PART II
FEATURES OF THE NATURAL ENVIRONMENT

3. CLIMATE

Elements of the Climate

Rainfall

Average Annual and Monthly Rainfall. - In the western and north-western parts of Victoria, there is an overall pattern of steadily decreasing average rainfall from south to north as the distance from the coast increases. At Portland on the coast, the average annual rainfall is 33½ inches, at Hamilton it is 26½ inches, at Horsham 17½ inches, at Ouyen in the Mallee 12½ inches, and at Mildura on the River Murray it is 10 inches. The isohyets trend in a general east-west direction from South Australia.

The average annual rainfall received by stations within the survey area varies from 17½ inches to 35 inches. To the west of the Grampians, the rainfall is part of the basic pattern for western Victoria just described, ranging from 26½ inches at Hamilton near the south-western corner, down to 17½, inches at Horsham on the northern boundary.

This pattern is greatly modified in the central and eastern parts of the area by the Grampians. The ranges lie in a north-south direction across the path of the rain-bearing westerly winds that move over the plains after crossing the Great Australian Bight and Southern Ocean. The average annual rainfall rises as high as 35 inches in the mountains, and there is a rain shadow to the east where Lake Lonsdale, Moyston and Willaura receive as little as 21 inches. Figure 2 shows the average annual isohyets which clearly indicate the pattern of incidence. The concentration of rain in the mountains, the rain shadow to their east and the regular spacing of isohyets over the western section are all evident.

The average distribution of rain during the year within the three rainfall zones is illustrated in Figure 3 where the average monthly rainfalls of five representative stations have been graphed. All places have a definite winter maximum and summer minimum distribution. Summer rainfalls at the five stations are of the same order, generally 1 to 1½, inches per month, and it is during the other seasons of the year that the differences in average rainfall arise.

Hamilton, Telangatuk East and Horsham (Figure 3) represent the western areas where the rainfall is not influenced by the mountains. The roughly parallel lines for the three stations show that the seasonal distribution of rain is the same. Throughout the year, the south-west is uniformly wetter than the central-west and the central-west than the north-west. Moyston is in the rain shadow to the east of the Grampians and its rainfall follows the same seasonal trend as the other three stations.

The graph emphasises the orographic nature of the rainfall within the mountains. The summer rainfall at Halls Gap is of the same order as that of the other places, so that its high annual precipitation comes from the very high falls of winter and spring rain caused by elevation of the rain-bearing clouds over the ranges.

Rainfall Probabilities.-A better understanding of the rainfall reliability is obtained by considering the probabilities of receiving specified amounts or more of rain for each month (Table 1).

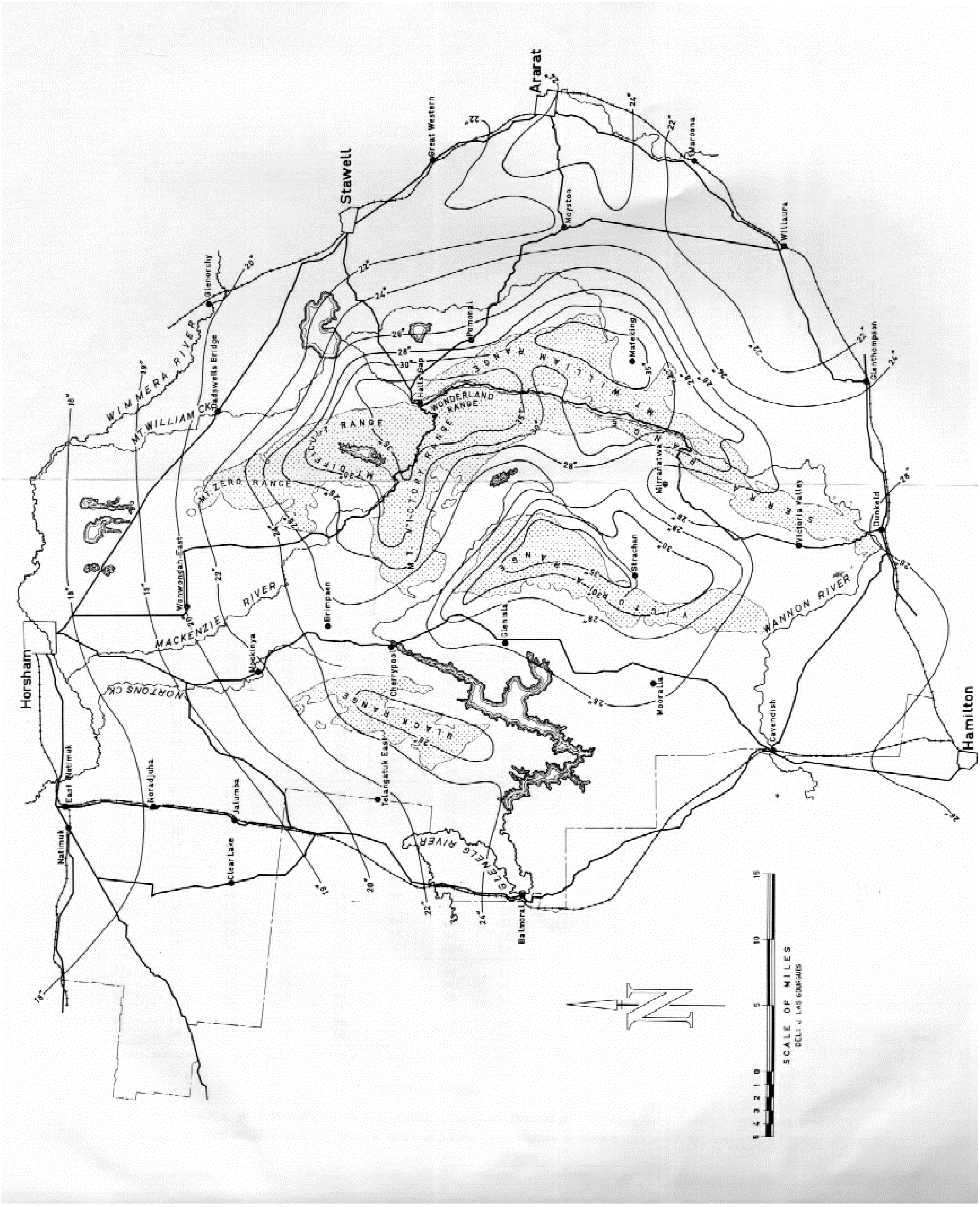

Figure 2 – Average annual isohyets
(constructed by C. E. Hounam, Commonwealth Bureau of Meteorology).

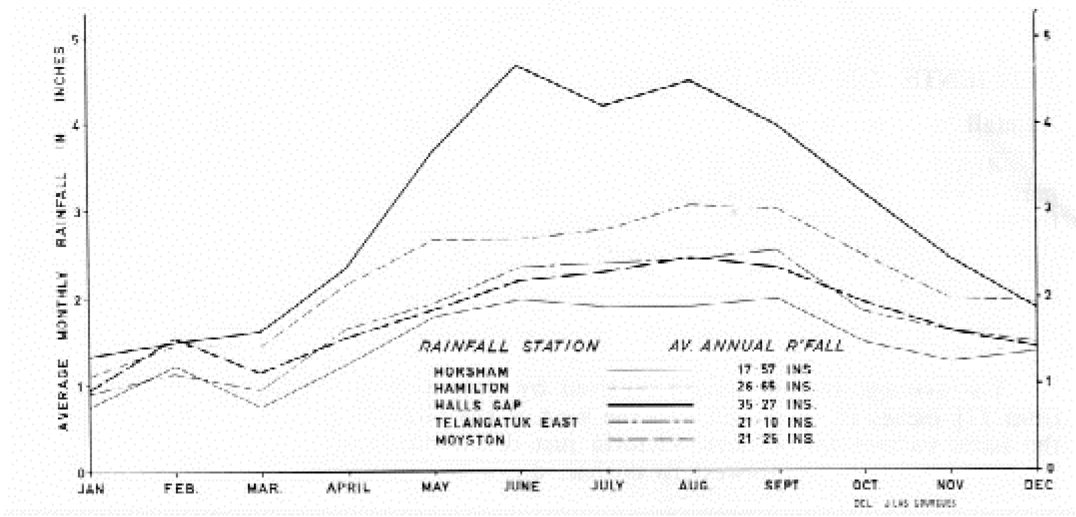

Figure 3 – The average monthly rainfall for selected rainfall stations.

For all the stations shown in the table, there is a high probability of having rainfalls exceeding one inch, for each month from May to October. During these months the probability of receiving such rainfall is almost 100 per cent for Halls Gap and Hamilton, and for Horsham, the probability is from 73 per cent to 83 per cent. The differences between the stations are progressively greater for higher rainfalls. From May to October at Halls Gap and Hamilton, the probability of receiving two inches or more each month is greater than 70 per cent, whereas at the other three stations, the probability is mostly less than 60 per cent. The overall figures for Halls Gap show that this station has the most reliable rain for example, for each of the three winter months, there is a probability of more than 50 per cent of at least four inches of rain being received.

Temperature

Records of average daily temperatures for Horsham, Ararat and Hamilton are given in Table 2. Two factors controlling air temperatures are the elevation above sea level and the distance from the coast. Horsham is at the lowest elevation (454 feet) and is farthest from the coast. Ararat is at the highest elevation (1,028 feet) and at an intermediate distance from the coast, and Hamilton is at an intermediate elevation (615 feet) and is nearest to the coast.

