contain very few remnants of the organic native vegetation.

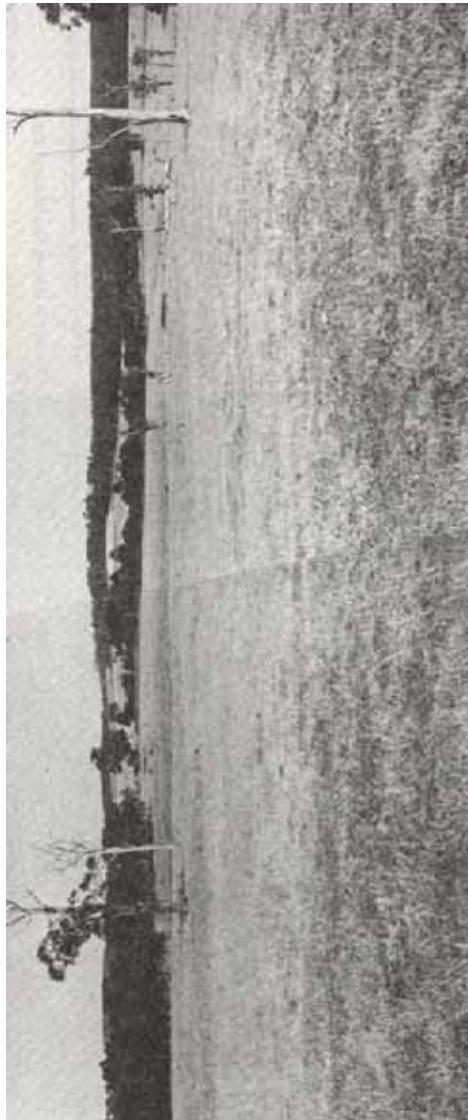
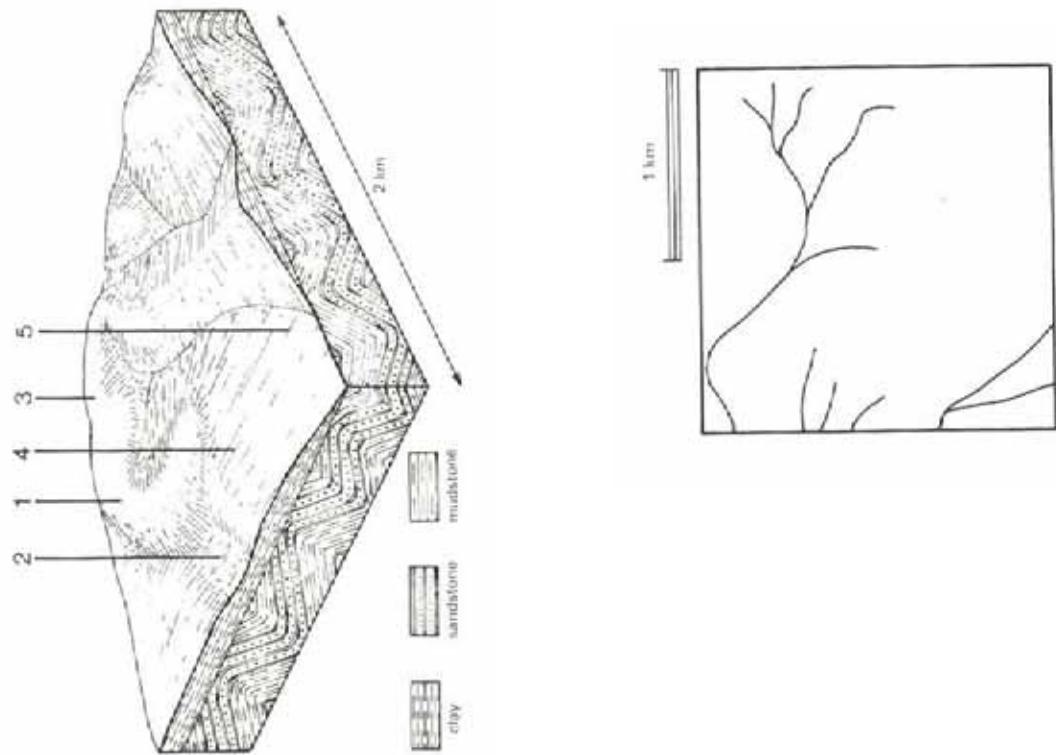
WINCHELSEA			Components and its proportion of land system
Area: 80 km ²			
CLIMATE			
Rainfall, mm	1	2	3
Temperature, 0°C	15%	75%	10%
Seasonal growth limitations			
GEOLOGY			
Age, lithology	Pleistocene basalt		
TOPOGRAPHY			
Landscape	Flat to gently undulating plain abutting the north side of the Barwon River		
Elevation, m	110 – 150		
Local relief, m	15		
Drainage pattern	Deltaic		
Drainage density, km/km ²			
Land form			
Land form element			
Slope (and range), %			
Slope shape			
NATIVE VEGETATION			
Structure			
Dominant species			
SOIL			
Parent material	In-situ deeply weathered basalt; some alluvium		
Description	Grey calcareous sodic duplex soils, coarse structure		
Surface texture	Sandy loam		
Permeability	Very low		
Depth, m	1.8		
LAND USE			
SOIL DETERIORATION HAZARD			
Critical land features, processes, forms	Soils of low permeability are prone to waterlogging and to salting where high water tables occur.	Soils of low permeability are prone to waterlogging and to salting where high water tables occur.	Minor hazards

7.41 Wonga Land System

Adjacent to the lateritic plateau around Simpson and at a similar elevation, a gently undulating plain without lateritic ironstone extends eastwards towards Barongarook. The parent material is mainly Tertiary sand and clay, with some minor redistribution on sand veneers in some parts and outcrops of deeply weathered Cretaceous sandstone along the sides of some of the drainage lines.

The soils exhibit similar mottling and deep weathering to those found in the Simpson land system, and are prone to nutrient deficiencies and phosphate fixation. Open forests of *Eucalyptus obliqua* occur over most of the landscape, although *E. baxteri* tends to dominate on the polygenetic soils with hardpans. *Acacia mucronata* acts as a strong indicator of the presence of Cretaceous outcrops.

Most areas remain uncleared and are selectively logged for hardwood timber, although most timber is of insufficient size to provide good sawlogs.



The cleared area in the foreground contrasts with the native hardwood forests.

WONGA		Component and its proportion of land system	
	1 km ²	2	3
	45%	7%	25%
CLIMATE			
Rainfall, mm	Annual: 850 – 950, lowest January (40), highest August (120)		
Temperature, 0°C	Annual: 13, lowest July (8), highest February (18)		
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August		
Precipitation: less than potential evapotranspiration late October – March			
GEOLOGY			
Age, lithology	Paleocene marine unconsolidated clay, silt and sand	Lower Cretaceous feldspathic sandstone and siltstone	
TOPOGRAPHY			
Landscape	Undulating plain in the north part of the Gellibrand River catchment		
Elevation, m	120 – 340		
Local relief, m	30		
Drainage pattern	Parallel and dendritic		
Land form	Undulating plain		
Drainage density, km/km ²	1.2		
Crest, upper slope			
7 (0-12)	Slope	Lower slope	
Convex	4 (0-7)	10 (4-14)	
Slope (and range), %	Concave	Linear	
Slope shape			
NATIVE VEGETATION			
Structure			
Dominant species	<i>E. obliqua</i> , <i>E. radiata</i> , <i>E. baxteri</i> , <i>E. ovata</i> , <i>E. nitida</i> , <i>E. baxteri</i> , <i>E. ovata</i> , <i>E. radiata</i> , <i>E. obliqua</i> , occasionally <i>E. aromaphloia</i>	Open forest	Open forest
SOIL			
Parent material			
Description	Colluvial sand on sand, silt and clay	Colluvial sand on sand, silt and clay	Clay, silt and sand
Surface texture	Mottled yellow and red gradational soils	Grey sand soils, weakly structured clay underlay	Yellow-brown gradational soils, coarse structure
Permeability	Sandy loam	Sandy loam	Fine sandy clay loam
Depth, m	Moderate	Low	Low
	>2	>2	1.5
LAND USE			
Minor cleared areas: Beef cattle grazing; dairy farming			
Low inherent fertility and phosphorus fixation lead to nutrient decline.	Low permeability and perched water tables lead to seasonal waterlogging and soil compaction.	Low inherent fertility and leaching of permeable surfaces lead to nutrient decline. Low permeabilities lead to seasonal waterlogging and soil compaction.	Dispersible clay subsoils of low permeability are prone to gully erosion. Steeper slopes are prone to sheet erosion.
SOIL DETERIORATION HAZARD			
Critical land features, processes, forms			

7.42 Yahoo Creek Land System

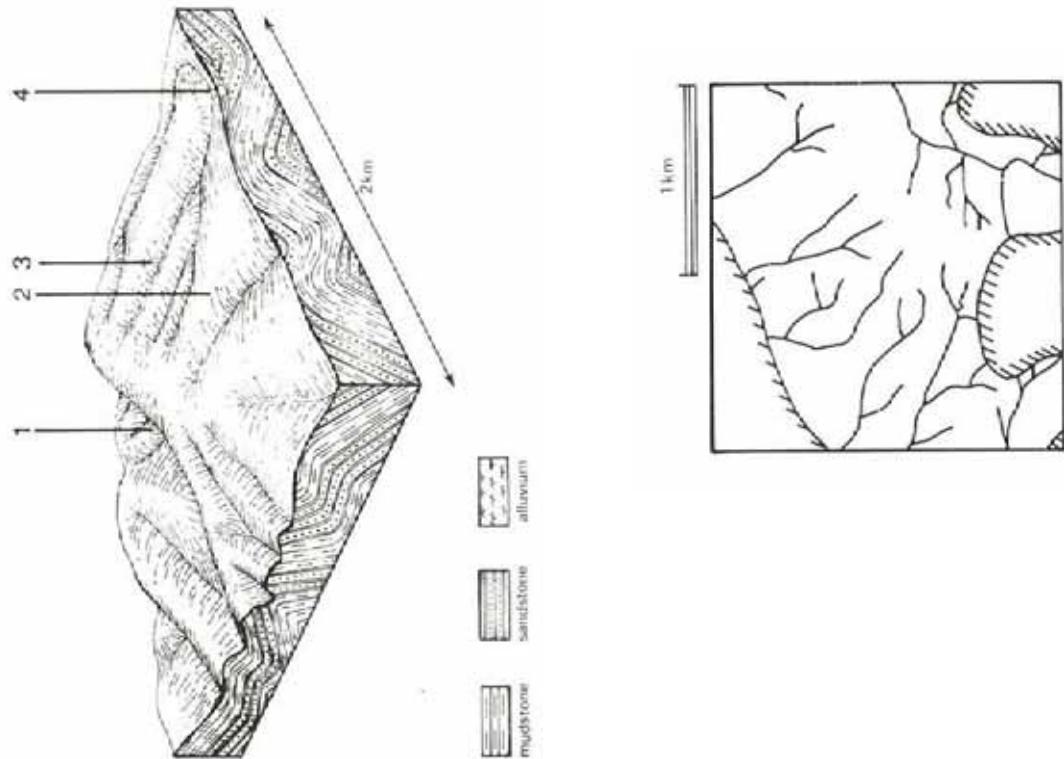
North of the Gellibrand River, Cretaceous sandstones and mudstones outcrop in the valleys of the Yahoo Creek, Gum Gully Creek and an unnamed creek to the west of Black Bridge road. These sediments belong to the Moonlight Head Beds of the Otway Group. Slopes are steep and valleys are narrow, in sharp contrast to the rounded hills of adjacent Tertiary sediments.

The soils are similar to those found on other outcrops of Cretaceous sediments in the Range, with the exception that surface horizons contain appreciably more sand and the parent material is usually highly weathered. Open forests of *Eucalyptus obliqua*, *E. ovata* and *E. aromaphloia* are similar to those found on the drier slopes of the Forrest land system.

Most parts of the valleys remain virtually uncleared and quite remote. Hardwood forestry is the main land use, although the rugged terrain makes access difficult. Some softwood plantations have been established in the catchment of Yahoo Creek. Landslips occur on these soils under native forest, and the incidence increases dramatically following clearing. Sheet erosion and gully erosion are also prone to occur.



The steep and rugged hills surrounding Yahoo Creek are difficult to manage. Scrub regrowth rapidly takes over recently cleared slopes.