July is the coldest month and February is the hottest month at each of the three stations. During the three winter months, Horsham is the station with the highest average daily maxima (56°F. to 59°F.) and the lowest average minima (39°F. to 40°F.) during the same three months, Ararat is the station with the lowest maximum and highest minimum temperatures. During summer, Horsham has the highest temperatures recorded in the area and Hamilton has the lowest temperatures.

Table 1 – Percentage chances of receiving amounts or more of rain for each month for five representative stations
(Collated from the Glenelg and Wimmera Regional Reports, Central Planning Authority of Victoria).

Station	Rainfall (inches)	Percentage Probability											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Halls Gap	½ or more	78	70	78	92	99	100	100	99	100	97	95	91
	1 or more	49	66	61	81	95	97	98	96	99	92	84	74
	1½ or more	25	34	43	64	89	92	93	93	94	86	70	47
	2 or more	16	25	30	51	77	87	87	88	85	75	55	33
	3 or more	10	13	15	34	56	74	73	73	66	51	59	21
	4 or more	6	8	7	17	34	54	50	55	45	26	13	11
Hamilton	½ or more	84	70	84	96	99	100	100	100	100	99	95	92
	1 or more	51	44	63	88	97	98	99	98	99	93	82	72
	1½ or more	26	30	45	67	88	89	94	90	92	85	63	51
	2 or more	17	20	31	50	67	75	75	81	77	72	45	34
	3 or more	7	12	14	21	34	47	40	47	43	36	17	11
	4 or more	3	5	5	7	13	19	20	19	18	12	5	3
Telangatuk East	½ or more	67	66	67	84	96	97	100	96	98	94	90	76
	1 or more	42	38	45	63	82	86	96	89	91	83	65	57
	1½ or more	20	26	25	46	66	73	83	80	79	64	48	42
	2 or more	8	20	15	31	51	55	65	66	60	44	33	29
	3 or more	4	11	8	10	23	30	33	30	33	18	13	11
	4 or more	1	6	4	6	7	13	14	10	13	4	6	2
Moyston	½ or more	73	61	68	83	96	98	98	93	98	93	85	81
	1 or more	40	45	50	62	81	85	95	88	87	80	64	56
	1½ or more	23	32	29	47	60	71	80	75	71	66	48	37
	2 or more	16	22	23	34	46	56	59	63	54	50	35	25
	3 or more	7	13	15	16	19	27	25	32	22	26	13	7
	4 or more	4	7	9	3	7	11	7	9	9	10	4	1
Horsham	½ or more	52	56	60	77	91	96	96	95	95	90	75	66
	1 or more	27	32	36	53	73	82	83	81	77	73	53	40
	1½ or more	15	22	22	38	54	68	61	60	57	50	34	29
	2 or more	10	16	12	25	39	50	36	35	40	35	22	21
	3 or more	4	9	5	7	16	21	7	11	13	13	8	8
	4 or more	2	4	4	1	2	6	1	4	2	5	2	1

Table 2 – Average daily temperatures at Horsham, Ararat and Hamilton

Station	Average Daily Temp.	Temperature in Fahrenheit											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Horhsham	Maximum	85.1	86.3	80.2	70.7	63.0	56.6	56.0	59.0	64.1	70.2	77.2	82.7
	Minimum	55.2	55.9	51.9	47.0	42.9	40.2	38.8	39.9	41.9	45.1	49.6	53.2
	Mean	70.2	71.1	66.1	58.9	53.0	48.4	47.4	49.4	53.0	47.6	63.4	67.9
Ararat	Maximum	78.9	79.33	74.1	64.9	58.5	52.1	51.5	54.3	59.2	64.9	70.7	75.5
	Minimum	52.6	54.6	52.3	47.7	44.7	41.2	40.0	41.1	43.3	45.5	48.3	51.2
	Mean	65.7	67.0	63.2	56.3	51.6	46.7	45.9	47.7	51.4	55.2	59.5	63.5
Hamilton	Maximum	77.3	78.7	74.2	66.3	61.1	55.1	54.1	56.2	59.9	64.8	69.1	74.0
	Minimum	50.7	52.4	49.9	46.3	43.2	40.2	39.3	40.4	42.3	44.0	46.3	49.2
	Mean	64.0	65.6	62.1	56.1	51.7	47.6	46.7	48.3	51.1	54.4	47.7	61.6

Table 3 – Average 9.00 am saturation deficits and estimated evaporation at Horsham, Ararat and Hamilton

Station	-		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Horsham	SD	in	0.346	0.306	0.227	0.130	0.068	0.043	0.035	0.060	0.097	0.170	0.248	0.289
	Evap	in	7.34	6.48	4.81	2.76	1.44	0.91	0.74	1.27	2.06	3.60	5.25	6.13
Ararat	SD	in	0.285	0.255	0.178	0.110	0.068	0.040	0.041	0.054	0.095	0.153	0.209	0.238
	Evap	in	6.04	5.41	3.78	2.33	1.44	0.85	0.87	1.14	2.02	3.24	4.43	5.05
Hamilton	SD	in	0.270	0.251	0.180	0.100	0.060	0.039	0.040	0.060	0.089	0.134	0.181	0.221
	Evap	in	5.72	5.32	3.82	2.12	1.27	0.83	0.85	1.27	1.89	2.84	3.84	4.68

Humidity and Evaporation

Humidity is an expression of the content of water vapour in the air and is measured in a number of ways one method is by the use of saturation deficit which is the difference between the saturation vapour pressure in the air at a given dry bulb temperature and the actual vapour pressure at the same temperature.

Because it expresses the moisture deficiency of the air, saturation deficit can be used to estimate evaporation and this is valuable in areas where there are no evaporimeters. The formula commonly used in Australia, and used in this work, was proposed by Prescott (1938) and is E 21.2 S.D., where E is the estimated evaporation in inches from a free water surface and S.D. is the saturation deficit measured in inches of mercury at 9.00 a.m. Prescott (1951) and Hounam (1947, 1961) have indicated the lack of precision in this method. Penman's (1948) method of calculating evaporation is widely regarded as the most accurate but it requires data for wind speed and solar radiation which are unavailable for stations in the area.

The figures for saturation deficit and estimated evaporation for Horsham, Ararat and Hamilton are given in Table 3. Horsham, in keeping with its higher temperatures, has the highest amounts of evaporation for all months except July. At Hamilton, the evaporation is lowest for all months except March and August. The difference between the two cities is greater in summer than in winter, for example, at Horsham the figure for January is 28 per cent higher and for June it is 10 per cent higher than the figures for the same months at Hamilton.

Interpretation for Pasture Growth

Effective Rain

Climatic data have been used in many ways to relate the elements of climate to the growth of pastures. Usually this climate-growth relationship is expressed by formulae used for estimating the effectiveness of rain and the length of the growing season. Effective rain is defined as the amount of rain required to start growth after the break of season and maintain it above wilting point. In Prescott's (1951) formula, rain is said to be effective for the month if the ratio $P/E^{0.75}>0.54$, where P is the monthly rainfall and E is the measured or calculated monthly evaporation from a free water surface. The length of the growing season for any place is taken, on an average monthly basis, as the number of consecutive months with effective rain.

Effective rain and length of growing season are treated in the following way by the Commonwealth Bureau of Meteorology (Table 4). The length of the growing season is regarded by the Bureau as the number of consecutive months in which the chance of receiving rain at least equal to or greater than the effective amount of rain is fifty per cent or higher.

Table 4 - Percentage chances of receiving monthly rain equal to or greater than the effective amount for five representative stations. (Collated from the Wimmera and Glenelg Regional Reports, Central Planning Authority of Victoria).

-	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Horsham	9	17	18	48	78	93	95	92	82	55	27	20
Moyston	15	25	27	58	87	95	98	93	90	70	44	28
Telangatuk East	8	22	22	61	88	96	99	95	94	70	43	31
Hamilton	19	26	48	87	98	100	100	99	100	89	64	44
Halls Gap	17	26	40	78	97	100	100	99	99	87	66	35

On this basis, at Horsham there is a six-month growing season from May to October, although the figure for April is very close to 50 per cent so that an early start to the season may be expected every few years. At Moyston and Telangatuk East the growing season is seven months and the higher figures for April and October indicate that the season is likely to be more reliable than at Horsham. Similarly at Hamilton, there is an eight-month season from April to November and local opinion agrees with this estimate. The possibility of the growing season commencing in March and/or finishing in December in wetter-than-average years is also shown by the values of 48 per cent for March and 44 per cent for December. Despite the high annual rainfall at Halls Gap, the growing season there is the same as at Hamilton, and this illustrates the predominantly winter incidence of the high rainfall over the mountains. The much higher average annual rainfall for Halls Gap does not mean a longer growing season for that area than elsewhere in western Victoria, except for soils with a high moisture-holding capacity.

Potential Evapo-Transpiration

Thornthwaite (1948) introduced the concept of potential evapo-transpiration which is defined as the maximum amount of water that would be transpired and evaporated provided there is a full leaf cover in the plant community and unlimited water available within the root-zone. It is controlled from day to day by the weather but its long-term value may be calculated from certain elements of climate which are temperature, saturation vapour pressure and duration of sunlight.

This concept can be used to provide an estimate of the water status of the soil by considering the balance between rainfall and potential evapo-transpiration. During months of low rainfall and high temperatures, potential evapo-transpiration exceeds rainfall causing a soil moisture deficit, that is, a drier soil. During the cooler and wetter period of the year, the opposite occurs so that the soil is at its maximum water content and the surplus is lost as run-off and underground drainage. The advantage of this method over the previous method (which uses effective rain) is that allowance is made for soil moisture storage, which can extend the growing season beyond the occasion when potential evapo-transpiration first exceeds rainfall.

Potential evapo-transpiration has been calculated for Horsham, Ararat and Hamilton by using Leeper's (1950) simplification of Thornthwaite's method.

The graphs of average monthly potential evapo-transpiration and average monthly rainfall for the three stations are shown in Figure 4. The point where the two lines first cross represents the start of the growing season so that at Hamilton the growing season starts about a month earlier (April), on the average, than at Horsham (May) with Ararat between the two stations. The third line on each graph indicates that soil moisture can extend the growing season beyond the point where potential evapo-transpiration exceeds rainfall. The line represents the average monthly supply of water in a soil with a storage capacity of one inch of rain. Values between nought and one inch at the beginning and the end of the growing season are the differences between the rainfall and potential evapotranspiration for the months concerned.

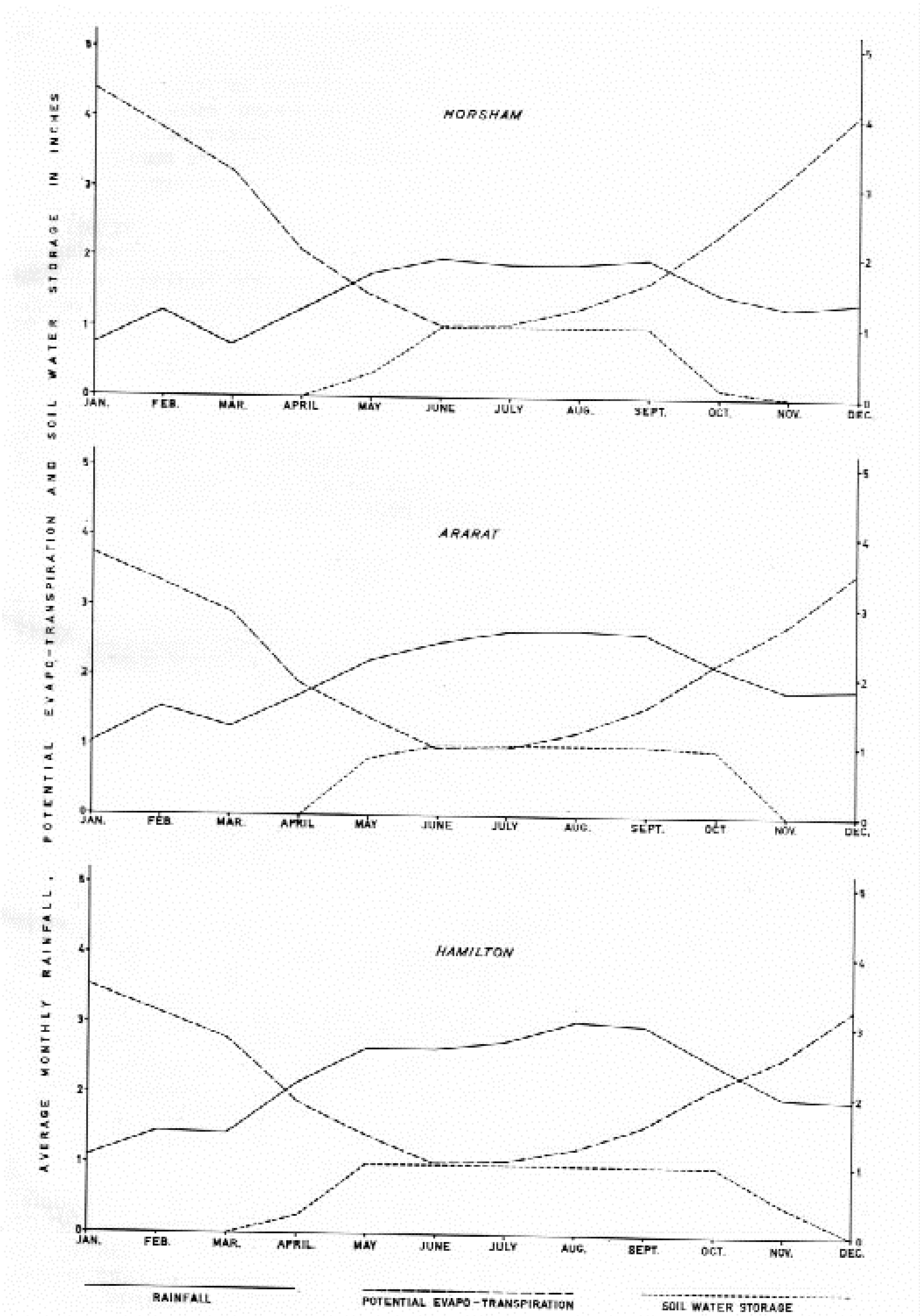

Figure 4 – Diagrammatic illustration of the length of the growing season at three centres'

This method again illustrates the gradual lengthening of the growing season from Horsham to Hamilton. During October the soil moisture is low at Horsham and the season is drawing to a close whereas at Ararat the soil is almost fully charged with water and the growing season extends into early November. At Hamilton, the soil has an appreciable supply of water during November and the close of the season is towards the end of the month or even into the early part of December if the spring is wetter than average.

Cold

Over southern Australia, the coldest period of the year coincides with the middle of the season of adequate moisture so that the rapid growth of the pastures is interrupted.

The average mean monthly air temperature is a convenient guide to winter growth. Trumble (1939) suggested that in southern Australia an average mean monthly temperature of 50^{o}F. is a useful point of separation between vigorous and slow plant growth, when no other factor is limiting, and that 45^{o}F. is a point of separation between slow growth and no growth. Stations within the survey area have mean monthly temperatures between these figures during the three winter months (Figure 5).

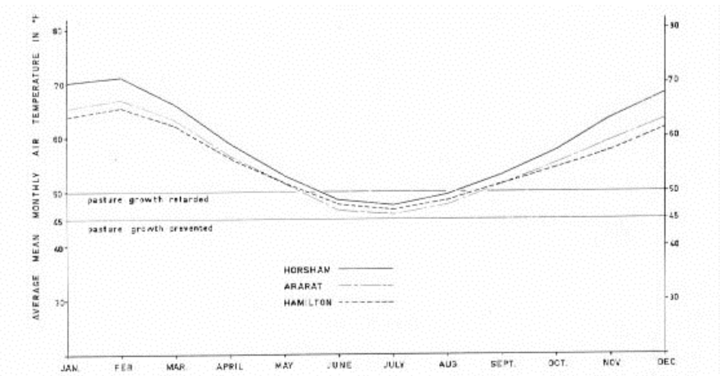

Figure 5 – Relationship between pasture growth and air temperature

Interpretation for Erosion Hazard

An important element of climate used for assessing erosion hazard is rainfall intensity. In the absence of a pluviometer, an approximate estimate of rainfall intensity for each month is obtained by dividing the monthly rainfall by the number of wet days for the month, a "wetday" being a day receiving at least one point of rain. Rainfall intensity is therefore expressed as points of rain per wet day.

The average monthly rainfall intensifies at five stations within the area are presented in Figure 6. The intensities for the four stations on the plains are highest during summer and early autumn and lowest during winter. In fact the differences between the intensities for the two seasons are greater than illustrated because the summer rains often come as short, heavy thunderstorms whereas in winter the rain is more often gentle and intermittent over longer periods during the day.

The period of highest intensities coincides with the season of the year when annual pastures have dried off and which, if grazed too severely, may then afford little protection to the dry soil. This combination of circumstances helps to create a high erosion hazard for part of the year in the undulating and hilly parts of the area.

Hamilton is the station where the rain is of lowest intensity for most of the year although its average monthly rainfall figures are higher than those for the other stations on the plains. Stawell and Ararat represent an area of comparatively high-intensity rain in the eastern part of the survey area. Halls Gap is exceptional in that the highest intensities of rainfall are in winter and they are the highest winter intensities in the area. This again demonstrates the orographic nature of the rain over the mountains.

Summary

The area of the survey can be divided into five climatic zones, the central mountainous zone being represented by Halls Gap, the northern plains by Horsham, the southern plains by Hamilton, the western plains by Telangatuk East and the eastern hills by Moyston and Ararat.

The central mountainous zone extending around Halls Gap and Wartook Reservoir has the highest annual rainfall which is characterised by very high falls during the winter months. For monthly falls of less than two inches, the rain is no more reliable than it is at Hamilton on the well-watered southern plains. For monthly falls of two inches or more, the rain over the mountains is more reliable than in the other climatic zones.

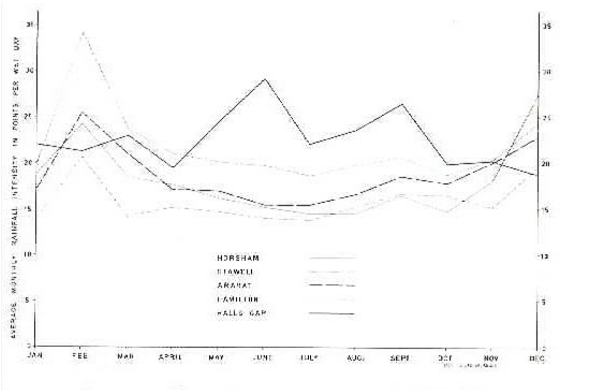

Figure 6 – The average monthly rainfall intensity for selected rainfall stations

Of the farming areas, the southern plains have the highest and most reliable rainfall, the lowest average intensities, the lowest evaporation and the longest growing season. The northern plains have the lowest and least reliable rainfall, the highest maximum temperatures, the highest evaporation and the shortest growing season. The climates of the western plains and eastern hills are similar to each other and are intermediate between the climates of the northern and southern plains. One notable feature of the climate over the eastern hills is the high rainfall intensities during the summer and early autumn. This adds to the erosion hazard in hilly country because the heavy rain comes at the time of the year when the soil is dry and the dead annual pastures, if overgrazed, may give little protection to the soil.