YAHOO CREEK

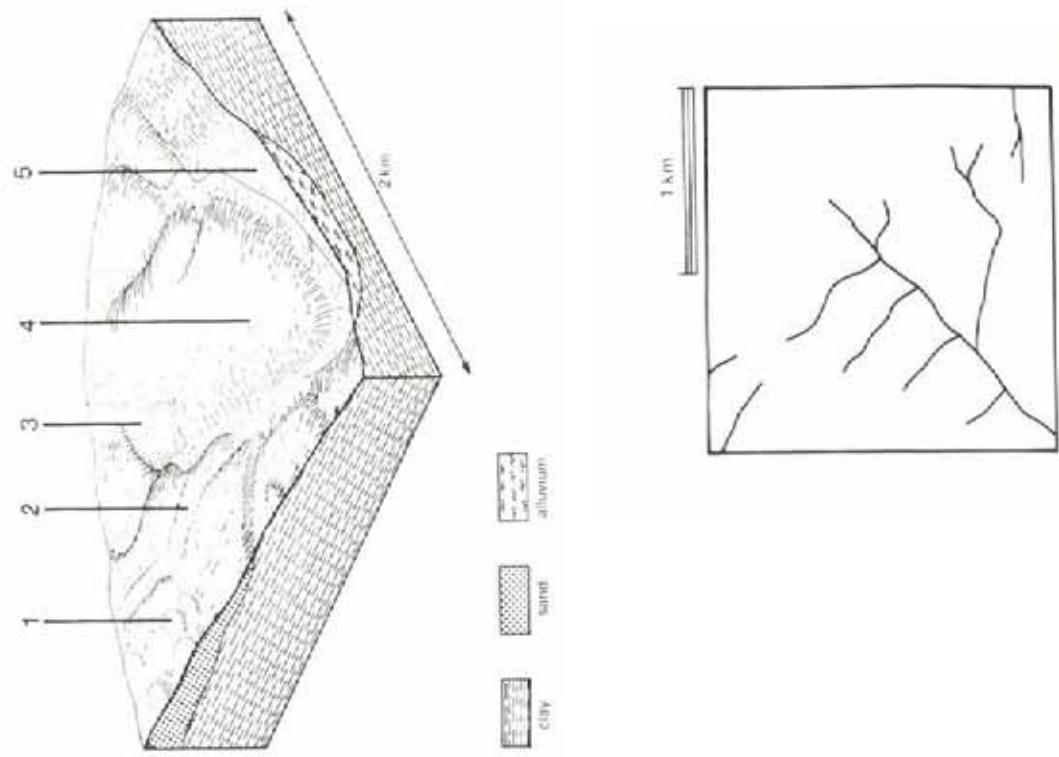
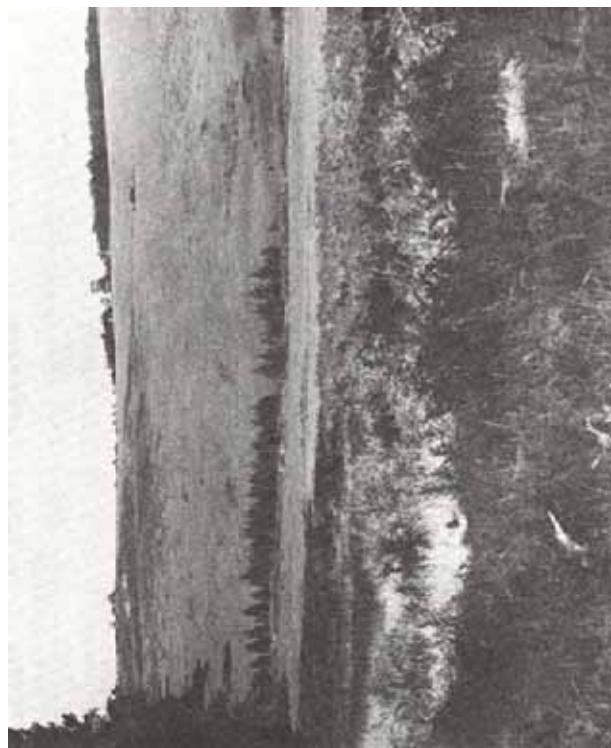
		Components and its proportion of land system		
		1 35%	2 45%	3 15%
		4 5%		4 5%
CLIMATE				
Rainfall, mm				
Temperature, 0°C				
Seasonal growth limitations				
GEOLOGY				
Age, lithology				
TOPOGRAPHY				
Landscape		Deeply dissected hills to the north of Gellibrand River		
Elevation, m		60 – 270		
Local relief, m		110		
Drainage pattern		Dendritic with small radial areas		
Drainage density, km/km ²				
Land form				
Slope (and range), %				
Slope shape				
NATIVE VEGETATION				
Structure				
Dominant species				
SOIL				
Parent material				
Description		In-situ weathered rock Stony brown gradational soils		
Surface texture				
Permeability				
Depth, m				
LAND USE				
SOIL DETERIORATION HAZARD				

7.43 Yeodene Land System

West of Yeodene, a rolling and irregular landscape forms part of a broad ridge extending from the foothills of the Ranges towards Colac. Tertiary sand outcrops on most parts of the landscape, often forming a veneer over exposures of Tertiary silt and clay.

The soils have loamy sand or sandy loam surface textures and are prone to nutrient and moisture deficiencies. Hardpans between the sand veneers and clay horizons may result in perched water tables, although only small areas have such poor site drainage that frequent waterlogging occurs.

Sand and gravel have been extensively mined in some areas, and pine plantations have been established near Yeodene. However, most of the area remains in a fairly natural state and constitutes a significant area of natural vegetation close to Colac. Its potential for recreation is at present not fully utilized. Only minor areas have been cleared for agriculture, but the establishment of improved pastures is difficult.



Acid sands in this comparatively dry area will not support vigorous pastures and the control of weeds such as Pteridium esculentum and Rubus spp. is difficult.

YEODENE		Component and its proportion of land system		
		1 35%	2 25%	3 5%
CLIMATE		4 30%		
Rainfall, mm	Annual: 750 – 850, lowest January (40), highest August (100)			
Temperature, °C	Annual: 13, lowest July (8), highest February (9)			
Seasonal growth limitations	Temperature: less than 10°C (av.) June – August			
GEOLOGY		Paleocene unconsolidated sand, silt and clay Recent sand veneer		
TOPOGRAPHY		Rolling plain in the western parts of the Barwon catchment and northern parts of the Gellibrand catchment 120 – 260		
Landscape				
Elevation, m	40			
Local relief, m				
Drainage pattern				
Land form				
Drainage density, km/km ²				
Slope (and range), %				
Slope shape				
NATIVE VEGETATION				
Structure				
Dominant species				
SOIL				
Parent material				
Description				
Surface texture				
Permeability				
Depth, m				
LAND USE				
SOIL DETERIORATION				
HAZARD				
Critical land features, processes, forms				

8. SOIL CONSERVATION

In their natural condition, soil and vegetation are stable except on some exposed coastal situations. Upon disturbance, however, a major change in one causes changes in the others. If the vegetation is damaged, the soil erodes. If the soil deteriorates, then the vegetation degenerates. In both cases the quality and regulation of the waters will decline. The sensitivity of the land varies between land systems.

Soils deterioration occurs in various forms. Sheet, rill, gully and wind erosion result in the loss of soil material, as does mass movement, although to a more limited extent. Soil salting, loss of nutrients and decline in structure result in lower plant growth and water usage. Deterioration of streams frequently results, and accelerated stream flow may lead to flooding, streambank erosion and excessive sedimentation of land and utilities. Access and trafficability become more difficult and aesthetic appeal is lost.



Exposure of tree roots and elevation of grass tussocks on small pedestals indicates that sheet erosion losses have been quite extensive on these steep northerly facing slopes abutting Moggs Creek.

All forms of deterioration involve the community in losses, either directly or indirectly, and these losses are part of the less obvious costs associated with a particular activity or form of production.

Types of Deterioration

Sheet erosion

Sheet erosion is the removal of surface layers of soil by water. The impact of raindrops disturbs soil particles, which may then be suspended in turbulent surface run-off water and carried downslope. The susceptibility depends on the structure, permeability and dispersibility of the soil, the length and gradient of the slope, the intensity of the rain-storm and the degree of protection that the soil receives from the cover of vegetation and litter. Often only small amounts of material are removed at any one time. The exposure of tree roots, elevation of grass tussocks on small pedestals of topsoil and accumulation of soil material on the uphill side of fences and other obstructions often provide evidence of sheet erosion.

The most sensitive areas are found on the drier slopes of the Otway Range in the Lorne, Forrest, Moggs Creek and Yahoo Creek land systems. Long steep slopes, weakly structured and often dispersible topsoils and low infiltration rates are critical factors. The steep hills of the Mount Mackenzie and Bunker Hill land systems are less susceptible, as infiltration rates are high. Other sensitive areas occur in most land systems, except for the lateritic plateaux, basalt plains and alluvial deposits.

Gully erosion

When water is concentrated into small rivulets or drainage lines, its eroding action can result in the development of shallow channels, known as rills, or deep and extensive gullies. In the most severe cases, gullies can undermine bridges and roads as well as create problems of access and management.



Wormbete Creek, a tributary of the Barwon River, causes particular problems through actively eroding gullies. Headward extension of this gully has caused loss of productive land, damaged fences, decreased trafficability and access and reduced aesthetic appeal.

The mechanisms by which gullies have been initiated and continue to extend both laterally and headward take many different forms. All forms stem from an imbalance in the hydrological regime, usually brought about by the replacement of the native vegetation with pasture species or crops.

The coarsely structured, dispersible soils of the Deepdene land system and the Heytesbury settlement area are prone to sapping, leading to extensive gully and tunnel erosion. Many of the drainage lines in the Paraparap and Anglesea land systems are also susceptible. In the higher-rainfall areas, scouring is a more important mechanism than sapping and this is responsible for much of the damage in the Pennyroyal and Barwon River land systems.

Mass movement

The migration of material downslope under the action of gravity can range from rockslides and avalanches through to earth flows and soil creep. The gradient of the natural or artificial slope is the critical factor in determining the susceptibility to mass movement. When saturated with water, the soil loses much of its cohesive strength and, combined with the added weight of soil water, the force of gravity may take the soil beyond the threshold of stability. Under natural conditions the binding effect of tree roots increases this threshold value. Vibrations such as earthquakes or even the passing of traffic aggravate the instability by bringing about slight compaction of the solids. This forces out pore water, which cannot escape and so acts as a lubricant to the soil mass.

In the Lorne and Aire land systems, the soil material liberated may slide down the hillside, particularly if bedding or joint plains are parallel to the slope of the land (Joyce and Evans 1976). More commonly, however, slumps (as distinct from landslides) occur. The shearing plane takes a curved form, with the soil moving vertically downwards at the toe. The soils on slopes close to the coast are highly dispersible and are very prone to both landslides and landslips.

Apart from the Otway Range, the Heytesbury settlement area contains highly susceptible areas. Springs emerging from below the base of the lateritic capping in the Tomahawk Creek land system have probably increased in incidence and total flow since clearing. Prolonged saturation often results in slumps at these points in the landscape.

The Deepdene, Pennyroyal and Anglesea land systems also possess sensitive areas. In weakly structured dispersible soils, these slumps may trigger off earth flows, where the original slumped mass moves downhill each successive season, pushing more soil in front of it in a slow turbulent flow. Notable earth flows are found in the Lorne and Anglesea land systems.



Earth flows are a common feature of the steep hills: This one near Upper Gellibrand threatens the road that crosses it.

Salting

Wherever landscapes contain significant levels of soluble salts, these salts tend to accumulate in groundwater and run-off. Land use changes involving replacement of the native vegetation often lead to a rise in the regional water tables, upsetting the natural hydrological regime. The soluble salts in the groundwater are concentrated near the surface as the water evaporates. Salts frequently reach toxic levels, restricting plant growth.

In Victoria this process tends to be most marked in areas with rainfalls between 600 and 700 mm (Gibbons 1971). The Paraparap, Deepdene, Birregurra, Winchelsea and Anglesea land systems are among the most susceptible.



Rising salt concentrations in the topsoil both stunt and kills the pasture in lower parts of the landscape. Stock often camp on these areas, trampling the vegetation, and this may lead to sheet and gully erosion.

Lateritic landscapes have been associated with high salt content of associated soils and groundwaters (Dimmock *et al.* 1974). Although no soil salting has been observed in the wetter climates of the Heytesbury settlement area, rises in the salinity of streams have been recorded since the widespread clearing of the dissected lateritic plateaux.

Soil nutrient decline

The cycle of soil nutrients from root absorption through biomass, litter fall, leaching and root absorption again is sensitive to change. Removal or replacement of deep-rooted native vegetation may result in marked increases in run-off (Blake 1975) and a lower ability of the shallow-rooted introduced species to intercept nutrients being leached downwards. Litter fall may be reduced, leading to fewer organic colloids and adsorbed plant nutrients in the surface soil. Soil temperatures may rise, leading to more rapid oxidation of the existing organic matter.

Highly permeable soils of low initial fertility are the most susceptible. These include the sands of the Bald Hills, Chapple Vale, Redwater Creek, Bunker Hill, Yeodene and Porcupine Creek land systems. To a lesser extent, the Beech Forest, Mount Sabine, Mount Mackenzie and Hordern Vale land systems are also susceptible.

Phosphorus fixation is another hazard relating to soil fertility. Although not directly a deterioration of the land in itself, it can severely limit the growth of introduced crops and pastures, thus aggravating leaching of nutrients. Susceptible areas are the lateritic landscapes of the Simpson, Gherang Gherang and Wonga land systems, and to a lesser extent the Deepdene, Paraparap, Barongarook and Anglesea land systems.



Land use in the upper parts of the Barwon River catchment effects land downstream. Unwise use can result in increased flooding, sedimentation and prolonged waterlogging.

Soil structure decline

Soil structure may deteriorate due to loss of organic matter or disturbance. Organic colloids are the main binding force of the structural units of the surface soil. Removal or humification without replacement results in loss of surface structure. Disturbance, particularly when the soil is wet and cohesive forces are low, may mechanically shatter the structural units. Soils with initially weak surface structure are the most susceptible. Such soils tend to have a low infiltration capacity, low available water capacity, dispersion problems and a tendency to set hard in summer.

The majority of soils in the study area are susceptible to structure decline. Particularly susceptible areas are found in the poorly drained parts of the Tomahawk Creek, Kennedys Creek and Waarre land systems.

Wind erosion

Sandy soils are poorly structured and have a low water-holding capacity. In the Cape Otway and Point Roadknight land systems, strong onshore winds and poor protection from the indigenous vegetation, especially when trampled by frequent pedestrian traffic or cattle, result in the dunes becoming unstable. Roads and utilities are affected by shifting dunes in these areas.

Deterioration of streams

The above forms of deterioration are essentially on-site effects. However, they also result in off-site effects, the most important of which is the deterioration of streams.

The loss of soil material, soil structure, soil fertility and associated plant vigour leads to increased surface run-off, with less water percolating through the soil. The height and incidence of flooding increase, and the perennial nature of streams diminishes. Turbidity rises while erosion is taking place. Increased salinity of streams from cleared catchments containing significant quantities of soluble salts limits their use for domestic and irrigation purposes.

Soil Conservation and Land Use

Grazing

The management of land for grazing usually involves replacement of the native trees and shrubs with shallow-rooted grasses and forbs. The accompanying change to the natural hydrological regime leads to the previously mentioned forms of deterioration.

Gully erosion has occurred in many areas and has been particularly prevalent in the steep drainage lines of the Deepdene land system to the west of the Barwon River. Headward eroding gullies are also common in some of the eastern tributaries of the Barwon River, such as Wormbete Creek.

Soil salting has occurred in many of the drainage lines of the plains to the north and east of the Otway Range. Pastures on saline areas become yellow, and less vigorous. Stock accumulate on these areas and trample the vegetation, which may lead to other forms of deterioration such as gully erosion.

Overgrazing of sloping land and trampling of the vegetation and soil have led to sheet erosion in many places, particularly the foothills of the Range and parts of the Heytesbury settlement area. Much of the damage occurs during the summer months, when the highest-intensity rainstorms coincide with a period of low growth potential, as shown in Figure 5. If grazing has been heavy, the soil has little or no protective vegetative cover when these summer thunderstorms occur, and losses can be severe.

Landslips are common the steep slopes of the Otway Range and are increasing in occurrence following clearing in the Heytesbury settlement area. Cleared hillsides of the Lorne, Forrest, Yahoo Creek, Pennyroyal and Aire land systems are covered by terracettes, often referred to as 'sheep tracks'. They are in fact the surface expression of numerous small slumps and are usually found where unweathered rock is close to the surface. Where they adjoin previous slipped areas, they have a stabilizing influence, preventing larger rotational slumps from occurring (Joyce and Evans 1976).