4. GEOLOGY AND PHYSIOGRAPHY*

Parent Materials of the Soils

Palaeozoic Rocks

Cambrian. - The Cambrian rocks are restricted in extent and consist mainly of cherts, shales and greenstones found to the east of the Grampians as a broken line of low, isolated hills. Decomposed greenstone also outcrops in the western Black Range, near Mt. Talbot, and in some areas of stream dissection in the Dundas Tablelands.

Ordovician.-The Ordovician rocks consist of sandstones, shales and mudstones and they were intensively folded in Post-Ordovician times and widely metamorphosed to slates, hornfels, and schists by the intrusion of igneous masses and associated quartz reefs and veins.

These rocks are found mainly in the eastern parts of the area around Ararat, Moyston and Stawell and they were intensively mined during the gold rushes of the 1850's.

Upper Devonian-Lower Carboniferous-The most important rocks of Upper Devonian-Lower- Carboniferous age are the Grampians sedimentary rocks which consist of massive beds of hard, quartzose sandstones interbedded with thin, soft, red siltstones and sandstones. The quartzose sandstones are composed almost entirely of silica (Spencer-Jones 1965, gives figures in excess of 95 per cent), and are formed of quartz grains of sand size cemented together by a matrix of secondary quartz. By contrast, the soft, thin sandstones and siltstones have a greater percentage of felspars which are present in the sand fraction as grains of mica and in the matrix as a proportion of clay.

The Grampians sandstones show their greatest development in the Grampians Ranges, but there are several smaller outcrops to the west, the largest of these are the western Black Range near Rocklands Reservoir, Mt. Arapiles near Natimuk, and the Dundas Range just outside the area north-west of Cavendish.

Another group of rocks of this period are the rhyolite and trachyte lavas which, in western Victoria, occur at the base of the Grampians sandstones, and with the sandstones overlie the Cambrian and Ordovician rocks. Many outcrops are exposed in the zones of stream dissection below the peneplain surface of the Dundas Tableland, for example, around the Rocklands dam and near Cavendish.

Igneous Intrusions-A number of igneous masses at one time intruded into the Ordovician and Grampians sedimentary rocks. The intrusions are now exposed as hills and plains of granite and granodiorite, and the larger of them are in Victoria Valley in the Grampians, between Ararat and Moyston, and between Great Western and Stawell.

Cainozoic Rocks and Unconsolidated Sediments

Tertiary Sands and Gravels-Coarse sands and gravels of Miocene age are found overlying some of the Ordovician rocks in the eastern parts of the area.

Tertiary Sea Deposits-During the Tertiary Era, the Southern Ocean advanced over parts of south-eastern Australia and it reached the maximum extent of its incursion during the Miocene Period. At this stage the sea formed a broad bight, known as the Murray Gulf, that extended across the south-cast of South Australia and the west and north-west of Victoria into New South Wales (Gloe 1947, Hills 1959, Johns and Lawrence 1964). It is thought that the Grampians and Dundas Tablelands were promontories jutting into the sea so that the northern parts of the present survey, to the south of Horsham, would have been towards its shallow southern edge. Gloe and Johns and Lawrence consider that the shallow marine conditions of the sea in this area favoured the deposition of thin Miocene marls and clays instead of the thick deposits of marine limestone laid down under deeper parts of the sea further to the north and west.

With the gradual uplift of the Murray Gulf during Pliocene times the sea slowly retreated towards its present position depositing thin estuarine clays and sands over the southern Wimmera. Pleistocene and Holocene fluviatile sands and clays now form a veneer over this area.

Extensive plains of Pliocene and Post-Pliocene fluviatile alluvia also occur in the eastern and south-eastern parts of the survey and in Victoria Valley in the Grampians. In addition to these sediments, Holocene siliceous sands were

* For a fuller treatment of the geology and physiography, reference is made to the Wimmera and Glenelg Regional Reports of the Central Planning Authority of Victoria in which the Mines Department of Victoria has contributed detailed chapters.

deposited as outwash material below the sandstone ranges and also built up as lunettes around many swamps on the plains.

Laterite*---During the Pliocene Period, considerable areas in the central western and south-western parts were lateritized, particularly the surface of the Dundas Tablelands. Today the zone of ironstone is frequently exposed at the top of the escarpment and at other places where there is a sharp break-away in the land surface also the mottled zone underlies the present cover of soil in many places.

Newer Basalt-Basaltic plains occur in the south and south-east, between Hamilton and Willaura, and are an edge of the extensive basaltic plain covering most of the Western District. The basalts are of Pleistocene age (Spencer-Jones 1965) and belong to the series of Newer Basalts in Victoria.

Artesian Basin-Gloe (1947) and Johns and Lawrence (1964) have mapped the boundary of the Murray Artesian Basin and indicated the known and probable intake areas. The northern part of the survey area comes within the boundary of the basin. However the water in this section of the basin is not of good quality.

Land-Forms

The land-form has been defined as a specific configuration of the land surface (Downes *et al* 1957) and can be regarded as a product of the geomorphological processes at work in shaping the earth's surface. It is one of the criteria used for recognizing and delineating the mapping units of this survey. Ten land-forms are included and their descriptions follow.

Plain

The plain is the predominant land-form and three categories have been recognized (on the basis of slope) which are related to their geomorphological history and parent materials.

Flat Plain-The flat plain comprises areas of estuarine and fluviatile deposition. The land in this category may have slopes up to one per cent.

Laterite is composed of an upper zone of ironstone, a middle zone of red and white mottled clay and a lower zone of white (pallid) clay.

Undulating Plain.-The undulating plain includes areas of basalt and areas where Palaeozoic rocks have been severely dissected and eroded. Slopes range from one to five per cent. The undulating plain is itself sub-divided into slightly, gently and severely undulating forms. The basalt plains are slightly to gently undulating and the plains on Palaeozoic rocks are gently to severely undulating.
Rolling Plain.-The rolling plain is confined to those areas of Palaeozoic rocks where geological erosion has not yet reduced the land surface to the level of an undulating plain and which therefore have steeper slopes, usually between five and ten per cent.

Situated on the flat plain, and forming part of it, there may be the following land-forms swamp, lunette, ridge, sand dune, sand sheet, and stony rise.

Swamp and Lunette

These two land-forms are dealt with together because they are intimately related to one another. The lunette is a crescent-shaped ridge around the eastern side of the swamp and is derived from the swamp by the movement of wind-blown material from its bed (Plate 2).

Ridge

In the north-western parts of the area there is a number of ridges elongated in a N.N.W.-S.S.E. direction and contiguous with the extensive ridge system in the neighbouring Shire of Kowree (Blackburn and Gibbons 1956). Similar ridges have been noted in the Mallee by Hills (1939, 1959) and Rowan and Downes (1963). It has been suggested that the ridges are stranded coastal dunes formed during the retreat of the Tertiary Murray Sea (Anon. 1961a, Blackburn 1962).

The ridges within the area of this survey vary considerably in their dimensions from the small ridges, which are up to half a mile long, a quarter of a mile wide and about twenty feet high, to the largest ridges which are up to twelve miles long, one mile wide and over one hundred feet in height. These land-forms are close to and parallel with each other and form intervening troughs in which chains of swamps and lakes sometimes occur.

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* Laterite is composed of an upper zone of ironstone, a middle zone of red and white mottled clay and a lower zone of white (pallid) clay).

Sand Dune

The sand dunes in this area are elongated in an E-W. direction, and are generally a quarter of a mile to one mile long, fifty to one hundred yards wide and no more than about twenty feet high (Plate 3). These dimensions are smaller then those given for the Mallee dunes (Rowan and Downes 1963). Also, the dunes within this survey have a broad, flattened top rather than a sharp crest.

Sand Sheet

This is a broad deposit of sand laid down over a former land surface by wind or water. Sand sheets occur in two forms as outwash material surrounding the sandstone ranges of the Grampians and as smaller sheets scattered over the northern and central-western plains.

Stony Rise

The stony rise, a feature of the basalt plains, is a sharp crest or ridge in the basalt surface with abundant outcropping boulders.

Throughout **the** basalt plain of the Western District, stony rises vary in size and in their degree of development. In their extreme form they are broken, contorted tracts of land derived from the most recent lava flows. However within the survey area there are few rises and they are very small. They occur as isolated crests two or three chains in length and no more than about ten feet in height.

Hill

The hills are composed of Palaeozoic rocks and have very long slopes with gradients in excess of those of the rolling plain. The separation of hills from mountains is arbitrary but within the survey area an elevation of 600 feet to 900 feet above the plain is used.

Cuesta

Cuesta is a Spanish name given to a land-form of distinctive shape and origin in which a long gentle upward slope ends in an abrupt escarpment. It develops in gently dipping sedimentary rocks where hard, resistant beds overlie softer, erodible beds. As the softer beds are worn away by long-term geological erosion, the upper ones remain elevated above the surrounding countryside (Figure 7). The diagram illustrates the features of the cuesta. The dip slope approximates to the angle of dip of the beds, and the outcropping ends of the upper, resistant beds form the cliff-like escarpment or scarp face. The scree slope develops below the scarp by scree and colluvium moving downslope over the land surface formed by the exposure of the underlying softer beds. The strike is the direction of alignment of the scarp ridge and is at right angles to the direction of dip.

The ranges of the Grampians and western Black Range are excellent examples of the cuesta (Plate 4) in which the massive, quartzose sandstones are the resistant beds, and the interbedded, softer siltstones and sandstones are extensively eroded. Closely associated with the Grampians cuestas and derived from them by weathering and erosion are extensive sheets of siliceous sand forming outwash slopes on both sides of each range (Figure 7).

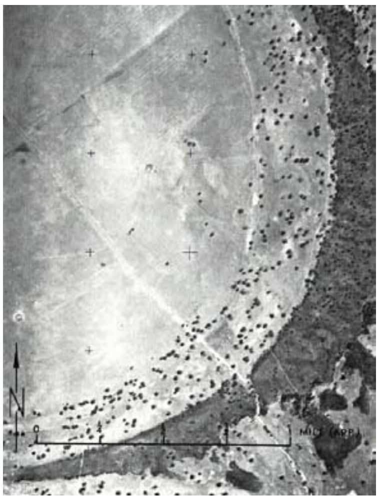

Plate 2 – The crescent or sickle shape of the lunette is well illustrated in this aerial photograph. The dark tone is caused by its dense cover of bracken.

Plate 3 – Sand dunes are scattered individually over the plains south of Horsham. Most of them are cleared and wind-eroded.

Tableland

A tableland is a flat, elevated surface usually composed of hard, resistant rock and bounded by a scarp abruptly leading down to the adjoining valleys or lowlands.

The development of the tableland and cuesta follow similar lines, the difference being that the sedimentary rocks are horizontal in the former and dipping at an angle in the latter land-form.

Geomorphological Units

The geomorphological units within the area of this survey are based to a large extent on the detailed geological map of the Grampians area by Spencer-Jones. Extensive areas around the periphery of this survey are outside the geological map, and the information provided by the map was extended to these areas.

Table 5 lists four geomorphological divisions and eight sub-divisions and Figure 8 shows their distribution. The sub-divisions are used as important criteria for delineating the mapping units of the survey (land-systems and land-units) and in Chapter Nine this relationship is explained in more detail.

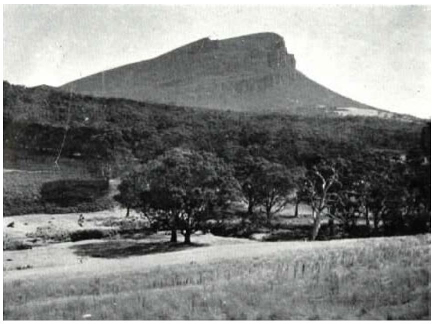

Plate 4 – Mt Abrupt, near Dunkeld, clearly shows the features of the cuesta. The long dip slope on the left rises steadily to the summit and then gives way sharply to the precipitous scarp face. Below the scarp falls the gentle curve of the scree slope.

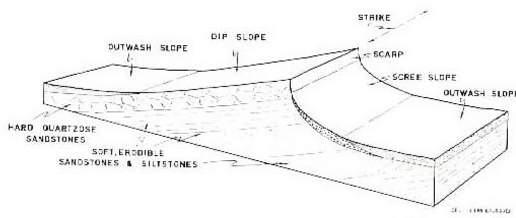

Figure 7 – A diagram illustrating the features of the cuesta land-form.

Table 5 – Geomorphological units in the Grampians Survey

Geomorphological Divisions	Geomorphological Sub-Divisions
Areas of depositon of unconsolidated sediments	(i) Plains of fluviatile and estuarine sediments (ii) Dunes and sheets of siliceous sand (iii) Areas where (I) and (ii) closely intermingle
Areas of extrusion lavas	(iv) Plains of basalt
Areas of laterite	(v) Lateritic tablelands (vi) Lateritic plains
Areas of dissected Palaeozoic rocks	(vii) Hills and plains of mature dissection (viii) Central mountainous zone

Plains of Fluviatile and Estuarine Sediments

The sediments forming the plains of this sub-division are Pliocene to Pleistocene in age, with localised Holocene deposits in swamps and along stream courses. The plains are broadly divided into three areas as described in the following paragraphs.

Two of the areas make up the northern plains which were formerly submerged under the shallow edge of the Tertiary Murray Sea. Their present surface deposits are predominantly clay materials on which calcareous clay soils have formed. In the first area, the plains are flat and poorly drained. Small intermittent streams flow across them from sources in the Grampians and join the Wimmera River along the northern boundary of the survey. The bigger of the tributaries are Mackenzie River, Mt. William Creek and Norton's Creek and a feature of their drainage pattern is the effluents and anabranches which leave the main channels. The second area is in the north-western section of the plains where N.N.W-S.S.E. ridges form an undulating landscape of alternating ridges and troughs. Streams are absent, and drainage waters from the ridges move very slowly along chains of swamps in the troughs.

The third area of plain includes the comparatively narrow alluvial plains of streams that drain upland areas of Palaeozoic rocks in the eastern and southern parts of the survey. Soils with sandy to loamy topsoils and clay subsoils occur throughout this area.

Dunes and Sheets of Siliceous Sand

Deep deposits of quartz sand of Early Holocene age are found in many sites and have been conveniently placed into three groups.

The first group is by far the most extensive and consists of the broad zone of outwash sands surrounding each of the Grampians ranges and the western Black Range. This material takes the form of gently sloping sand sheets which gradually level out toward their boundary with the alluvial plains (Figure 7). The number of depositional layers involved and their depths are unknown. Many small streams flow down the escarpments of the ranges and across the outwash slopes, some to disappear into the deep sand and others to eventually join the larger streams that flow across the plains. Because of the activity of the streams, the outwash slopes have undergone mild dissection which is evident as very gentle undulations at right angles to their direction of slope.

The second group of deposits includes many small areas of sand sheets and sand dunes found over widely scattered parts of the northern and central-western plains. Their mode of deposition is thought to be aeolian (Spencer-Jones priv. comm.) in contrast to the outwash slopes which were deposited by water. The sand sheets in the vicinity of Rocklands Reservoir and the western Black Range do not have dunes and are generally deeper than the sheets further north and north-west where the sand of the original deposits has been redistributed to form sand dunes and accompanying shallow sheets.

Lunettes of sand are the third kind of deposit, and are associated with swamps on the western plains between Toolondo and Mockinya, and on the south-eastern plains between Moyston and Dunkeld.

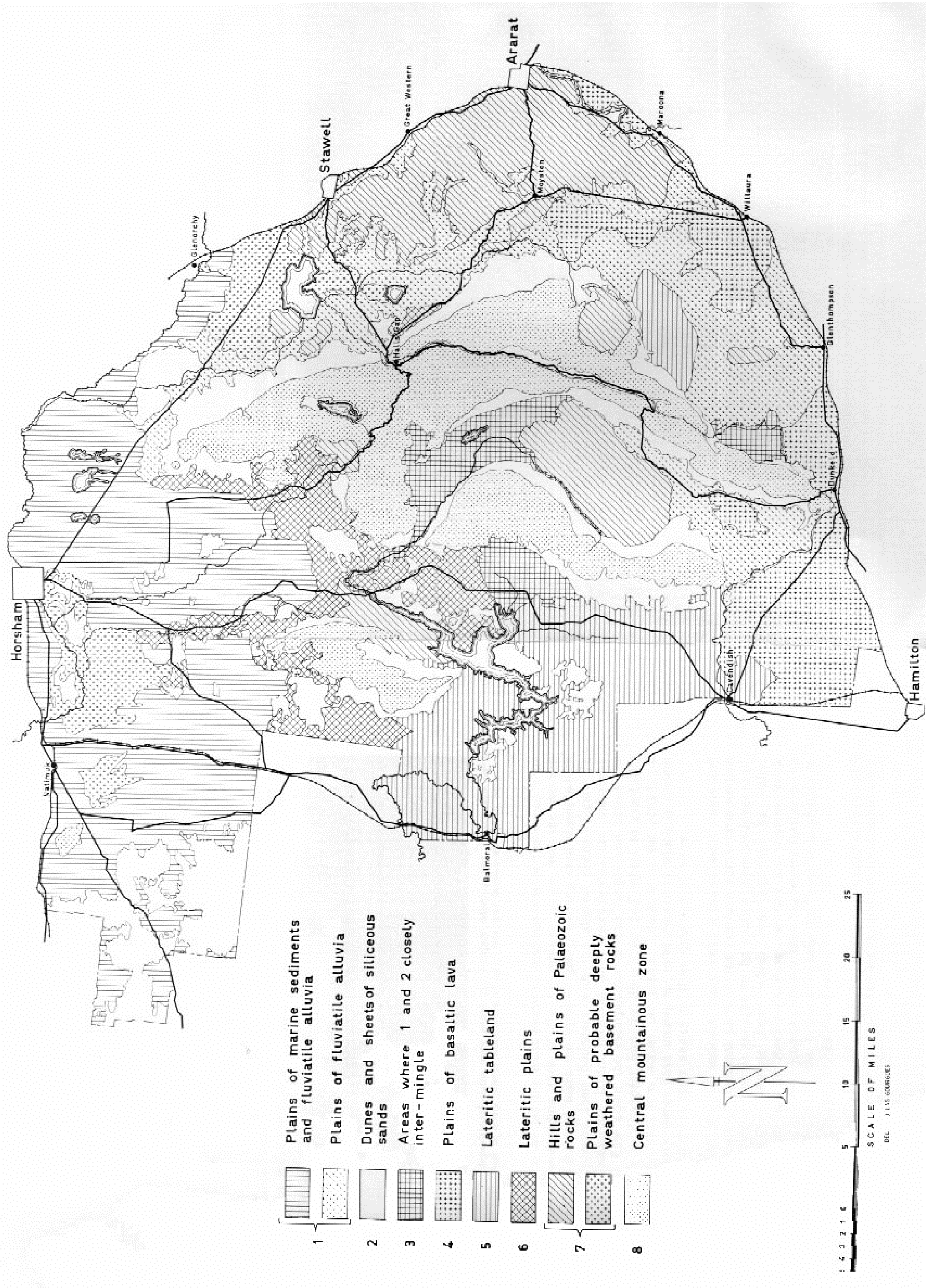

Figure 8 – Geomorphological subdivisions in the Grampians Survey

Plate 5 – The northern depositional plains were under the Tertiary Murray Sea. They now have gilgaied clay soils, and in many places woodlands of grey box and buloke as shown here.