Soil nutrient losses are prevalent on the freely drained soils of the high-rainfall areas, but regular topdressing has often maintained or increased soil fertility of the more productive land. Topdressing is not economic on many of the sand and phosphate-fixing soils, and the low levels of nutrients initially present tend to be lost under grazing.

Deterioration of soil structure in the Beech Forest and Mount Sabine land systems after prolonged periods of pasture growth is presumably associated with lower levels of organic matter. Loss of surface structure by pugging is a problem in most wet areas, particularly where cattle are grazed during winter.

Overgrazing and trampling by cattle have led to wind erosion of sand dunes near the mouth of the Aire River. The native grasses are susceptible to trampling and establishing of improved pastures is difficult. The dunes east of Torquay also show evidence of past grazing damage.

With the exception of wind erosion, prevention of these forms of deterioration primarily rests with maintaining a hydrological balance similar to that of the original system under native vegetation. Deep-rooted perennial pasture species, such as *Phalaris tuberosa*, and trees can tap moisture and nutrients from well below the soil surface, thus reducing total run-off and recycling nutrients. Continues use of fertilizers is necessary to maintain vigorous plant growth and actively using soil water. Dense root and shoot growth also lend physical stability to the soil, limiting mass movement, sheet and gully erosion.

Treatment of existing problems may be expensive. Actively eroding gullies can be stabilized by diverting run-off or replacing the head of the gully with a concrete structure or a grassed chute. The appropriate method depends on the mechanisms involved.

Salt-affected areas can be revegetated by sowing salt-tolerant grasses such as *Agropyron* spp. and *Puccinella* spp. Soil amelioration with gypsum is often used to improve drainage.

Overgrazing should be avoided on areas prone to sheet erosion. Where slopes are too steep for drilling of seed and fertilizer, aerial seeding of improved pasture species may be practicable.

Landslips can sometimes be halted by fencing out the slumped area and planting trees. Run-off water from roads, dairies and buildings should not be discharged onto susceptible slopes, particularly in the Heytesbury settlement area. In the Waarre land system, slopes of more than about 18% are susceptible, while the Tomahawk Creek and Kennedys Creek land systems have a steeper critical angle.

Under grazing it is particularly difficult to control wind erosion on the coastal dunes. Although some light grazing can be supported, overgrazing damages the vegetation and the shifting dunes will not usually revegetate naturally. Expensive reclamation work, such as hand-planting *Ammophila arenaria*, will be required.

Cropping

Sheet erosion has occurred on much of the sloping land used for cropping in the Beech Forest, Hordern Vale and Bellbrae land systems. Intense spring and summer rains often occur after ploughing or sowing, and the surface run-off remove the more fertile topsoil.

Contour cultivation, retention of trash and strip cropping can reduce these losses. Problems are encountered, however, in handling machinery along the contour on sloping land.

Overtopping causes serious damage to soil structure. Mechanical disturbance shatters the structural units, often weakened from depletion of organic matter. Fields that have been cropped for several generations in the Beech Forest land system show marked decline in surface soil structure.

Rotations incorporating those with nitrogen-fixing legumes, will increase organic matter. Continued use of fertilizers is necessary to maintain vigorous growth and to return organic matter to the soil.

Forestry

Both establishment and harvesting of hardwood and softwood forests cause serious changes to the natural hydrological balance. Pine establishment on disused agricultural land and previously forested land has led to widespread deterioration. The steep north- and west-facing slopes of the Lorne, Forrest, Moggs Creek, Aire, Mount Mackenzie, Bunker Hill and Yahoo Creek land systems are the most severely affected.



Steep slopes in and around drainage lines are more stable under hardwood than softwood forestry, because of longer growth period and more selective logging practices.

Sheet erosion losses can be minimised by working in coupes along the contour, and by maintaining an adequate vegetative cover with litter layers over the soil surface.

The incidence of landslips increases following harvesting, when the binding effect of tree roots is removed and the soil is subject to saturation for longer periods. The study area share the current trend to reduce the total area of productive forest land and manage this smaller area for higher yields. As with agriculture, nutrients removed in forest produce need to be replaced through the use of fertilizers. The fertilizer requirements of soils designated for long-term hardwood and softwood production require investigation.

Fuel-reduction burns are an established part of forestry practice and most of the native hardwood stands are burnt every few years by low-intensity fire, mainly in spring or autumn. When the litter and humus are burnt, the nutrients in the ash become more soluble. Although this increases the rate of removal by leaching. The long-term effect that fuel-reduction burning may have on soil fertility requires further investigation.

Residential use

One of the results of residential development is an increase in the area of surfaces, such as roads, paths and roofs, impermeable to rainfall. Diversion of this water into drainage lines has increased the incidence of landslips, gully erosion and siltation.

Development of the coastal belt from Torquay to Apollo Bay has resulted in many problems. Careful planning is needed to confine development to gentler areas and dispose of run-off water in properly constructed drains.

Recreation

The sand dunes at Cape Otway, Point Impossible, Point Roadknight, Anglesea, Apollo Bay and other localities along the coast have been trampled by pedestrian traffic. Drifting sand has encroached onto roads, building and other services.

Sand dunes afford inland areas the best protection from the erosive power of the sea. The native species that colonize these dunes are very susceptible to trampling pressure and the introduced grass *Ammophila arenaria* is widely used to restabilize drifting dunes. Fencing the dunes off from pedestrian access and siting of access tracks away from wind hollow have also been found necessary to ensure successful rehabilitation.



Coastal dunes are in a constant state of seasonal flux. This photo was taken in early spring, after heavy winter seas had removed much of the sand from the beach and formed a small cliff.

Over-use of pedestrian access tracks in the Anglesea and Rivernook land systems, where the soils are highly dispersible, has led to deep rilling and gullying along coastal cliffs. These tracks need to be sited along gentle slopes without long straight steep sections and with adequate provision for the disposal of surface run-off.

Off-road vehicle activity causes sheet and rill erosion on steep sloping land close to tourist centres along the coast. The passage of trail bikes, dune buggies and four-wheel-drive vehicles destroys the vegetative cover and disturbs the soil surface. Areas need to be provided and managed for these activities on less sensitive sites, such as disused sand and gravel extraction pits.



Trail bikes can cause major problems in sensitive areas. Here, vegetation has been destroyed and rapid surface run-off has removed topsoil and cut rills into the subsoil.

Roads and tracks

Scouring of forest roads and tracks is particularly severe in the high-rainfall areas. Where drainage is inadequate, water becomes concentrated in wheel ruts. Care is needed in road design, with domes surfaces and adequate table drains and culverts to dispose of water on safe vegetated areas. Long straight steep sections are to be avoided, but cross ripping gives long slopes some protection from scouring. Closure of some forest roads in winter will limit the creation of deep wheel ruts.

The diversion of run-off water from roads and tracks may lead to landslips. Fill batters on mountain roads are particularly susceptible. As far as possible, water in table drains should be diverted onto gentle slopes.

Rilling and slumping are problems on the over-steep slopes of road batters. Some of the larger road batters in the Mount Mackenzie land system are particularly susceptible to rilling. Rockslides and slumps along the Great Ocean Road are a hazard to motorists, and expensive clean-up operations are undertaken each wet period. Many of the road batters in the Heytesbury settlement area exhibit severe slumping.

Correct design of road batters minimizes these problems. In exposed rock or other compacted material, near-vertical-cut batters can be successfully made, but generally a slope of 200% is recommended for stable soils while some soils will still be a source of sediment at slopes less than 50%. A catch drain constructed near the top of the batter will divert water. In large batters, further catch drains should be installed at intervals down the slope. Subsoil drainage may need to be provided

in areas prone to slumping. Protection of the soil can be achieved by spraying with bitumen mulch or chemical stabilizers. Plant cover is established by 'keying in' topsoil and applying seed and fertilizer mixtures (Gavin, Knight and Richmond 1979).

Extractive industries

Disused sand and gravel extraction pits provide a poor medium for plant germination. Compacted sand on sloping pits are prone to sheet and rill erosion, and abandoned sites in Chapple Vale, Bald Hills, Gherang Gherang, Porcupine Creek and Ferguson Hill land systems remain as scars on the landscape. The impermeable silicified hardpans in the Riverook land system have led to extensive deep rilling. Similar damage has occurred on silicified hardpans in the Junction Track land system.

Reclamation procedures for these extraction sites involve the initial retention of the topsoil overburden and its subsequent redistribution over the surface to a depth of at least 20 cm. Regeneration of native species can be encouraged by hand planting or spreading seed, but usually the topsoil contains sufficient seed. Steeply sloping land is not suitable for extraction pits, and surface run-off water needs to be diverted onto gentle spurs.



Large road batters and other bare surfaces can deteriorate rapidly. This road re-alignment near Mount Mackenzie is a source of copious sediment in the Gellibrand water supply catchment.

Water supply protection

All domestic water supply catchment within the study area are used for other purposes as well as the supply of water. The maintenance of water quality mainly depends on successful soil conservation practices in these other land uses.

Poorly sited and maintained roads and tracks, streambank and gully erosion and poorly managed forestry operations appear to be the main sources of sediment in streams. High colour can also result from excessive forest trash in drainage lines, from diversion of dairy effluent into water-courses and from stock gaining free access to streams.

Land use also influences water quantity. Higher yields of water are obtained from agricultural land, but compaction of the soil surface and reduced interception storage result in increased surface runoff. Larger flows thus occur during and immediately after storms, with less water being stored for slow release to streams. The perennial nature of streams declines. Water supply systems without large storage dams are the most affected, as the lowest summer flow limits the total supply potential. Storage dams also allow some of the coarser sediment time to settle before reticulation to residential centres, and this results in a less sensitive system than river offtakes provide.



Silicified hardpans near Rotter Point are prone to deep and extensive rilling in old unreclaimed extraction pits.

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APPENDIX I – Analytical Data for Soil Profiles

Profile no.; soil group; parent material	Depth of sample horizon	Field texture	Gravel	cm	Particle-size distribution		1:5 soil water suspension			HCl extract			Exchangeable cations																	
					Coarse sand	Fine sand	Clay	pH	EC ₂₅₀	Cl ⁻	Ca	Mg	K	Na	CEC	Ca	Mg	K	Na	H										
414																														
Brown gradational soil	A1	0-8	L	0	14	40	23	18	5.1	120	0.011	5.0	0.38	17	2.8	16	180	0.026	4.8	2.9	0.4	0.2	22.2	13	2	1	61			
Tertiary clay and sand	A1	8-13	L	4	14	39	22	21	5.2	93	0.009	3.4	0.20	22	3.2	9	140	0.014	0.098	3.3	2.1	0.4	0.2	20.2	16	10	2	1	71	
	A3	13-20	CL	2	11	35	18	35	5.3	63	0.004	1.3	0.08	21	5.2	4	140	0.011	0.14	1.7	4.6	0.4	0.2	17.4	10	26	2	1	61	
	B2	30-45	HC	0	7	29	14	49	5.3	63	0.004	0.9	0.072	16	6.8	3	180	0.012	0.23	1.6	3.9	0.5	0.2	19.0	8	21	3	1	67	
	C	90-120	MC	0	1	18	11	68	6.1	65	0.004	0.4	0.032	16	9.4	2	200	0.014	0.38	0.6	6.6	0.6	0.3	30.7	2	22	2	1	73	
415																														
Brown calcareous sand soil, uniform texture	A1	0-8	SL	0	53	28	4	8	7.9	270	0.025	5.1	0.43	15	16	100	0.047	0.070	35.9	3.6	0.3	0.2	19.3	87	12	1				
	A1	8-15	SL	0	63	25	3	8	8.4	230	0.023	4.1	0.37	14	14	100	0.044	0.062	24.6	1.0	0.2	0.1	4.4	98	1	1				
Recent aeolian sand	C	150-180	COS	<1	85	12	1	2	9.1	91	0.003	0.1	0.006	22	3	20	0.025	0.030	1.4	<0.05	<0.05	<0.05								
416																														
Brown gradational soil	A11	0-1	L	2	1	16	35	27	16	5.0	230	0.018	8.7	0.46	25	1.1	11	140	0.010	0.088	2.2	1.8	0.5	0.3	23.0	10	8	2	1	79
Cretaceous sandstone, mudstone and siltstone	A12	1-8	L	3	17	34	28	15	4.8	180	0.013	4.5	0.21	28	1.1	11	31	0.007	0.074	0.7	1.3	0.4	0.3	19.4	4	7	2	2	85	
	A12	8-16	L	2	16	33	27	20	4.9	110	0.004	1.8	0.069	34	2.3	7	140	0.007	0.074	0.7	1.3	0.4	0.3	19.4	4	7	2	2	85	
	A3	16-23	SCL	2	14	31	26	26	5.0	87	0.007	1.0	0.051	25	2.3	3	120	0.006	0.12	0.3	1.1	0.3	0.2	11.3	3	10	3	2	82	
	B21	23-30	LC	10	11	21	20	44	4.9	110	0.012	0.7	0.052	18	4.7	2	120	0.008	0.19	0.6	2.7	0.3	0.3	16.4	4	16	2	2	76	
	B22	45-60	MC	0	42	31	13	12	4.8	130	0.019	0.2	0.018	14	3.3	14	3.3	0.029	0.26	0.7	0.9	0.4	0.2	13.0	5	7	2	1	85	
418																														
Brown friable gradational soil	A11	0-8	L	2	6	30	23	30	4.8	370	0.026	8.1	0.66	16	3.5	18	320	0.047	0.15	4.3	5.4	0.9	0.4	26.3	16	21	3	2	58	
Cretaceous sandstone, mudstone and siltstone	A12	8-15	CL	5	32	27	30	5.0	300	0.028	5.3	0.46	15	3.7	10	260	0.039	0.16	3.4	4.0	0.7	0.3	24.5	14	16	3	1	66		
	A12	15-30	CL	3	27	36	31	26	5.1	190	0.017	3.1	0.26	16	5.8	140	0.026	0.22	1.5	1.6	0.4	0.3	17.0	9	9	2	2	78		
	B21	30-45	MC	3	3	24	14	53	5.0	220	0.025	1.9	0.15	16	5.8	140	0.026	0.22	0.7	0.9	0.4	0.2	13.0	5	7	2	1	85		
	B22	90-120	LC	3	4	45	15	33	4.6	210	0.030	0.5	0.043	15	3.9	160	0.029	0.26	0.7	0.9	0.4	0.2	13.0	5	7	2	1	85		
424																														
Brown duplex soil	A11	0-8	FSL	0	6	45	20	21	5.4	280	0.025	5.1	0.37	18	1.4	11	260	0.014	0.13	8.5	4.3	0.9	0.6	25.7	33	17	4	2	44	
Cretaceous sandstone, mudstone and siltstone	A12	8-15	SL	2	7	48	22	17	5.5	220	0.021	2.8	0.19	19	1.1	4	200	0.008	0.12	5.9	3.4	0.6	0.5	17.7	33	19	3	3	42	
	A2	15-30	FSCL	3	3	41	20	33	5.8	160	0.014	1.3	0.093	18	2.4	2	240	0.005	0.20	7.7	5.0	0.8	0.6	18.5	42	27	4	3	44	
	B2	30-60	HC	2	2	34	20	45	5.2	140	0.014	0.6	0.060	13	4.7	1	220	0.007	0.33	5.0	8.8	0.8	1.1	26.7	19	34	3	4	40	
	B3	60-90	FSC	5	4	48	13	33	5.2	130	0.014	0.4	0.040	13	5.4	2	200	0.007	0.32	1.4	13.8	0.7	1.7	27.5	5	50	3	6	36	
	C	90-185		1	2	47	16	33	5.3	160	0.015	0.4	0.035	15	2.1	2	200	0.007	0.32	1.4	13.8	0.7	1.7	27.5	5	50	3	6	36	