A Composite Sub-Division

In some areas there is a close intermingling of fluviatile deposits and sheets of siliceous sand. This occurs in flat valleys in and around the Grampians where stream flow is sluggish and the main channel divides into numerous diffuse drainage lines choked with tall heath vegetation. Sheets of siliceous sand partly cover older deposits of fluviatile material, and associated with the close intermingling of sediments are numerous changes of soil and vegetation which occur in an otherwise seemingly random fashion.

Plains of Basalt

The plains of Newer Basalt have a gently to severely undulating topography. Because of the topography and the relative youthfulness of the flows, the drainage systems of the plains are poorly developed. Streams are few and in some areas swamps are a common feature of the landscape. Some parts of the plains have scattered small stony rises and also basalt boulders lying over the ground.

The pre-basaltic drainage system of the plains around the southern Grampians was changed after the extrusion of the lava flows (Fenner 1918). The Wannon River and a number of smaller streams flowing out of the mountains were checked and diverted by the lavas. Several large marginal swamps subsequently developed along the edge of the flows, and are located near Dunkeld and north-cast towards Moyston.

Lateritic Tablelands

Near Rocklands Reservoir and south to Cavendish there are tablelands capped with laterite and drained by numerous streams. The tablelands developed as the streams cut through the hard capping, and they are now characterized by a flat surface separated from steep-sided valleys by a scarp. Palaeozoic basement rocks forming the core of the tablelands are often exposed in the valleys as outcrops of greenstone, granite, rhyolite and trachyte.

This geomorphological unit is the eastern extremity of the much larger Dundas Tablelands which have developed to their greatest degree beyond the western boundary of the survey. By comparison, the tableland area included in this work is of milder dissection and its valleys are therefore not as deep nor as wide.

Lateritic Plains

Lateritic plains make up most of the land between the Grampians and the western Black Range, and Spencer-Jones has mapped them as a northern extension of the laterites of the Dundas Tablelands. The plains are slightly to gently undulating and the laterite is exposed at the surface in only a few places.

Scattered over the plains are small sheets of sand belonging to the second sub-division.

Hills and Plains of Maturely-Dissected Palaeozoic Rocks

Included in this sub-division are dissected Palaeozoic rocks that have been severely eroded to form a landscape of generally moderate relief. However, some areas are more resistant to geological erosion and stand above the plains as hills.

The igneous intrusions are now exposed as plains and hills of weathered granitic rocks over which scattered rock outcrops and tors are found. On some intrusions, differential erosion has led to the formation of neighbouring hills and plains on the same mass. The plains are gently undulating to rolling, and have clearly defined drainage systems. The underlying rocks are not strongly jointed and so the drainage pattern is normally dendritic. The hills rise to an average height above sea level of 1,500 feet and have the characteristic rounded outline of hills formed on rocks of this type.

Ordovician and metamorphosed Ordovician sedimentary rocks form another important area within this geomorphological sub-division. Like the granitic masses, the sedimentary rocks have reached an advanced stage of

erosion and now form undulating to rolling plains with clearly defined drainage systems. Hills occupy a small proportion of the area.
In the north-western parts of the Ordovician area, the outcrops of rock are fewer and smaller. They are separated by broad areas of younger alluvium and in places they are capped with thin deposits of Miocene sands and gravels. The topography is gently undulating with low rises formed by the deeply weathered rocks.

Cambrian greenstones, cherts and shales are found to the cast of the Grampians as a broken line of low hills. They protrude through the alluvial plains as erosion residuals.

This geomorphological unit also includes some areas in the north-eastern and northern parts of the survey which some geological maps show as Plio-Pleistocene sediments. However, because of their undulating topography, it is thought rather that these areas are plains formed by prolonged erosion of deeply weathered basement rocks (Spencer-Jones priv. comm). As such they have been included within the area of maturely dissected Palaeozoic rocks.

Plate 6 – The Grampians Ranges stand out as high ridges of hard, resistant sandstones, and the intervening valleys have formed by the erosion of interbedded softer rocks. Between Mt William Range in the background and Serra Range in the foreground is the valley of the Wannon River.

Central Mountainous Zone

The central mountainous zone comprises the Grampians and the western Black Range, that is, it includes the areas of sedimentary rocks belonging to the Grampians Group. Although near the north-western boundary of the survey, Mt. Arapiles is also part of the sub-division.

The Grampians and western Black Range consist of a series of parallel ranges extending in a north-south direction for a maximum distance of 53 miles. The ranges are very good examples of the cuesta land-form and in most cases the sandstone beds dip to the west with the scarp faces pointing to the east. Hills (1936, 1959) considers that the dip of the beds was developed by monoclinal folding of the sandstones after faulting movements occurred in the underlying Ordovician rocks. In a few instances the beds dip to the east as a result of localized synclinal folding within the sandstones (Spencer-Jones 1965).

The ranges and valleys have developed by differential erosion of alternating groups of hard and soft rocks (Hills 1936, 1959). The ranges, being composed of massive beds of hard quartzose sandstones, have offered a much greater resistance to erosion and stand out as high mountain ridges. The intervening valleys have been excavated in the softer and thinly bedded red sandstones and siltstones (Plate 6). Streams flowing in the valleys are termed subsequent streams because their courses have been determined by the position of the soft rocks, for example, the mountain tracts of the Wannon River and Fyans Creek.

5. SOILS

Generalised and small-scale soil maps that include the area of the Grampians survey within their boundaries have been presented by Northcote (1960a) and Skene (1960, 1961).

Classification of the Soils

Except for Northcote's Factual Key (1960b), no scheme of soil classification adequately classifies all the soil groupings that have been recognized during the field work. Several classifications and authors in Australia have been referred to and they are indicated in Table 6. Ten soil groups and fourteen sub-groups have been adopted from the sources shown. The groups are not necessarily great soil groups although most of them belong to that category. The name solonetzic soil" (Group 6) was taken from the survey of the neighbouring Shire of Kowree (Blackburn and Gibbons 1956) and it includes the gilgaied* solonetzic soils described by those authors and also the solodised solonetz and solonetz great soil groups used by Hallsworth, Costin and Gibbons (1953) and Stephens (1962). Group 8 does not appear in the sources quoted and it has been used to account for brown clay soils that would have been included in Group 9 were it not for the acidic profile and the absence of free calcium carbonate in the soil.

Description and Distribution of the Soil Groupings

(1) Lithosol

Lithosols are mineral soils directly overlying the parent rock and with little or no profile development beyond the accumulation of organic matter at the surface. In many cases they are shallow and very stony and for these reasons they are often called skeletal soils.

The most common examples of this group in the survey are found on quartzose sandstones in the Grampians and western Black Range. They are brownish grey or dark grey loamy sands usually less than twelve inches in depth and either with or without pieces of sandstone.

Another group of lithosols is found on the stony rises of the basaltic plains near the southern boundary of the survey area. These soils are shallow reddish brown loams lying directly on the basalt and surround by outcropping boulders. Leeper, Nicholls and Wadham (1936) first described soils of this kind and named them Corangamite stony loam. Sometimes there is a small textural change with depth to a clay loam.

(2) Nomopodzol

The nomopodzols have formed in deep deposits of quartz sand. Off-white or light grey sand occupies the upper two to three feet except for the surface few inches where organic matter has darkened the soil. Below the off-white sand is a subsoil of yellow, yellowish brown or brown sand and this horizon is in turn underlain by clayey sand or sandy clay at depths usually greater than three feet below the surface and often between four and five feet.

The nomopodzols are very acidic, their pH values range from 4.5 at the surface to 5.5 and 6.0 in the deep subsoil. The very low amounts of clay in the profile and the high acidity are associated with very low amounts of plant nutrients, particularly potassium, calcium, magnesium, copper, zinc, phosphorus and nitrogen. These deficiencies become very important when nomopodzols are considered for pasture development. This aspect is considered in more detail in the last section of this chapter.

Two sub-groups are recognized. The ***organo nomopodzol*** (or humus nomopodzol) is identified by a thin zone of dark brown sand at the boundary between the sub-surface zone of off-white sand and the subsoil of yellow to brown sand. In wet sites the dark brown sand is cemented to form a hardpan called "coffee rock".

The iron ***nomopodzol*** conforms to the general description of nomopodzols given above, that is, it does not have the dark brown sand or coffee rock in the subsoil. This sub-group is divided into two series of soils, the Grampians Plains series and the Grampians Ranges series. The former is found in deep deposits of quartz sand, for example the outwash slopes surrounding each of the Grampians ranges, and it contains typical or “normal" examples of iron nomopodzols. The latter series includes soils that occur over many parts of the sandstone ranges. They are comparatively shallow and rocky and are exceptions to the general description. They are more correctly regarded as soil-rock layers superimposed one over the other. A fuller explanation is given in Appendix IA.

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* Gilgais are small, regular undulations of the soil and they consist of alternate raised mounds (called puffs) and intervening hollows (called shelves).

Table 6 – Soil groupings used in the Grampians Survey

Soil Group		Sub-group	Classification with synonymous or similar soil groupings. Hallsworth, Costin and Gibbons (1953), Northcote (1960b), Stephens (1962)	Land-systems where found
1.	Lithosol (Hallsworth and Costin 1950)		Stephens – skeletal, Northcote – on sandstone Uc 1.23 - on Uml	Grampians Ranges (Dunkeld)
2.	Nomopodzol (Hallsworth, Costin and Gibbons 1953)	Organo (Humus)	Stephens – podzol, ground-water podzol Northcote – Uc 2.21, Uc 2.32, Uc 2.33	Grampians Plains Moora Valley
		Iron	Stephens – podzol Northcote – Uc 2.21	(Kowree)
3.	Leptopodzol (Hallsworth, Costin and Gibbons 1953)	Iron	Northcote – Uc 4.2, Uc 5.11	Grampians Plains Grampians Ranges Kowree Parrie Yalloak
		Clay	Northcote – Gn 2.21	
4.	Podzolic Deep Sand (Blackburn 1953a)		Northcote – Uc 1.21	Warratong (Telangatuk)
5.	Solodic Soil (Hallsworth, Costin and Gibbons 1953)	Red	Stephens – red podzolic Northcote – Dr in part	Mt William Creek Parrie Yalloak Dunkeld Willaura Dundas Brimpaen Ararat Mirranatwa Mt Dryden
		Brown	Stephens – grey-brown podzolic Northcote – Db, Dd in part	
		Yellow	Stephens – yellow podzolic, Northcote – Dy in part	
6.	Solonetzic Soil (Blackburn and Gibbons 1956)	Red	Hallsworth, Costin and Gibbons – solodised Stephens – solodised solonetz and solonetz Northcote – Dr4, Dr5, in part	Telangatuk Ullswater Mt William Creek Warratong Brimpaen Darracourt (Parrie Yalloak) (Moora Valley)
		Brown	Hallsworth, Costin and Gibbons – solodised solonetz and solonetz Stephens – solodised solonetz and solonetz Northcote – Db3, Db4, Dy4, Dy5 in part	
		Gilgaied	Shelf; Hallsworth, Costin and Gibbons – solodised solonets Stephens – solodised solonetz	Telangatuk
			Puff; Stephens – grey soil of heavy texture Northcote – Ug 5.2	Ullswater

	Soil Group	Sub-group	Classification with synonymous or similar soil groupings. Hallsworth, Costin and Gibbons (1953), Northcote (1960b), Stephens (1962)	Land-systems where found
7.	Red-brown Earth (Hallsworth and Costin 1950)		Stephens – red-brown earth Northcote – Dr2.1, Dr2.2, Dr2.3 in part Db1.2, Db1.3 in part	Horsham
8.	Acidic Brown Clay	Gilgaied	Shelf; Northcote – Uf6.51, Ug1 Puff; Northcote – Ug5.3	Dunkeld (Darracourt)
9.	Brown Soil of Heavy Texture (Stephens 1962)	Gilgaied	Shelf; Northcote – Ug5.4, Ug5.16 Puff; Northcote – Ug5.2	East Wonwondah
10.	Grey Soil of Heavy Texture (Stephens 1962)	Gilgaied	Shelf and Puff; Northcote – Ug5.2	Horsham
		Non-gilgaied	Northcote – Uf6.61, Uf6.51, Ug1	Willaura Parrie Yalloak Telangatuk
11.	Meadow Soil (Hallsworth and Costin 1950)	Calcareous	Stephens – weisenboden Northcote – Ug5.15, Ug5.16	

(3) Leptopodzol

The leptopodzols have formed in deep deposits of quartz sand and also in deposits containing both sand and clay. They are not so acid nor infertile as nomopodzols nor are their upper layers so devoid of colour. The sub-surface horizon usually has pale shades of brown, yellow or grey which gradually become stronger in the subsoil. Textures down the profile are sand, or else loamy sand at the surface gradually changing to clay loam and then to light clay in the deep subsoil at about thirty inches. These textural differences divide the group into iron and clay leptopodzols respectively.

Iron leptopodzols have small variations in their properties that divide the sub-group into the *Serra* and *Nekeeya series.* The Serra series is found mainly on the upper outwash slopes immediately below each of the Grampians ranges. The pH values of its soils are generally within the range of 5.0 at the surface and 6-5 in the deep subsoil and their colours are brownish yellow to yellow. Soils of the Nekeeya series are characteristically located in sandy lunettes in the eastern and southern parts of the survey. They have pinkish brown colours below the surface and by comparison with the Serra series they are less acid (pH 6.0-6.9) and have coarser sand throughout their profiles.

The ***clay leptopodzols*** are also divided into two *series,* the Mt. Victory series and the Illawarra series. The Mt. Victory series is part of the podzol complex of soils found in and around the Grampians ranges. The soils of this series have yellow and yellowish brown colours and the textures change gradually down the profile from loamy sand at the surface to light clay in the deep subsoil at about thirty inches. Soils of the Illawarra series have developed in deposits of Tertiary sands and gravels that occur near Stawell on the crests and upper slopes of a gently undulating plain. The series differs from the Mt. Victory series in the following features. First, the clay subsoil is much closer to the surface, usually between twelve and twenty inches. Second, the sub-surface horizon has a range of characteristic colours of which strong brown is the commonest. Third, there are large amounts of quartz gravel and coarse sand imparting gravelly and gritty textures throughout the profile. These soils have pH values of around 5.0 at the surface and 6.0 to 6.5 in the clay subsoil. They are still regarded as infertile soils although they are riot as deficient in pasture nutrients as the other podzols.

(4) Podzolic Deep Sand

This descriptive name indicates that these soils have formed in deep deposits of quartz sand and that they bear some likeness to the podzols by being acidic, infertile sands. However, they are not as acid and they have paler colours in the lower horizons. The sub-surface is off-white or cream and even at depths of four and five feet the colour of the sand is no stronger than light yellow. Their pH values are between 6.0 and 6.8 and they have very low amounts of plant nutrients.

The name of this soil group was first used by Blackburn (1959a) to describe soils developed in sand dunes in the Tatiara District of South Australia. The name has been adopted in this report because there are very similar land-forms and soils on the northern plains south of Horsham. Some workers may prefer to call these soils undifferentiated sands. Northcote (1960a) has placed them in his Class Uc 1.2 that is, non-calcareous, uniformly coarse-textured soils showing little if any pedologic organisation

(5) Solodic Soils

The solodic soils and also the solonetzic soils of Group (6) are recognized by the sharp change of texture in the upper part of their profiles, that is, the A horizon has medium to coarse textures (loam to sand) and there is a sudden change over one or two inches to a subsoil of clay or heavy clay.

The A horizon in the solodic soils is generally a fine sand loam although loams, coarse sandy loams and gravelly sandy loams do occur. The surface layer is darkened by organic matter to dark shades of brown and grey but the greater part of the A horizon, between the surface layer and the clay subsoil, is off-white or very light grey. Often there is a thin layer above the clay made of a mixture of bleached soil and small stones of iron oxide called buckshot. These two features develop as a result of a perched water table that lies on top of the clay during wet periods of the year.

The depth of the A horizon is usually between nine inches and sixteen inches but depths ranging from five inches to thirty inches have been recorded. The clay is tough and hard to penetrate. When wet it becomes relatively impermeable to water and when dry it cracks and breaks up partly into smaller aggregates. In most parts of the survey area the surface of the clay is plane, that is, flat and parallel to the ground. Solodic soils do not have secondary chemicals such as free lime (calcium carbonate) and gypsum (calcium sulphate) in their profiles.

These soils are acid throughout their profiles with pH values in the A horizon between 5.0 and 6.0 and in the clay subsoil generally between 6.0 and 6.9. They have fewer deficiencies of pasture nutrients than the podzols and in many areas only phosphorus and nitrogen need to be supplemented. Molybdenum is also in short supply where solodic soils have formed on granitic rocks and Ordovician sedimentary rocks, and the possibility of a potassium deficiency on granitic rocks should not be overlooked where the A horizons are very deep and gritty.

Plate 8 – A cutting through a sand dune has exposed this profile of a podzolic deep sand.

Plate 9 – A solodic soil.

On the right the profile is freshly exposed and the sharp change from the A horizon to the clay of the B horizon is indicated by sudden darkening at the 10 inch mark. On the left is an undisturbed, weathered profile. The hard sandy loam in the A horizon projects beyond the cracked and erodible clay.

(6) Solonetzic Soils

Solonetzic soils have some features in common with solodic soils, the most important one being a subsoil of heavy clay sharply differentiated from the upper horizons of much sandier material. Also, the levels of pasture nutrients are of the same order.

The solonetzic soils within the survey area are separated from the solodic soils by the following features. First, the A horizon generally has coarser textures (sands and loamy sands), although fine sandy loams in the surface horizon do occur. Second, the surface of the clay subsoil is irregular to domed (or columnar) rather than plane. Third, soft deposits of free lime are commonly but not necessarily present in the deeper layers of the subsoil. Fourth, the solonetzic soils are much less acid than the solodic soils pH values in the A horizon are between 6.0 and 6.5 and they rise to neutral and alkaline values in the clay subsoil.