Profile no.; soil group; parent material	Horizon	Depth of sample	Particle-size distribution			1:5 soil water suspension			HCl extract						Exchangeable cations														
			Coarse sand			Fine sand			P			K			Milliequivalents/100g			% of CEC											
			Gravel	S	D	pH	EC _{25°C}	Cl ⁻	SiO ₂	C	O ₂	Zn	Fe ₂ O ₃	Free Fe ₂ O ₃	P available	K available	Ca	Mg	K	Na	CEC	C _n	Mn	K	Na	H			
426																													
White sand soil, uniform texture	A11	0-1	SL	5	68	13	4	6	4.4	94	0.009	9.0	0.34	34	0.2	9	120	0.005	0.034	4.7	2.0	0.3	22.7	21	9	1	1	68	
	A12	1-8	SL	5	66	15	5	5	4.2	100	0.006	6.8	0.21	42	0.1	7	70	0.003	0.016	2.3	1.7	0.2	20.3	11	8	1	1	79	
	A12	8-15	SL	6	70	19	4	3	4.2	52	0.005	3.6	0.11	43	<0.1	4	60	0.002	0.012	1.4	0.8	0.1	12.1	11	7	1	1	80	
Tertiary sand	A12	15-30	SL	10	73	19	5	2	4.4	35	0.003	1.5	0.048	41	<0.1	3	40	0.001	0.008	0.6	0.4	0.08	6.2	10	6	1	1	82	
	C	30-60	LCS	14	68	24	4	1	4.7	24	0.002	0.5	0.017	38	<0.1	0.1	0.003	0.001	0.008	0.4	<0.05	0.07	0.03	2.5	16	<1	3	1	80
	C	120-180	LCS	16	80	14	3	2	5.5	22	0.001	0.1	0.003	43	<0.1														
428																													
Dark brown gradational soil	O	1-0	SIL	8	4	10	18	24	4.6	300	0.025	1.7	0.82	27		33	540	0.034	0.21	11.5	6.0	1.3	0.4	30.8					
	A1	0-8	CL	<1	6	34	24	26	4.4	160	0.011	9.9	0.55	23		13	280	0.025	0.19	3.1	2.7	0.7	0.2	21.0					
	A1	8-15	CL	0	7	36	27	24	4.5	90	0.008	6.1	0.32	25		10	220	0.019	0.18	0.9	1.3	0.5	0.1	16.3					
Cretaceous sandstone, mudstone and siltstone	A3	15-30	CL	<1	7	38	24	27	4.5	94	0.006	3.2	0.17	24		6	120	0.012	0.19	0.4	0.5	0.3	0.06	13.0					
	B2	30-60	MC	<1	7	38	21	34	4.7	50	0.004	1.1	0.075	19		0.009	0.20	0.20	0.3	0.5	0.3	0.09	12.8						
	C	120-150	SL	0	7	64	16	13	4.8	88	0.010	0.3	0.023	17		0.027	0.23	0.3	0.5	0.1	0.3	0.1	12.1						
489																	11	340											
Red calcareous gradational soil	A1	0-10	SCL	3						6.5	99						4	240											
	B21	10-20	MC	<1						6.1	64						3	580											
Tertiary limestone	B22	30-50	MC	<1						6.7	113																		
490																													
Yellow brown calcareous A1 sodic duplex soil, coarse structure	A1	0-10	FSL	3	30	51	6	9	5.3	76	0.011	2.0	0.16	16	1.8	9	90	0.014	0.060	3.3	1.4	0.1	0.3	10.3	32	14	1	3	50
	A1	10-15	FSL	3	31	50	6	10	5.5	83	0.011	1.4	0.10	18	2.1	5	70	0.009	0.060	2.6	1.3	0.1	0.4	7.6	34	17	1	5	43
	B21	20-30	HC	1	15	22	2	59	6.6	280	0.028	1.0	0.099	13	5.7	3	200	0.007	0.19	5.0	7.5	0.4	3.4	16.0	31	21			
	B22	50-60	HC	6	13	13	<1	67	8.2	510	0.048	0.3	0.043	9	6.2	3	220	0.006	0.23	3.6	9.1	0.3	4.1	17.5	21	23			
Tertiary calcareous clay and marl	C	100-110	SC	1	23	23	1	50	8.1	110	0.045		5.8	3	140	0.006	0.15		2.5	6.8	0.4	4.1	9.4	27	41				
492																													
Mottled yellow and red duplex soil	A1	0-10	FSL	13	17	59	5	16	5.7	150	0.015	1.4	0.093	20	2.8	7	140	0.018	0.10	2.7	2.7	0.3	0.2	7.4	36	36	4	3	21
	A1	10-20	FSL	13	17	57	7	17	5.4	180	0.019	1.3	0.083	20	2.9	5	140	0.011	0.085	2.8	2.8	0.3	0.4	9.0	31	31	3	4	31
	A1	20-30	FSL	11	18	59	8	12	5.5	160	0.017	1.1	0.068	21	2.3	3	120	0.007	0.085	2.4	2.3	0.2	0.4	7.5	32	30	3	5	30
	B2	50-80	MC	8	4	13	4	75	5.8	360	0.047	0.7	0.072	13	5.7	3	280	0.012	0.44	4.7	8.5	0.7	1.3	18.5	26	46	4	7	18
Tertiary clay and sand	C	110-120	MC	24	2	26	3	66	6.2	340	0.045	0.7	0.045	6.2	3	90	0.008	0.30	3.2	8.1	0.2	0.2	14.1	23	58	1	14	4	

Profile no.; soil group; parent material	Depth of sample	Field texture	Gravels	Particle-size distribution				1:5 soil water suspension				HCl extract				Exchangeable cations				USG									
				Fine sand		Coarse sand		pH		EC _{25°C}		Cl ⁻		Ca		Mg		K											
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%										
607				cm																									
Brown gradational soil, weak structure	O ₂	10-0	CL	4	0.2	6	23	38	4.4	290	0.026	15.1	1.04	19	1.0	95	280	0.056	0.22	0.2	1.3	79.6	<1	2	1	2	95		
A ₁	0-10	CL	4	0.4	27	22	4.5	270	0.023	12.0	0.91	17	0.5	95	220	0.056	0.22	0.06	1.2	7.7	1.1	71.6	<1	2	1	2	95		
A ₁	10-20	CL	9	<1	12	35	26	4.6	240	0.023	10.7	0.84	17	0.7	96	220	0.051	0.23	0.08	1.1	0.7	1.0	67.0	<1	2	1	1	95	
A ₂	50-70	SICL	8	<1	17	39	27	5.0	76	0.010						0.060	0.26	0.04	1.0	0.6	0.8	47.0	<1	2	1	2	95		
Recent alluvium																													
608																													
Grey sand soil with hardpan, uniform texture	A ₁	0-10	LFS	4	70	10	4	6	4.6	58	0.006	5.9	0.25	31	0.4	10	80	0.005	0.020	0.5	0.7	0.2	0.3	26.4	2	3	1	1	93
A ₁	10-20	LFS	4	78	10	4	9	4.5	41	0.004	3.6	0.14	33	0.09	11	40	0.002	0.006	0.3	0.6	0.07	0.13	13.8	2	4	1	1	92	
A ₂	30-60	FS	5	78	15	4	4.6	18	0.001								0.001	0.002	0.08	0.14	<0.01	0.04	21.6	<1	1	<1	<1	59	
B ₁	60-69	LFS	3	70	13	3	9	4.3	47	0.004						0.01	0.003	0.013	0.05	0.17	0.03	0.04	22	14.7	<1	<1	<1	98	
B ₂	69-75	SCL	7	62	9	6	17	4.2	48	0.004						0.08	0.004	<0.01	0.02	0.01	0.04	16.1	<1	<1	<1	<1	99		
Tertiary sand																	0.09	0.002	0.009	0.01	0.05	0.02	0.10	19.3	<1	<1	<1	<1	99
609																													
Black sand soil, uniform texture	O ₂	10-0	SIL	4	19	5	6	21	3.8	210	0.026	29.5	0.91	42	0.5	56	340	0.020	0.050	0.1	1.6	0.9	1.4	11.9	<1	1	1	1	97
A ₁₁	0-10	SIL	3	54	7	6	13	4.3	95	0.011	16.9	0.56	39	0.3	46	200	0.011	0.026	0.04	0.7	0.05	0.8	70.0	<1	1	1	1	97	
A ₁₁	10-20	SIL	4	67	10	3	7	4.4	50	0.004	9.4	0.31	39	0.1	50	80	0.006	0.010	0.02	0.4	0.02	0.4	76.7	<1	1	1	1	98	
A ₁₂	20-50	COSL	3	17	73	3	2	4.5	24	0.002						0.07	0.002	0.005	0.01	0.15	0.07	0.13	15.6	<1	1	1	1	98	
A ₂	50-80	COS	4	14	81	1	3	4.6	20	0.001						0.04	0.001	0.004	0.01	0.10	0.06	0.06	6.7	<1	1	1	1	97	
Recent alluvium, plant remains																													
732																													
Stony brown gradational soil.	A ₁	0-10	FSL	25	15	39	24	19	5.2	44	0.005	2.0	0.17	15	1.7	7	140	0.011	0.069	0.6	0.7	0.4	0.1	20.4	3	3	2	<1	92
B ₂	10-20	SCL	31	44	24	14	5.6	31	0.004	0.77	0.056	1.8	1.6	3	100	0.012	0.095	0.5	1.6	0.3	0.1	14.1	4	11	2	1	82		
B ₂	20-30	SCL	24	44	24	14	5.6	25	0.004	0.38	0.035	1.4	1.8	5	100	0.012	0.095	0.5	1.6	0.3	0.1	24.1	1	32	1	2	64		
B ₂	30-60	FSCL	17	61	15	11	5.6	32	0.006						2.8	0.034	0.11	0.2	7.6	0.2	0.4	1.6	31.0	2	51	1	5	41	
C ₁	60-90	FSCL	34	9	37	21	32	5.6	51	0.010					2.2	0.005	0.21	0.6	15.7	0.4	1.6	31.0	2	51	1	5	41		
C ₂	90-120	SICL	11	5	37	21	32	5.6	51	0.010					2.2	0.005	0.21	0.6	15.7	0.4	1.6	31.0	2	51	1	5	41		
Cretaceous sandstone and mudstone																													
733																													
Grey gradational soil.	A ₁	0-10	CL	10	2	21	26	42	5.5	78	0.009	3.9	0.36	14	2.6	44	260	0.033	0.32	3.6	6.3	0.8	0.5	36.8	10	17	2	1	70
A ₃	20-30	CL	2	1	16	30	48	6.1	70	0.011	1.7	0.15	15	2.7	6	100	0.018	0.26	4.1	8.2	0.4	0.8	29.4	14	28	1	3	54	
B ₂	40-60	CL	2	1	19	38	46	6.0	79	0.014					2.4	1	0.019	0.19	2.7	6.2	0.2	0.8	21.4	13	28	1	4	53	
C ₁	83-120	SL	2	2	56	22	18	6.1	56	0.009					1.4	1	0.006	0.15	1.2	3.7	0.1	0.7	11.4	11	32	1	6	50	
C ₁	150-170	SL	2	5	63	15	16	6.5	56	0.009					1.6	1	0.009	0.13	1.4	4.4	0.1	0.9	10.4	13	42	1	9	35	
C ₂	170-200	LS	2	10	59	14	14	6.5	110	0.015					1.9	1	0.019	0.19	1.7	5.3	0.1	1.0	15.1	11	45	1	7	46	

Profile no.; soil group; parent material	Depth of sample	Horizon	Particle-size distribution			1:5 soil water suspension			HCl extract			Exchangeable cations						USG	
			Coarse sand			Fine sand			Hd			P			K				
			%	%	%	%	%	%	%	%	%	%	%	%	%	%	%		
734																			
Yellow sodic duplex soil	A1	0-10	FSL	2	9	70	8	10	5.3	42	0.004	2.2	0.22	13	1.3	0.9	0.1	13.2	SC
	A1	10-20	FSL	1					5.6	35	0.003	1.6	0.13	16	0.9	0.2	0.2	16.6	SC
	A1	20-27	FSL	6	9	74	11	4	5.8	24	0.003	0.88	0.095	12	6	0.009	0.071	9	78
Tertiary sand and clay	A2	30-42	FSL	5	1	63	6	27	7.7	280	0.027			0.006	0.046	1.0	0.9	0.2	5.6
	B2	60-80	HC	5	0.4	56	11	32	8.1	470	0.051			0.011	0.16	2.8	11.9	0.2	SC
	C	120-140	LC	5	0.2	62	10	28	8.0	480	0.056			0.009	0.24	3.2	14.8	0.4	SC
	C	150-180	LC	2										0.008	0.20	2.6	13.1	0.4	SC
735																			
Brown duplex soil.	A1	0-5	CL	<1	4	25	37	25	5.3	110	0.012	4.6	0.36	17	1.3	10	300	0.015	ML
	A1	10-20	CL	2	21	35	36	4.9	130	0.020	1.0	0.094	14	1.6	7	160	0.008	ML	
Cretaceous sandstone and mudstone	A2	20-30	CL	2					5.4	83	0.010	0.83	0.096	11	6	200	0.010	0.54	ML
B21	30-60	MC	14	0.4	6	23	64	5.4	98	0.013			3.4				11.6	CH	
B22	60-80	MC	4	0.4	7	24	63	5.4	120	0.018			3.7				15.0	CH	
B3	90-120	LC	32					5.6	120	0.015			2.5				0.53	CH	
	C	128-150	LC	62					5.7	130	0.016			2.5				14.0	CH
736																			
Brown friable gradational soil.	A1	0-10	CL	6	4	41	27	23	5.5	84	0.008	4.7	0.39	16	22	360	0.037	0.21	SM
	A1	10-20	CL	6					5.3	45	0.005	2.7	0.21	17	3.0	18	160	0.2	SM
	A1	20-25	CL	9					5.2	39	0.003	2.2	0.18	16	23	120	0.042	0.27	SM
Cretaceous sandstone and mudstone	A1	25-30	MC	8	2	29	23	38	5.1	38	0.004			3.6			0.34	0.34	ML
B21	60-90	LC	12	5	26	19	44	4.8	39	0.005			3.9			0.034	<0.01	ML	
B22	120-150	LC	8	21	42	18	16	4.9	32	0.004			2.6			0.039	<0.01	ML	
737																			
Grey sand soil, structured clay underlay	A1	0-10	LSCL	1	28	41	12	12	4.8	63	0.005	4.2	0.32	17	0.4	22	0.019	0.068	SC
	A1	10-20	LSCL	<1	35	41	11	10	4.7	25	0.002	1.3	0.076	22	0.2	11	40	0.004	SC
	A1	20-30	SCL	<1	34	38	16	17	4.7	22	0.002	0.80	0.046	23	0.1	8	30	0.003	SC
	A1	30-40	CL	10	30	32	13	19	5.1	42	0.003	3.9	0.18	28	3.1	8	120	0.008	SC
B21	40-60	MC	13	3	13	14	67	4.9	67	0.004			5.4			0.006	0.36	SC	
II C1	90-120	MC	5	0.4	24	20	52	4.8	42	0.005			3.0			0.003	0.27	SC	
II C2	150-180	MC	8	0.4	7	32	54	4.9	89	0.012			4.3			0.008	<0.01	SC	
D2																5.4	0.3	SC	
739																			
Black sand soil, uniform texture	A11	0-10	SL	<1	39	38	3	8	4.1	110	0.011	7.1	0.26	37	0.2	11	120	0.006	SW-SC
	A11	10-20	SL	<1	44	45	3	5	4.1	67	0.007	4.0	0.16	33	0.1	9	70	0.003	SW-SC
	A12	20-30	LS	0													2.6	0.003	SW-SC
	A12	30-60	LS	<1													0.063	0.004	SW-SC
	A12	60-85	LS	<1													0.067	0.004	SW-SC
	A12	85-90	FSL	<1	22	62	3	9	4.2	52	0.006	1.7	0.067	33	0.1	9	20	0.004	SW-SC
	B1	90-120	FSL	7	14	73	3	7	4.4	36	0.005	2.4	0.076	41	2.5		0.005	0.06	SW-SC
	C	150-180	LFS	<1	88	3	8	4.5	45	0.004			0.3	0.029	0.3	0.1	0.09	0.01	SW-SC

Profile no.; soil group; parent material	Depth of sample cm	Soil texture fine sand G1	Particle-size distribution			1:6 soil water suspension			HCl extract			Exchangable cations						USG			
			Coarse sand G2			pH MC			Cl ⁻ MC			P K _{2O}			Ca Mg K Na CEC						
			%	%	%	%	%	%	%	%	%	ppm	%	%	%	%	%	%			
740 Yellow sand soil, uniform texture Tertiary sand	A11 0-10	LS	3	51	38	4	8	6.7	35	0.004	1.0	0.044	30	5	40	0.003	0.029	0.5	4.4	SM	
	A11 10-20	LS	3	51	38	4	8	6.1	23	0.002	0.58	0.031	24	1.2	4	40	0.020	0.027	0.1	0.04	SM
	A11 20-30	LS	3	56	32	4	8	5.9	16	0.001	0.40	0.020	26	1.3	4	40	0.005	0.025	0.05	0.05	SM
	A11 60-90	LS	4	74	19	2	7	5.7	15	0.001	1.3	0.006	1.3	1.3	0.5	0.004	0.015	<0.01	0.01	73	SM
	A12 120-150	LS	4	74	19	2	7	5.8	12	0.001	0.5	0.004	1.3	1.3	0.5	0.004	<0.01	0.009	0.06	0.01	81
	C 180-210	S	0	87	9	1	4	5.8	12									<1	7	7	SM
741 Yellow gradational soil, weak structure Tertiary sand and clay	A11 0-10	SL	0	8	71	4	8	4.7	89	0.007	5.6	0.24	30	0.2	41	120	0.012	0.033	1.5	1.5	SP-SP
	A11 10-15	SL	3	11	76	5	6	4.5	82	0.007	3.3	0.14	31	1.0	10	100	0.004	0.021	0.1	0.2	SP-SP
	A11 15-20	LS	1	11	76	5	6	4.5	51	0.005	1.9	0.080	31	0.2	8	50	0.005	0.026	0.05	0.05	SP-SP
	A12 20-30	LS	2	11	78	6	5	5.2	24	0.003	1.3	0.056	30	5	40	40	0.005	0.024	0.2	0.4	SP-SP
	A12 37-47	S	1	22	59	6	13	5.9	49	0.005	0.4	0.007	67	0.6	0.6	0.078	0.008	0.03	0.09	0.4	84
	A2 60-90	CS	2	23	58	6	14	5.8	60	0.006	2.1	0.008	3.6	3.6	0.1	0.1	0.013	0.072	0.3	0.3	SP-SP
742 Grey sand soil, uniform texture Tertiary sand	B21 120-150	SCL	<1	43	36	4	16	5.5	85	0.013											
	B22 180-210	LSCL	0																		
	C 210-240	S	<1																		
	C 240-270	S	<1																		
	A1 0-10	LS	<1	47	43	5	4.2	58	0.006	4.8	0.22	28	9	70	5	50	0.002	0.011	<0.01	0.5	SW
	A1 10-20	LS	<1	47	43	5	4.2	52	0.005	3.5	0.14	33	0.1	5	20	3	10	0.001	0.003	<0.01	0.15
743 Yellow-brown calcareous sodic duplex soil, coarse structure Tertiary calcareous clay	A1 20-30	LS	<1	62	36	1	1	4.7	13	0.002	0.44	0.015	38	0.08	3	10	0.001	0.004	<0.01	0.02	SW
	A1 30-60	S	0	58	41	1	1	5.1	9	0.001	0.71	0.020	46	0.9	0.05	0.05	0.003	0.003	<0.01	0.04	SW
	A2 60-90	S	0	66	29	1	4	4.4	14	0.002	0.4	0.002	46	0.5	0.002	0.009	0.002	0.009	0.04	0.05	SW
	B21 90-98	LS	0	56	40	2	4	5.2	14	0.001	0.2	0.001	2	0.2	0.2	0.001	0.010	0.04	0.02	2	94
	B22 120-150	LS	<1	78	19	2	2	5.4	11	0.001	0.78	0.036	28	0.5	0.004	0.016	0.005	0.03	0.06	0.05	SP
	C1 150-180	HC	3	10	23	10	44	8.5	860	0.085											
744 Mottled yellow and red duplex soil	A11 0-10	FSL	<1	24	42	9	18	5.0	72	0.008	3.1	0.22	18	1.1	11	90	0.014	0.103	1.7	2.0	SW
	A11 10-20	FSL	<1	32	45	9	12	5.4	32	0.003	1.4	0.10	18	7	50	40	0.006	0.061	0.7	1.2	SW
	A2 20-30	SCL	2	14	24	6	53	6.5	61	0.006	0.68	0.056	16	1.2	6	32	0.007	0.036	5.1	0.9	SW
	A2 38-60	HC	10	15	23	3	53	8.7	540	0.037						3.0	0.007	0.30	8.7	1.6	SW
	B2 90-120	HC	13	14	31	8	46	8.5	630	0.054						3.0	0.004	0.21	6.5	1.4	SW
	C1a 150-180	HC	5	10	23	10	44	8.5	860	0.085						1.1	0.005	0.22	7.1	1.6	SW
744 Tertiary clay and sand	A11 0-10	FSL	1	9	64	10	12	5.3	45	0.004	2.3	0.18	17	1.5	15	120	0.013	0.048	0.7	0.8	SW
	A11 10-20	FSL	3	12	66	13	8	5.5	29	0.002	1.1	0.072	20	7	50	50	0.004	0.024	0.5	0.3	SW
	A2 20-30	FSL	3	12	66	13	8	5.5	20	0.002	0.59	0.044	17	1.2	4	9.1	0.007	0.024	2.7	6.7	SW
	B2 60-90	MC	4	1	13	6	78	6.9	71	0.006									2.7	1	SW
	B2 90-120	MC	4	1	13	6	78	6.7	100	0.007									2.7	1	SW
	B2 120-150	MC	5	1	13	6	78	6.7	130	0.010									2.7	1	SW
744 Tertiary clay and sand	C 150-180	LC	4	1	13	6	78	6.9	99	0.011									2.7	1	SW
	C 180-210	LC	2	0.4	51	10	38	7.1	90	0.010									2.7	1	SW

Profile no.; soil group; parent material	Depth of sample Horizon	Particle-size distribution			1:5 soil water suspension			Exchangeable cations/mg Milliequivalents/100g								% of CEC				USG																	
		Fine sand		Gravel	pH	Cl ⁻	EC25°C	O _{25°C}	T _{25°C}	N _{25°C}	P (available)	K (available)	Ca	Mg	K	Na	Ca	Mg	K	Na																	
		Field texture	Coarse sand		%	%	%	%	%	%	ppm	ppm	%	%	%	%	%	%	%	%																	
783																																					
Brown duplex soil, coarse structure	A1	0-10	FSCL	1	14	62	14	5	6.9	87	0.010	2.8	0.23	16	0.9	10	140	0.012	0.048	6.6	3.7	0.4	0.9	16.9	43	24	3	6	24	SM							
	A1	10-20	FSCL	1	10	14	68	15	3	6.8	110	0.013	2.1	0.18	15	6	90	30	0.005	0.006	7.1	3.4	0.5	1.1	15.3	46	22	3	7	22	SM						
	A2	20-30	LFS	5	4	40	7	46	7.8	160	0.010	0.16	0.011	19	1.1	3	30	0.007	0.12	0.9	0.4	0.06	0.1	2.1	43	19	3	5	30	CH							
Lateritized Tertiary sand and clay	B21	60-90	MC	5	13	4	32	8	56	7.7	330	0.041					18.5	0.016	0.37	10.5	3.2	0.5	1.9	20.7	51	15	2	9	23	CH							
	B22	120-150	MC																																		
784																																					
Brown calcareous gradational soil, coarse structure	A1	0-10	LC	3	1	28	30	28	7.0	160	0.012	5.3	0.37	19	1.7	17	380	0.020	0.20	16.2	4.5	1.2	0.4	26.4	58	17	5	2	18	CH							
	B21	10-20	HC	4	20	HC	3	6.7	73	0.009	1.7	0.13	17	5	280	5	240																				
	B21	20-30	HC	3				6.6	60	0.009	0.96	0.080	16	3.2																							
	B21	30-42	HC	4	1	22	19	53	6.8	62	0.010																										
	B22	42-60	HC	6	0.4	16	16	61	7.3	83	0.013																										
Tertiary marl and calcareous clay	B2a	60-90	MC	10	6	19	37	25	8.6	130	0.014																										
	C1	90-120	MC	21	10	18	17	42	8.7	180	0.020																										
	C2	120-150	HC	17	2	15	16	54	8.8	340	0.036																										
	C2	165-180	MC	6	10	26	30	20	9.1	240	0.022																										
	C3	195-210	MC	13	1	18	14	55	8.9	410	0.037																										
	C4																																				

Field texture abbreviations:

S = sand, COS = coarse sand, FS = fine sand, LFS = loamy fine sand, LS = loamy sand, CS = clayey sand
 L = loam, CSL = coarse sandy loam, SL = sandy loam, FSL = fine sandy loam, FSCL = fine sandy clay loam, SCL = sandy clay loam, CL = clay loam

SICL = silty clay loam

C = clay, SC = silty clay, LC = light clay, FSC = fine sandy clay, SC = sandy clay, MC = medium clay, HC = heavy clay

Gr = gravelly

APPENDIX II – Methods of Soil Analysis

T. I. Leslie

All results are expressed in terms of oven-dry soil passing a 2 mm round-hole sieve, except gravel, which is reported as a percentage of the air-dry field sample.

Particle-size analysis – plummet balance method of Hutton (1956). With sand separation by hand decantation. The I.S.S.S. size fractions were separated: i.e. coarse sand 2 – 0.2 mm; fine sand 0.2 – 0.02 mm, silt 0.02 – 0.002 mm and clay <0.002 mm.

Electrolytic conductivity (EC 25°C) – a 1:5 soil:water suspension was shaken for 1 hour and, after temperature equilibration, conductivity was measured with a dip cell and direct-reading meter. Results are reported as microsiemens per centimetre (μScm^{-1}).

Soil reaction (pH) – by glass electrode and digital pH meter on the above suspension.

Chloride (Cl) – profiles 414 – 606 by electrometric silver nitrate titration of R. J. Best, as described by Piper (1942).

- by solid state selective-ion electrode and millivoltmeter on the same suspension, calibrated with potassium chloride standards.

Organic carbon (Org. C) – wet-combustion technique of Walkley and Black, described by Piper (1942). No recovery factor was applied, but the factor 1.3 C:N was used to calculate carbon:nitrogen ratios.

Total nitrogen (N) – Metson (1956). Semimicro Kjeldahl method, using a Markham still.

Free iron oxide (Fe_2O_3) – Haldane (1956). Finely ground soil was extracted with powdered zinc in ammonium chloride-oxalic acid buffer. Ferrous ion in the treated extract was titrated with potassium dichromate.

Hydrochloric acid extract for phosphorus and potassium (P, K) – 4 g of soil was refluxed for 4 hours with 20 ml constant boiling hydrochloric acid, with subsequent filtration and dilution of the filtrate to 200 ml. Phosphorus was determined by colorimetric method using molybdenum blue and potassium by atomic absorption.

Available phosphorus (Pav. P.p.m.) – Colwell (1963). 1 g soil was shaken with 100 ml 0.5 M sodium bicarbonate at pH 8.5 for 16 hours. Phosphorus was determined in the clarified extract by a colorimetric method (molybdenum blue).

Exchangeable cations – profiles 414 – 606 by the method of Hutton and Bond (unpublished data). Synopsis: soil leached with molar ammonium chloride solution (pH – 7.0) to displace exchangeable cations. Potassium and sodium in leachate determined by flame emission techniques. Calcium and magnesium determined by EDTA titration. Adsorbed ammonium ion was leached from the soil with sodium sulphate solution, and cation exchange capacity was determined from the excess of ammonium ion over chloride in the leachate.

- profiles 607 – 748 by extraction method of Tucker (1974), also described in Loveday (1974). Synopsis: soluble ion removal by 10% ethanediol in ethanol. Cation displacement by ammonium chloride in ethanol-water (2:1) at pH 8.5. Cation determinations by atomic absorption. Cation exchange capacity by measurement of ammonium ion displaced from the treated soil by a potassium nitrate-calcium nitrate solution.

Unified Soil Group (USG) – Engineers' classification, as Bureau of Reclamation (1974).

APPENDIX III – Soil Profile Descriptions

The standards used for soil properties are those of the U.S.D.A. (1951), with supplement (1962), Northcote (1974) and, in the case of sodicity, Northcote and Skene (1972).

Descriptive soil names are based on properties observable in the field, with the addition of sodicity as determined in the laboratory. To minimise the number of terms required, certain features are not mentioned if they match the ‘normal’ Victorian profile, which is reasonably stone-free, acidic, non-calcareous and apparently monogenetic, and in which the B horizon has moderate 1 – 2 cm blocky structure and firm consistence.

Terms used

The following terms are given in the order in which they appear in the descriptive name for the soils.

Stony – Significant (usually greater than 15%) quantities of stone, boulders and gravel are present through the profile.

Colour – Munsell soil colours of the B horizon are given, abbreviated where practical. In sand soils, the predominant colour is given, usually being that below the A horizon. In strongly mottled soils, the first colour given is the dominant for matrix colour.

Calcareous – Visible lime is present in the profile.

Sodic – The exchangeable sodium percentage is greater than 5% throughout most of the profile.

Friable – Peds are soft when both moist and dry.

Profile form

- » **Uniform** – no significant change in texture.
- » **Gradational** – gradual increase in clay content with depth.
- » **Duplex** – sudden increase in clay content from A to B horizons.
- » For uniform-texture profiles, textures are specified in the three classes sand, loam and clay according to texture grade – e.g. sand soils, uniform texture.

Soils(s) – This term is always used. In the case of uniform-textured soils, the term soil(s) precedes the profile form.

Structure – If the structure is unusual, this term is included. Typical B horizon structures are 1 – 2 cm moderate subangular blocky.

- » **Weak structure** – where massive or nearly so (except for sand soils, where a weak structure is normal).
- » **Coarse structure** – where ped sizes average several centimetres across and usually possess large shiny clay faces. Small secondary peds may be present.
- » **Fine structure** – where ped sizes are no more than a few millimetres in average dimension.

Ironstone – Where lateritization has resulted in the presence of ironstone either throughout or, more commonly, at the base, it is recorded. This does not include soils with ironstone nodules in the A₂ and B₁ horizons resulting from more recent pedogenesis.

Soil descriptions – Abbreviated field descriptions of the main soils in the area surveyed are presented below. The maps used are those of the 1:100,000 National Topographic map series, except for that of Geelong, which is a Country Fire Authority map based on the Australian National Grid.

Profile 414 – Brown gradational soil (Princetown 7520: map ref. 087107).

A ₁	0-13 cm	very dark brown (10YR2/2) loam, moderate subangular blocky structure, clear boundary
A ₃	13-45 cm	very dark brown (10YR2/2) clay loam, moderate angular blocky structure, diffuse boundary
B ₂	45-90 cm	very dark greyish brown (10YR3/2) heavy clay, moderate angular blocky structure (40 mm), diffuse boundary
C	90 cm	yellowish brown (10YR5/8) and grey (10YR6/1) mottled medium clay, massive.

Profile 415 – Brown calcareous sand soil, uniform texture (Otway 7620: map ref. 187963).

A ₁	0-15 cm	black (10YR2/1) sandy loam, apedal-single grain, clear boundary
B ₂	15-75 cm	black (10YR2/1) loamy sand, very weak subangular blocky structure (30 mm), gradual boundary
C	75 cm	pale-brown (10YR6/3) coarse sand, apedal-single grain.

Profile 416 – Brown gradational soil (Otway 7620: map ref. 336277).

A ₁₁	0-1 cm	black (10YR2/1) silty loam, crumb structure, abrupt boundary.
A ₁₂	1-15 cm	very dark greyish brown (10YR3/2) loam, moderate subangular blocky structure, clear boundary
A ₃	15-23 cm	dark greyish brown (10YR4/2) sandy clay loam, moderate subangular blocky structure, clear boundary
B ₂₁	23-45 cm	brownish yellow (10YR6/8) light clays with some greyish brown (10YR5/2) mottles, moderate angular blocky structure, gradual boundary
B ₂₂	45-90 cm	yellowish brown (10YR5/8) medium to heavy clays with very dark greyish brown (10YR3/2) ped faces, strong subangular blocky structure, clear wavy boundary
C	90 cm	weathering sandstone.

Profile 418 – Brown friable gradational soil (Princetown 7520: map ref. 077141).

A ₁₁	0-8 cm	very dark brown (10YR2/2) loam, crumb structure, clear boundary
A ₁₂	8-30 cm	dark-brown (7.5YR3/2) clay loam, moderate subangular blocky structure, gradual boundary
B ₂₁	30-75 cm	dark brown (7.5YR3/4) medium clay, moderate subangular blocky structure, friable peds, diffuse boundary
B ₂₂	75-140 cm	yellowish brown (10YR5/6) light clay, weak subangular blocky structure, friable peds, occasional decomposing parent material, diffuse boundary
C	140 cm	decomposing mudstones and/or siltstones.

Profile 424 – Brown duplex soil (Princetown 7520: map ref. 967088)

A ₁₁	0-8 cm	black (10YR2/1) fine sandy loam, crumb structure, clear wavy boundary
A ₁₂	8-15 cm	very dark greyish brown (10YR3/2) sandy loam, weak subangular blocky structure, occasional angular sandstones, clear wavy boundary
A ₂	15-30 cm	yellowish brown (10YR5/6) fine sandy clay loam, very weak subangular blocky structure, occasional angular sandstones, clear boundary
B ₂	30-60 cm	dark greyish brown (10YR4/2) fine sandy clay, moderate angular blocky structure (1 cm), occasional angular sandstones, gradual irregular boundary
B ₃	60-90 cm	dark greyish brown (10YR4/2) fine sandy clay, moderate angular blocky structure, discontinuous layers of decomposing rock, gradual irregular boundary
C	90 cm	weathering dipping beds of sandstones and mudstones with thin lenses of dark greyish brown (10YR4/2) clay down joint plains.

Profile 426 – White sand soil, uniform texture (Princetown 7520: map ref. 017154).

A ₁₁	0-1 cm	black (10YR2/1) sandy loam, weak subangular blocky structure, abundant quartz gravel, clear boundary
A ₁₂	1-30 cm	very dark grey (10YR7/1) merging to white (10YR8/1) loamy coarse sand, apedal-single grain, abundant quartz gravel and occasional stones
C	30 cm	light grey (10YR7/1) merging to white (10YR8/1) loamy coarse sand, apedal – single grain, abundant quartz gravel and occasional stones.

Profile 428 – Dark-brown gradational soils (Princetown 7520: map ref. 154130).

O ₂	1-0 cm	very dark brown (10YR2/2) silty loam, strong crumb structure, abrupt, smooth boundary.
A ₁	0-15 cm	very dark greyish brown (10YR3/2) clay loam, strong crumb structure, occasional angular sandstones, clear smooth boundary
A ₃	15-30 cm	dark greyish brown (10YR4/2) clay loam, moderate subangular blocky structure with some massive areas, angular sandstones, gradual boundary
B ₂	30-90 cm	dark yellowish brown (10YR4/4) medium clay with occasional pale-brown (10YR6/3) mottles, moderate subangular blocky structure (3 cm) angular sandstones up to 200 mm in diameter common, diffuse boundary
C	90 cm	dark yellowish brown (10YR4/8) sandy loam with greyish brown (7.5YR5/2) mottles increasing with depth, weak subangular blocky structure becoming massive with depth, weathering angular sandstones.

Profile 489 – Red calcareous gradational soil (Geelong 7721: map ref. 391716).

A ₁	0-10 cm	reddish brown (5YR4/4) sandy clay loam, weak crumb structure, clear boundary
B ₂₁	10-30 cm	yellowish red (5YR4/6) medium clay, strong subangular blocky structure (10 mm), diffuse boundary
B ₂₂	30-70 cm	yellowish red (5YR4/6) medium clay, strong subangular blocky (40 mm), hard when dry, diffuse boundary
C	70 cm	weathering limestone and marl

Profile 490 – Yellow-brown calcareous sodic duplex soil, coarse structure (Geelong 7721: map ref. 378710)

A ₁	0-15 cm	very dark greyish brown (10YR3/2) fine sandy loam, weak subangular blocky structure, abrupt boundary
B ₂₁	15-35 cm	brown (10YR4/3) heavy clay, strong subangular blocky structure (40 mm), hard when dry. Some ironstone gravel, diffuse boundary
B ₂₂	35-70 cm	yellowish brown (10YR5/4) heavy clay, strong subangular blocky structure (40 mm), hard when dry, diffuse boundary
C	70 cm	mottled light yellowish brown (10YR6/4) and yellowish red (5YR5/6) sandy clay, moderate subangular blocky structure (50 mm), hard when dry.

Profile 492 – Mottled yellow and red duplex soil (Geelong 7721: map ref. 345782)

A ₁	0-30 cm	brown (10YR4/3) fine sandy loam, very weak subangular blocky structure, some ironstone gravel, abrupt boundary
B ₂	30-110 cm	mottled yellowish brown (10YR5/6) and yellowish red (5YR5/6) medium clay, strong subangular blocky structure (4 mm), clay skins, diffuse irregular boundary.
C	110 cm	mottled dark red (2.5YR3/6), grey (10YR5/1) and yellowish brown (10YR5/8) medium clay, hard when dry, moderate subangular blocky structure.

Profile 497 – Yellow gradational soil, weak structure (Geelong 7721: map ref. 147603)

A ₁	0-10 cm	very dark greyish brown (10YR3/2) fine sandy loam, apedal-single grain, clear boundary
A ₂	10-20 cm	brown (10YR5/3) fine sandy loam, apedal-single grain, gradual boundary
A ₃	20-30 cm	yellowish brown (10YR5/4) fine sandy clay loam, weak subangular blocky structure (10 mm), diffuse boundary
B ₂	30-90 cm	brownish yellow (10YR6/6) merging to light yellowish brown (10YR6/4) sandy clay to light clay, weak subangular blocky structure, some ironstone fragments, diffuse boundary
C	90 cm	yellow (10YR7/6) sandy clay, apedal-single grain.

Profile 499 – Yellow-brown duplex soil, coarse structure (Geelong 7721: map ref. 282647)

A ₁	0-10 cm	black (10YR2/1) loamy fine sand, apedal-single grain, gradual boundary
A ₂	10-30 cm	grey (10YR5/1) loamy fine sand, apedal-single grain, clear wavy boundary
B ₂₁	30-50 cm	very dark greyish brown (10YR3/2) sandy clay loam, weak subangular blocky structure (40 mm), organic stains on ped faces, diffuse boundary
B ₂₂	50-120 cm	dark yellowish brown (10YR4/4) sandy clay loam, subangular blocky structure (40 mm), clay skins, diffuse boundary
C	120 cm	yellowish brown (10YR5/6) sandy clay, apedal-massive.

Profile 500 – Grey sand soil, kaolinitic clay underlay (Geelong 7721: map ref. 151633)

A ₁	0-10 cm	dark yellowish brown (10YR4/4) sandy clay loam, very weak subangular blocky structure, abundant quartz gravel, clear boundary
A ₂	10-50 cm	brownish yellow (10YR6/6) sandy clay loam, apedal, abundant quartz gravel
II*C	50 cm	very pale brown (10YR8/3) medium clay, weak platy structure, hard when dry

Profile 601 – Mottled yellow and red duplex soil with ironstone (Geelong 7721: map ref. 157687)

A ₁	0-20 cm	dark yellowish brown (10YR4/3) fine sandy loam, apedal-single grain, occasional ironstone gravel, gravel boundary
A ₃	20-30 cm	yellowish brown (10YR5/6) light clay with some red (2.5YR5/8) mottled, moderate subangular blocky structure (3 mm), ironstone gravel common, gradual boundary
B ₂₁	30-90 cm	mottled yellowish brown (10YR5/6) and red (2.5YR5/8) medium clay, strong angular blocky structure (2 mm), clay skins, abundant ironstone gravel, diffuse boundary
B ₂₂	90 cm	mottled dark yellowish brown (10YR4/6), light-grey (2.5YR7/1) and red (10YR4/6) heavy clay, strong angular blocky structure (2 mm), abundant ironstone gravel often in layers, or floaters of ironstone

Profile 606 – Yellow-brown sodic duplex soil, coarse structure (Geelong 7721: map ref. 249636)

A ₁	0-35 cm	black (10YR2/1) loamy fine sand, apedal-single grain, clear boundary
A ₂	35-60 cm	light brownish grey (10YR6/2) loamy fine sand, apedal, abrupt boundary
B ₂	60 cm	dark yellowish brown (10YR4/4) fine sandy clay with grey (10YR5/1) mottles, moderate subangular blocky structure (45 mm), hard when dry

Profile 607 – Brown gradational soil, weak structure (Princetown 7520: map ref. 161091)

O ₂	10-0 cm	very dark greyish brown (10YR3/2) clay loam, weak subangular blocky structure, clear boundary
A ₁	0-20 cm	very dark greyish brown (10YR3/2) clay loam, weak subangular blocky structure, clear boundary
A ₂	50-80 cm	very dark greyish brown (10YR3/2) silty clay loam, weak subangular blocky structure
	80 cm	water table

Profile 608 – Grey sand soil with hardpans, uniform texture (Princetown 7520: map ref. 045257)

A ₁	0-25 cm	very dark brown (10YR2/2) loamy fine sand, weak subangular blocky structure, gradual smooth boundary
A ₂	25-60 cm	very dark greyish brown (10YR3/2) fine sand, weak subangular blocky structure, occasional quartz gravel, clear wavy boundary
B ₁	60-69 cm	black (10YR2/1) loamy fine sand, apedal-single grain, clear wavy boundary
B ₂	69-75 cm	dark-brown (10YR3/2) sandy clay loam, apedal-single grain, abrupt wavy boundary
IIC _m	75 cm	dark yellowish brown (10YR4/4) cemented sand, apedal-massive, extremely hard

Profile 609 – Black sand soil, uniform texture (Princetown 7520: map ref. 462374)

O ₂	10-0 cm	black (10YR2/1) silty loam, weak crumb structure (1 mm), abundant roots, clear wavy boundary
B ₂	42-90 cm	dark greyish brown (10YR4/2) heavy clay, some yellow (10YR7/6) mottles, strong angular blocky (4 mm), diffuse wavy boundary
C	90 cm	mottled light grey (2.5YR7/3) and yellow (2.5YR7/6) light clay, weak angular blocky structure (2 mm)

Profile 735 – Brown duplex soil (Otway 7620: map ref. 527208)

A ₁	0-5 cm	black (10YR2/1) clay loam, moderate crumb structure, clear smooth boundary
A ₂	5-30 cm	dark greyish brown (10YR4/2) clay loam, light brownish grey (10YR6/2) when dry, weak angular blocky structure, clear smooth boundary
B ₂₁	30-60 cm	dark greyish brown (10YR4/2) medium clay with yellowish brown (10YR5/6) mottles, moderate angular blocky structure (4 mm), diffuse boundary
B ₂₂	60-90 cm	greyish brown (10YR5/2) medium clay with yellow (10YR7/8) mottles, strong angular blocky structure (4 mm), clear wavy boundary
B ₃	90-128 cm	greyish brown (2.5YR5/2) light clay with yellow (2.5YR7/8) mottles, moderate angular blocky structure, abundant weathering sandstones
C	128 cm	weathering with lenses of clay between joints

Profile 736 – Brown friable gradational soil (Otway 7620: map ref. 482308)

A ₁	0-25 cm	very dark greyish brown (10YR3/2) clay loam, moderate subangular blocky structure, diffuse smooth boundary
B ₂₁	25-30 cm	dark yellowish brown (10YR3/4) medium clay, strong subangular blocky structure (11 mm), friable peds, gradual boundary
B ₂₂	30-110 cm	brown (7.5YR4/4) light clay, moderate angular blocky structure (1 mm), friable peds, angular weathering sandstone fragments common, clear irregular boundary
C	110 cm	yellowish brown (10YR5/6) light clay, weak subangular blocky structure, weathering sandstone fragments common

Profile 737 – Grey sand soil, structured clay underlay (Otway 7620: map ref. 379338).

A ₁	0-10 cm	very dark brown (10YR2/2) light sandy clay loam, weak subangular blocky structure (3 mm), gradual wavy boundary
A ₂	10-20 cm	very dark greyish brown (10YR3/2) light sandy clay loam, weak subangular blocky structure (3 mm), gradual wavy boundary
B ₁	20-30 cm	very dark brown (7.5YR2/2) sandy clay loam, weak subangular blocky structure, abrupt boundary, broken horizon
B _{2m}	30-40 cm	mottled dark yellowish brown (10YR4/4) and black (10YR2/1) clay loam, apedal-massive, ferruginous and organic cementation, extremely hard when dry, clear boundary
IIC ₁	40-72 cm	mottled yellowish brown (10YR5/8) and dark greyish brown (10YR4/2) medium clay, moderate angular blocky structure (40 mm), organic stains on ped faces, diffuse boundary
IIC ₂	72 cm	mottled light grey (2.5YR6/0) and yellowish brown (10YR5/8) medium clay, moderate angular blocky structure

Profile 739 – Black sand soil, uniform texture (Princetown 7520: map ref. 131133)

A ₁₁	0-20 cm	black (7.5YR2/1) sandy loam, moderate crumb structure, very high in organic matter, diffuse boundary
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A ₁₂	20-85 cm	black (7.5YR2/1) loamy sand, apedal-single grain, clear wavy boundary
B ₁	85-90 cm	very dark brown (7.5YR2/1) fine sandy loam, apedal-massive, ferruginous stains, abrupt wavy boundary
B _{2m}	90-120 cm	very dark brown (7.5YR2/2) fine sandy loam, apedal-massive, very firm when moist, extremely hard when dry, ferruginous cementations, abrupt boundary, broken horizon
C	120 cm	very pale brown (10YR7/3) loamy fine sand, apedal-single grain, occasional gavel layers and ironstone beds

Profile 740 – Yellow sand soil, uniform texture (Princetown 7520: map ref. 162312)

A ₁₁	0-60 cm	brown (7.5YR4/4) loamy sand, apedal-single grain, occasional ironstone and quartz gravel, gradual irregular boundary
A ₁₂	60-110 cm	strong brown (7.5YR5/6) loamy sand, apedal-single grain, gradual smooth boundary
B ₂	110-180 cm	yellowish red (5YR5/8) loamy sand, apedal-single grain, occasional ironstone and quartz gravel, gradual irregular boundary
C	180 cm	strong brown (7.5YR5/6) sand with some red (2.5YR4/8) mottles, apedal.

Profile 741 – Yellow gradational soil, weak structure (Princetown 7520: map ref. 000241)

A ₁₁	0-15 cm	black (10YR2/1) sandy loam, apedal-single grain, clear smooth boundary
A ₁₂	15-37 cm	black (10YR2/1) loamy sand, apedal-single grain, clear wavy boundary
A ₂	37-47 cm	dark yellowish brown (10YR4/4) sand, light-grey (10YR7/1) when dry, apedal-single grain, abrupt boundary, broken horizon.
B ₂₁	47-90 cm	brown (7.5YR4/4) clayey sand with some brownish yellow (10YR6/6) mottles, weak subangular blocky structure (2 mm), ironstone gravel and angular fragments common, diffuse smooth boundary
B ₂₂	90-180 cm	brown (7.5YR4/4) light sandy clay loam with some brownish yellow (10YR6/6) mottles, weak subangular blocky structure, ironstone common, clear wavy boundary
C	180 cm	yellowish red (5YR4/8) light sandy clay loam, apedal-massive.

Profile 742 – Grey sand soil, uniform texture (Otway 7620: map ref. 180319)

A ₁	0-30 cm	black (10YR2/1) loamy sand, apedal-single grain, gradual smooth boundary
A ₂	30-90 cm	dark-grey (10YR4/1) sand, light-grey (10YR6/1) with depth, apedal-single grain, abrupt irregular boundary with tongues continuing to more than 2 m depth
B ₂₁	90-98 cm	dark brown (7.5YR3/2) loamy sand, apedal-single grain, hard when dry, clear irregular boundary, existing as cappings to undulating horizon
B ₂₂	98-170 cm	dark yellowish brown (10YR4/6) loamy sand, apedal-single grain, some ironstone gravel and stones, gradual boundary, exists as columns separated by tongues of A ₂ horizon material
C ₁	170-210 cm	yellowish brown (10YR5/6) sand, apedal-single grain, some ironstone, clear smooth boundary
C _{2m}	210 cm	mottled brownish yellow (10YR6/8) and black (10YR2/1), apedal-massive, extremely hard when wet and dry, ferruginous cementation.

Profile 743 – Yellow-brown calcareous sodic duplex soil, coarse structure (Colac 7621: map ref. 416549)

A ₁	0-20 cm	very dark brown (10YR2/2) fine sandy loam, moderate crumb structure (2 mm), diffuse smooth boundary
A ₂	20-38 cm	very dark brown (10YR2/3) sandy clay loam, greyish brown (10YR5/2) when dry, moderate subangular blocky structure (8 mm), some ironstone gravel, abrupt wavy boundary
B ₂₁	38-60 cm	very dark brown (10YR2/2) heavy clay, strong angular blocky structure (2 mm), very hard when dry, diffuse smooth boundary
B ₂₂	60-120 cm	dark greyish brown (2.5YR4/2) heavy clay, strong angular blocky structure (35 mm) with angular blocky (2 mm) secondary structure, hard when dry, soft accumulations of calcium carbonate, gradual smooth boundary.

Profile 744 – Mottled yellow and red duplex soil (Colac 7621: map ref. 434469)

A ₁₁	0-10 cm	very dark brown (10YR2/3) fine sandy loam, moderate subangular blocky structure (3 mm), clear smooth
A ₁₂	10-20 cm	very dark brown (10YR2/3) fine sandy loam, moderate subangular blocky structure (3 mm), gradual wavy boundary
A ₂	20-44 cm	yellowish brown (10YR5/4) fine sandy loam, pale-brown (10YR6/3) when dry, apedal-massive, some ironstone gravel, abrupt wavy boundary
B ₂	44-150 cm	mottled yellowish brown (10YR4/4) and red (2.5YR4/8) medium clay, strong angular blocky structure (4 mm), clay skins, gradual wavy boundary
C	150 cm	mottled yellowish brown (10YR5/6) red, (2.5YR4/8) and grey (2.5YR5/0) light clay, weak subangular blocky structure.

Profile 746 – Mottled yellow and red gradational soil (Colac 7621: map ref. 319393)

A ₁	0-10 cm	very dark greyish brown (10YR3/2) clay loam, weak subangular blocky structure (5 mm), clear smooth boundary
B ₁	10-48 cm	dark yellowish brown (10YR4/4) light clay, weak subangular blocky structure (3 mm), gradual wavy boundary
B ₂	48-100 cm	mottled dark greyish brown (10YR4/6) and yellowish red (5YR5/8) medium clay, strong angular blocky structure (1 mm), clay skins, gradual wavy boundary
B ₃	100-150 cm	mottled strong brown (7.5YR5/6), red (2.5YR4/8) and grey (2.5YR5/0) medium clay, moderate angular blocky structure, gradual irregular boundary
C	150 cm	mottled grey (2.5YR6/0), red (2.5YR4/8) and reddish yellow (7.5YR6/8) medium clay, moderate angular blocky structure (5 mm), occasional ironstone.

Profile 748 – Brown gradational soil (Corangamite 7521: map ref. 147368)

A ₁	0-6 cm	very dark brown (10YR2/2) sandy clay loam, weak subangular blocky structure (11 mm), clear smooth boundary
A ₂	6-17 cm	brown (10YR4/3) fine sandy clay loam, weak angular blocky structure (9 mm), gradual wavy boundary
B ₂₁	17-30 cm	brown (10YR4/3) medium clay, strong subangular blocky structure (45 mm), diffuse wavy boundary
B ₂₂	30-90 cm	dark yellowish brown (10YR4/4) medium clay, strong angular blocky structure (2 mm), clay skins, gradual smooth boundary
B ₃	90-104 cm	mottled grey (5YR5/1) and brownish yellow (10YR6/8) sandy clay, weak subangular blocky structure, some iron cemented gravel and stones, abrupt boundary, broken horizon
C	104 cm	weathering sandstone

Profile 749 – Red gradational soil, weak structure (Princetown 7520: map ref. 055325)

A ₁	0-5 cm	dark-brown (7.5YR3/2) silty loam, apedal-single grain, ironstone gravel common
A ₃	5-20 cm	yellowish red (5YR4/6) clay loam, weak subangular blocky structure (5 mm), abundant ironstone gravel, gradual smooth boundary
B ₂₁	20-45 cm	yellowish red (5YR4/6) silty clay loam, moderate subangular blocky structure (5 mm), occasional ironstone gravel, gradual irregular boundary
C	90 cm	brown (7.5YR4/6) clay loam, weak angular blocky structure (4 mm), ironstone gravel common.

Profile 750 – Yellow-brown gradational soil, coarse structure (Princetown 7520: map ref. 982271)

O ₂	2-0 cm	black (10YR2/1) fine sandy clay loam, weak crumb structure (1 mm), abrupt wavy boundary
A ₁	0-14 cm	black (10YR2/1) fine sandy loam, weak subangular blocky structure (15 mm), clear wavy boundary
A ₃	14-26 cm	dark greyish brown (10YR4/2), fine sandy loam, brown (10YR5/3) when dry, weak angular blocky structure, hard when dry, gradual wavy boundary
B ₁	26-60 cm	brown (10YR4/3) medium clay with yellow (10YR7/6) mottles, moderate subangular blocky structure (3 mm), hard when dry, gradual wavy boundary
B ₂	60-105 cm	mottled grey (2.5YR6/0) and brownish yellow (10YR6/6) medium clay, strong angular blocky structure (4 mm), clay skins, hard when dry, gradual irregular boundary
IIC ₁	105 cm	mottled grey (10YR6/1) and yellow (10YR7/6) medium clay, some gleying, moderate columnar structure (60 mm), strong angular blocky secondary structure (8 mm), clay skins.

Profile 782 – Mottled yellow and red gradational soil with ironstone (Princetown 7520: map ref. 987357)

A ₁	0-10 cm	very dark greyish brown (10YR3/2) sandy clay loam, moderate subangular blocky structure (5 mm), occasional ironstone gravel, gradual smooth boundary
A ₂	10-41 cm	strong brown (7.5YR3/6) clay loam, weak subangular blocky structure (3 mm), ironstone gravel common, diffuse smooth boundary
A ₃	41-60 cm	strong brown (7.5YR5/6) silty clay loam, moderate subangular blocky structure, ironstone gravel common, diffuse smooth boundary
B ₂	60-120 cm	mottled yellowish brown (10YR5/4) and yellowish brown (10YR5/4) silty clay, strong subangular blocky structure (4 mm), clay skins, ironstone gravel common, diffuse irregular boundary
B ₃	120-150 cm	mottled grey (2.5YR5/0), red (2.5YR4/8) and yellowish brown (10YR5/4) silty clay, strong subangular blocky structure (4 mm), clay skins, ironstone gravel common, diffuse irregular boundary
C	150 cm	mottled grey (2.5YR5/0) and red (10YR4/6) silty clay, strong angular blocky structure (2 mm), clay skins, abundant ironstone gravel or complete bands of continuous ironstone alternating with kaolinitic clay.

Profile 783 – Brown duplex soil, coarse structure (Princetown 7520: map ref. 825187)

A ₁	0-20 cm	black (10YR2/1) fine sandy clay loam, moderate subangular blocky structure (3 mm, clear smooth boundary
A ₂	20-35 cm	greyish brown (10YR5/2) loamy fine sand, light-grey (10YR7/1) when dry, apedal-massive, occasional ironstone gravel, abrupt smooth boundary
B ₂₁	35-100 cm	dark yellowish brown (10YR4/4) medium clay, strong angular blocky structure (50 mm) with strong angular blocky secondary structure (4 mm), clay skins, diffuse wavy boundary
B ₂₂	100 cm	mottled yellowish brown (10YR5/6), yellowish red (5YR5/8) and grey (10YR5/1) medium clay, weak angular blocky structure, clay skins, occasional ironstone gravel

Profile 784 – Brown calcareous gradational soil, coarse structure (Princetown 7520: map ref. 887167)

A ₁	0-10 cm	black (10YR2/1) light clay, moderate subangular blocky structure (3 mm), gradual wavy boundary
B ₂₁	10-42 cm	dark yellowish brown (10YR4/4) heavy clay, moderate subangular blocky structure (3 mm), clay skins, hard when dry, diffuse smooth boundary
B ₂₂	42-60 cm	dark yellowish brown (10YR5/4) heavy clay, strong angular blocky structure (3 mm), clay skins, diffuse wavy boundary
B _{2ca}	60-90 cm	very pale brown (10YR7/4) medium clay, dominated by soft accumulations of calcium carbonate, moderate subangular blocky structure (6 mm), clear wavy boundary
C ₁	90-120 cm	mottled light grey (10YR7/1) and brownish yellow (10YR6/6) medium clay, weak subangular blocky structure (50 mm), calcium carbonate concretions common, gradual wavy boundary
C ₂	120-165 cm	mottled light yellowish brown (10YR6/4) and light-grey (10YR7/1) heavy clay, weak angular blocky structure (50 mm), some calcium carbonate concretions, clear smooth boundary
C ₃	165-180 cm	mottled very pale brown (10YR7/3), brownish yellow (10YR6/8) and grey (10YR6/1) medium clay, apedal-massive, soft nodules of lime and phosphate common, clear smooth boundary
C ₄	180 cm	mottled pale brown (10YR6/3), yellow (10YR7/8) and grey (10YR6/1) medium clay, weak angular blocky structure (80 mm), some calcium carbonate concretions.



Grey sand soil with hardpan, uniform texture – Profile 608



Grey sand soil, uniform texture – Profile 742



Black sand soil, uniform texture – Profile 739



Black sand soil, uniform texture – Profile 609



Yellow-brown gradational soil, coarse structure – Profile 750



Grey sand soil, structured clay underlay – Profile 747



Brown friable gradational soil – Profile 736



Brown calcareous gradational soil, coarse structure – Profile 784



Mottled yellow and red gradational soil with Mottled yellow and red gradational soil – Profile 746
ironstone – Profile 782



Mottled yellow and red duplex soil – Profile 744



Brown duplex soil, coarse structure – Profile 783

APPENDIX IV – Minor Components of Land Systems

Anglesea

1. Outcrops of Tertiary limestone with red calcareous gradational soil occur at Aireys Inlet. They are severely affected by the coastal environment as in component 1, but the soils are gradational and permeability is high. On the more sheltered sites these area are similar to the steeper slopes of the Bellbrae land system.
2. The estuarine swamps at Anglesea have small areas of saline soils supporting communities of *Arthrocnemum arbusculum*, which are similar to the swamps found in Connewarre land system.
3. Some of the recent gully infills and depositional fans in the lower parts of the landscape have yellow gradational soils with weak structure. Open forests of *Eucalyptus baxteri*, *E. sideroxylon* and *E. obliqua* are encountered. The subsoils have high values for sodium on the exchange complex.

Barwon River

Soils in the northern parts are strongly influenced by alluvium derived from basalt. They have higher calcium carbonate levels reflected by higher pH values, and are more heavily textured in the subsoil. Permeabilities are lower.

Beech Forest

Remnants of Tertiary sediments are occasionally found on high parts of the landscape. Examples occur at Lavers Hill, Wyelangta and Weaproinah. White sand soils of uniform texture are found at Lavers Hill, and similar light-textured soils at the other sites.

Bunker Hill

Tertiary olivine basalt with brown gradational soils and open forests of *Eucalyptus obliqua* and *E. ovata* are encountered on the northern slopes of Bunker Hill. The soils are somewhat heavier-textured than those found on Cretaceous sediments, and permeabilities are lower.

Deepdene

On some of the steeper slopes below lateritic plateau remnants, indurated ironstone layers outcrop at the surface. Stony red gradational soils are found at these sites.

Gellibrand River

1. The most poorly drained sites are those furthest from the major stream channels and have grey gradational soils with strong gleying. The vegetation is a closed scrub of *Melaleuca squarrosa*, *Leptospermum juniperinum* and, in some areas, *L. lanigerum*
2. Free water surfaces may locally cover a significant part of the landscape. The lakes and swamps at the mouths of the Aire, Gellibrand and Barham Rivers provide a range of saline and fresh-water habitats.

Hordern Vale

1. To the east of Cape Otway, coastal erosion has exposed beds of Lower Cretaceous sediments below the Tertiary sediments. Brown duplex soils occur on steep slopes, and the vegetation is an open forest of *Eucalyptus globulus*, *E. obliqua* and *E. baxteri*.
2. Surrounding the low woodlands of *E. kitsoniana* and in some other localities, grey sand soils with structured clay underlays are frequently found. The drainage is often impeded and the vegetation is usually a closed scrub of *Melaleuca squarrosa* and *Leptospermum juniperinum*.

Kawarren

1. Tertiary olivine basalt with stony red gradational soils and open forest of *Eucalyptus obliqua* and *E. viminalis* is found at the Kawarren East State School, and on the sides of ‘basalt hill’ at Gellibrand. The crest of ‘basalt hill’ have heavy-textured brown gradational soils with *E. ovata*.
2. Some of the better-drained valley floors, such as Ten Mile Creek, have brown gradational soils with weak structures support tall open forests of *E. obliqua* and *E. viminalis*.

Lorne

1. Remnant hill cappings of Tertiary sediments exist at Lorne, Cape Patton, Skenes Creek, and south of Peters Hill along Ironbark Spur. The soils on these sediments are usually yellow gradational soils with weak structures, or grey sand soils with hardpans. The vegetation is commonly a woodland of *Eucalyptus obliqua*, *E. radiata* and *E. nitida*.
2. At the mouths of the Erskins, Cumberland, Wye and Kennett Rivers, and Skenes Creek, aeolian deposits of calcareous dune sand are found. Soils are yellow calcareous sand soils of uniform texture, which formerly supported tussock grasslands of *Spinifex hirsutus*, *Scirpus nodosus* and *Calocephalus brownii*. Many areas have become unstable due to trampling and destruction of native vegetation, and restabilization has been effected by hand-planting *Ammophila arenaria*.

Mount Sabine

Remnant hill cappings of Tertiary sediments are found at Benwerrin and just south of Boonah. Yellow gradational soils with weak structures contain quartz gravel and support woodlands of *Eucalyptus obliqua*, *E. nitida* and *E. radiata*.

Pennyroyal

1. Near Bambra, broad gentle crests overlie laterite. Mottled yellow and red duplex soils with ironstone occur on the indurated ironstone layers, overlying mottled clays.
2. On the highest parts of the landscape to the east of Bambra, high proportions of quartz gravel occur in the parent material, and stony yellow gradational soils have developed. Open forests of *Eucalyptus obliqua* and *E. radiata* and *E. viminalis* occupy these sites.
3. The northern margins of the land system often have grey sand soils of uniform texture developed on deep deposits of quartz sand. These areas carry woodland of *E. viminalis*, usually with *Pteridium esculentum* in the understorey.

Rivernook

1. Inland from Moonlight Head, yellow gradational soils with weak structures are common on moderate to steep slopes. The native vegetation is dependent on exposure to coastal winds, but areas carry *Eucalyptus baxteri*.
2. Near Apollo Bay, grey sand soils with structured clay underlays are found on many parts of the landscape and usually support low woodlands of *E. obliqua* with *Leptospermum juniperinum* and *Melaleuca squarrosa* in the understorey.

Tomahawk Creek

The northern side of Tomahawk Creek has alluvial terraces with coarsely structured yellow-brown gradational soils. Open forests of *Eucalyptus ovata* and *E. radiata* occur on these areas.

Wonga

Tertiary sediments with high proportions of quartz gravel are occasionally found. Woodland of *Eucalyptus baxteri* and *E. radiata* grows on stony yellow gradational soils.

APPENDIX V – Floristic List

Reference: J. H. Willis. ‘A Handook to Plants of Victoria’ Vol. I (1970), Vol. II (1972)

<i>Acacia implexa</i>	lightwood	<i>Hedycarya angustifolia</i>	austral mulberry
<i>Acacia longifolia</i>	sallow wattle	<i>Helichrysum paralium</i>	coast everlasting
<i>Acacia mucronata</i>	narrow-leaf wattle	<i>Isopogon ceratophyllus</i>	horny cone-bush
<i>Acacia myrtifolia</i>	myrtle wattle	<i>Juncus</i> spp.	rushes
<i>Acacia pycantha</i>	golden wattle	<i>Leptospermum juniperinum</i>	prickly tea-tree
<i>Acacia suaveolens</i>	sweet wattle	<i>Leptospermum laevigatum</i>	coast tea-tree
<i>Acacia verniciflua</i>	varnish wattle	<i>Leptospermum lanigerum</i>	woolly tea-tree
<i>Acacia verticillata</i>	prickly moses	<i>Leptospermum myrsinoides</i>	heath tea-tree
<i>Acrotriche serrulata</i>	honey-pots	<i>Leucopogon glacialis</i>	twisted beard-heath
<i>Agropyron</i> spp.	wheat grasses	<i>Leucopogon parviflorus</i>	coast beard-heath
<i>Agrostis</i> spp.	bent grasses	<i>Lolium perenne</i> *	perennial rye-grass
<i>Alyxia buxifolia</i>	sea-box	<i>Medicago sativa</i> *	lucerne
<i>Ammophila arenaria</i> *	marram grass	<i>Melaleuca ericifolia</i>	swamp paperbark
<i>Aotus ericooides</i>	common aotus	<i>Melaleuca lanceolata</i>	moonah
<i>Arthroc nemum arbusculum</i>	shrubby glasswort	<i>Melaleuca squarrosa</i>	scented paperbark
<i>Banksia marginata</i>	silver banksia	<i>Microsorium diversifolium</i>	kangaroo fern
<i>Bauera rubioides</i>	wiry bauera	<i>Nothofagus cunninghamii</i>	myrtle beech
<i>Bedfordia salicina</i>	blanket-leaf	<i>Olearia argophylla</i>	musk dairy-bush
<i>Belchnum nudum</i>	fishbone water-fern	<i>Phalaris tuberosa</i> *	Toowoomba canary-grass
<i>Bossiaea cinerea</i>	showy bossiaeae	<i>Phebalium squameum</i>	satinwood
<i>Bursaria spinosa</i>	sweet bursaria	<i>Picea sitchensis</i> *	spruce
<i>Calocephalus brownii</i>	cushion-bush	<i>Pinus radiata</i> *	Monterey pine
<i>Carduus tenuiflorus</i> *	slender thistle	<i>Pinus laricio</i> *	black pine
<i>Carex</i> spp.	sedges	<i>Platylodium obtusangulum</i>	common flat-pea
<i>Carpobrotus rossii</i>	karkalla	<i>Poa</i> spp.	tussock grass
<i>Cassinia aculeata</i>	dogwood	<i>Prostanthera lasianthos</i>	Victorian Christmas-bush
<i>Casuarina littoralis</i>	black she-oak	<i>Pseudotsuga menziesii</i> *	Douglas fir
<i>Casuarina stricta</i>	drooping she-oak	<i>Pteridium esculentum</i>	austral bracken
<i>Cirsium vulgare</i> *	spear thistle	<i>Puccinella</i> spp.	saltmarsh-grasses
<i>Cyathea marcescens</i>	skirted tree-fern	<i>Pultenaea muellieri</i>	Mueller's bush-pea
<i>Cynodon dactylon</i>	couch	<i>Ranunculus</i> spp.	buttercups
<i>Dactylis glomerata</i> *	cocksfoot	<i>Rubus</i> spp. *	blackberries
<i>Danthonia</i> spp.	wallaby grasses	<i>Samolus repens</i>	creeping brookweed
<i>Dicksonia antarctica</i>	soft tree-fern	<i>Scirpus calocarpus</i>	club-rush
<i>Dillwynia glaberrima</i>	smooth parrot-pea	<i>Scirpus nodosus</i>	knobby club-rush
<i>Epacris impressa</i>	common heath	<i>Schoenus apogon</i>	common bug-rush
<i>Eucalyptus aromaphloia</i>	scent-bark	<i>Senecio jacobaea</i>	ragwort
<i>Eucalyptus baxteri</i>	brown stringybark	<i>Silybum marianum</i> *	variegated thistle
<i>Eucalyptus camaldulensis</i>	river red gum	<i>Spinifex hirsutus</i>	hairy spinifex
<i>Eucalyptus cypellocarpa</i>	mountain grey gum	<i>Sprengelia incarnata</i>	pink swamp-heath
<i>Eucalyptus globulus</i>	southern blue gum	<i>Spyridium parvifolium</i>	Australian dusty miller
<i>Eucalyptus goniocalyx</i>	long-leaf box	<i>Stipa</i> spp.	spear grasses
<i>Eucalyptus leucoxylon</i>	yellow gum or white ironbark	<i>Tetragonia tetragonoides</i>	New Zealand spinach
<i>Eucalyptus nitida</i>	shining peppermint	<i>Tetrarrhena juncea</i>	forest wire grass
<i>Eucalyptus obliqua</i>	messmate stringybark	<i>Themeda australis</i>	kangaroo grass
<i>Eucalyptus ovata</i>	swamp gum	<i>Trifolium fragiferum</i> *	strawberry clover
<i>Eucalyptus pauciflora</i>	white sallee	<i>Trifolium incarnatum</i> *	crimson clover
<i>Eucalyptus radiata</i>	narrow-leaf peppermint	<i>Trifolium pratense</i> *	red clover
<i>Eucalyptus regnans</i>	mountain ash	<i>Trifolium repens</i> *	white clover
<i>Eucalyptus sideroxylon</i>	red ironbark	<i>Trifolium subterraneum</i> *	subterranean clover
<i>Eucalyptus viminalis</i>	manna gum	<i>Xanthorrhoea australis</i>	austral grass-tree
<i>Festuca arundinacea</i>	demeter fescue (tall fescue)		
<i>Demeter</i> *			
<i>Frankenia pauciflora</i>	southern sea-heath		
<i>Gahnia filum</i>	chaffy saw-edge		
<i>Gleichenia circinnata</i>	pouched coral-fern		
<i>Hakea ulicina</i>	furze hakea		

* exotic species