There are three sub-groups of which two are separated on the basis of colour and the third on its gilgai morphology. ***Red solonetzic soils*** have red and reddish brown clay subsoils and ***brown solonetzic soils*** have brown and yellowish brown mottled clays in the subsoil. ***Gilgaied solonetzic soils*** take their name from the solonetzic soil in the shelf whilst the puff is a calcareous grey clay described within Group (9). In this report, gilgaied soils are named after the soil group in which the soil in the shelf has been placed.

Of the three sub-groups, the brown solonetzic soils are most common in the survey. They are separated into two *series,* Warratong and Darracourt series, based on the depths and textures of the A horizon. Warratong series is found in sand sheets on the northern plains in association with podzolic deep sands in sand dunes. The texture of the A horizon is sand, and the depth to the clay subsoil is quite variable, extremes of five inches and three feet have been recorded. Darracourt series has fine sandy loams in the surface horizon and loamy sands in the sub-surface horizon and the depth to the clay is within a much narrower range, three inches to ten inches, although depths up to fifteen inches have been recorded.

Plate 10 – The surface of the clay subsoil in many solonetzic soils is shaped into domes, a feature that helps to distinguish these soils from solodic soils.
The tops of three domes (or columns) are clearly exposed in this example.

(7) Red-Brown Earth

The red-brown earths in the survey have a superficial resemblance to red solodic and red solonetzic soils in colour and in the subsoil of heavy clay. However, they can be distinguished from these soils if the following features are considered together.

The texture of the surface soil is either a loam or clay loam, seldom a sandy loam, and the texture of the sub-surface is also a foam or clay loam. Typically, the texture changes from a loam at the surface to a clay loam in the sub-surface soil. There is little or no bleaching above the clay subsoil, rather is the soil a light reddish brown. The clay in the subsoil is strongly red or brownish red and it has a better structure and is more friable than the clay in the solodic and solonetzic soils. Lime is found in the deeper layers and the pH values range from slightly acid in the A horizon (6.5 to 6.9) to strongly alkaline in the deep subsoil (8.5 to 9.5).

(8) Acidic Brown Clay

These soils are poorly structured gilgaied brown clays with acid to neutral profiles and without lime. They are similar to the brown soils of heavy texture described by Stephens (1962) in colour, texture and structure but require separation because of their acidity and lack of lime.

The shelf is a structureless dark brown or dark brownish grey clay except in the upper few inches where there is a weakly structured clay loam. The puff has no surface of clay loam, it has a better structure because of vertical cracks and it has stronger brown colours. Both shelf and puff are acid at the surface (pH 6.0 to 6.5) and they either remain acidic throughout their profiles or become neutral in the subsoil. Phosphorus and nitrogen are in very low amounts although the other plant nutrients are adequate for the needs of pastures.

(9) Brown Soil of Heavy Texture

Brown soils of heavy texture are gilgaied calcareous clays that take their name from the soil in the shelf of the gilgai complex. The shelf is not a depression between puffs, as it is in many gilgaied soils, but rather the level ground surface above which the puffs protrude.

In the top two or three inches of the shelf profile there is a hard and poorly structured greyish brown clay loam. Below this horizon, the soil changes to a hard, greyish brown clay with widely spaced cracks. In the deep subsoil the cracks disappear and there are scattered deposits of free lime. The surface has neutral pH values and the soil gradually becomes more and more alkaline with depth until in the layers with lime, the pH is 9.0 and higher. The shelf is well supplied with all pasture nutrients except phosphorus and nitrogen.

The soil in the puff is a light grey or light brown clay with abundant free lime in the form of small nodules and powder. When the puff is dry it is loose, well structured and friable, and the surface soil self-mulches to form very small aggregates whilst the sub-surface has many vertical and transverse cracks. The deep subsoil remains slightly moist and does not crack. The profile is very alkaline throughout and the only plant nutrients in short supply are phosphorus and nitrogen.

(10) Grey Soil of Heavy Texture

Grey soils of heavy texture are calcareous clays and they have been classified into gilgaied and non-gilgaied sub-groups of which the former is of greater importance.

The gilgaied grey soils of heavy texture also have been called Wimmera black soils, chernozem-like soils and black earths. The shelf is a dark grey or dark greyish brown clay that is friable and well structured in the top two inches but harder and more massive underneath. The subsoil remains slightly moist and shows no cracking. Free lime is absent from the upper horizons but is present in the subsoil. The puff is very similar to the shelf in its colour and texture and only differs in having much more free lime, more intensive cracking, a better structure and greater friability. The surface horizon self-mulches to a limited extent and this property is aided by cultivation. Pasture nutrients in these soils are in adequate supply except phosphorus and nitrogen. The shelf is neutral or slightly alkaline at the surface and becomes strongly alkaline in the subsoil whilst the puff is strongly alkaline throughout the profile.

Both the gilgaied grey soils of heavy texture and the brown soils of heavy texture are gilgaied calcareous clays. A comparison of their properties will help to clarify the differences between them and to assist in identifying and separating them in the field.

In the brown soils of heavy texture (Group 9), the shelf forms the level ground surface and its soil is a hard and poorly structured greyish brown clay except in the top two or three inches where the texture is clay loam. By contrast, the shelf in the gilgaied grey soils of heavy texture is a definite depression between puffs and its soil is a dark grey or dark greyish brown clay in all horizons with a better structure and greater friability, particularly in the surface horizon. It is much easier to plough and cultivate. The soils have similar analytical features.

The puffs of both groups are alike in a number of properties such as their analytical features, textural and structural profiles and the amount of free lime.

However the puffs of Group (9) are light grey or light brown rather than dark grey or dark greyish brown, they self-mulch to a greater degree and they are smaller.

Non-gilgaied soils in Group (10) form the second sub-group. They are grey clays with a very poor structure or none at all. They are neutral or slightly acid at the surface and alkaline in the subsoil where there are very small quantities of free lime.

Plate 13 – A close-up of the shelf of a gilgaied grey soil of heavy texture.
It has a moderate structure of subangular blocky units, an important difference from the shelf soil in Plate 11.

Plate 14 – A puff in a gilgaied soil of heavy texture.

(11) Meadow Soil

Meadow soils are black or very dark grey clays with a characteristic gley horizon in the subsoil. Gleying is evidence of a seasonal water table in the profile and it is recognized by mottled colours of orange, brown, grey and blue that provide a striking contrast to the very dark colours of the upper horizons. The meadow soils have a poor structure and they are slightly acid to neutral in the upper horizons. Some of them are alkaline in the subsoil where they have very small amounts of lime and others remain acid or neutral.

Distribution of the Soil Groups

The land-system map attached to this report gives some idea of the distribution of the soil groups. The legend to the map lists the land-systems and their environmental features, including the dominant soil groups.

The lithosols are found mainly on the sandstones of the Grampians Ranges land-system and also in the Dunkeld land-system on stony rises of the basaltic plain. The podzols of Groups (2) and (3) have developed in deep deposits of sand mapped as the Grampians Plains, Moora Valley and Kowree land-systems and also in sandy lunettes in Parrie Yalloak land-system. Podzolic deep sands (Group 4) are found mainly in sand dunes in Warratong land-system, and also in lunettes in Telangatuk land-system. The solodic soils of Group (5) are the most widespread group of soils in the survey. They occur on a variety of parent materials on unconsolidated sediments in Mt. William Creek and Parrie Yalloak land-systems, on the basaltic plains of Dunkeld and Willaura land systems, on lateritized materials in Dundas and Brimpaen land-systems, and on sedimentary and granitic rocks in Ararat, Mirranatwa, and Mt. Dryden land systems. Solonetzic soils (Group 6) are widely distributed on flat and gently undulating land in the Telangatuk, Ullswater, Mt. William Creek, Parrie Yalloak, Warratong, Moora Valley, Brimpaen and Darracourt land-systems. Groups (7), (9) and (10a) (red-brown earths and gilgaied brown and grey clays) are confined to the northern depositional plains in Horsham and East Wonwondah land-systems. The acidic brown clays of Group (8) are predominant in the Karabeal land-unit of the Dunkeld land-system and they are also found in localised wet sites in certain areas of Darracourt land-system. Non-gilgaied grey clays (Group 10b) and meadow soils (Group 11) are restricted to the margins of swamps that occur particularly in Willaura, Parrie Yalloak and Telangatuk land-systems.

Physical and Chemical Analyses

A comprehensive range of analyses was performed on the soils and the results are listed under each profile in Appendix 1B. Also, the analytical techniques used in the laboratory are briefly described in Appendix 1B. Brief references have been made in the previous section to some of the analytical features of each of the soil groups. In this section, some of the more important analytical features will be discussed in turn and their variation between soil groups emphasised. To assist this comparison, ten of the eleven soil groups have been placed into three categories on the basis of their similar texture profiles and it is the categories that are compared with each other here.

Category A comprises those groups with profiles of sand, that is, the nomopodzols, leptopodzols and podzolic deep sands.

Category B comprises those groups with coarse to medium textured A horizons abruptly overlying a clay B horizon, that is, the solodic soils, solonetzic soils and red-brown earths.

Category C is made up of those groups with clay profiles except for a thin horizon of clay loam at the surface, that is, the acidic brown clays, brown soils and grey soils of heavy texture, and meadow soils.

The categories bring together those soil groups with similar texture profiles, and this step facilitates a ready assessment of the value of the soil groups for primary production. Such an assessment is based on the physical and chemical properties of the three broad classes of soil texture :-sands, loams and clays. These aspects receive attention in the next section.

Particle Size Analysis

The particle size analyses can be used to illustrate the texture profiles of the three categories. This has been done in Figure 9 where the percentage clay in four representative profiles has been plotted against the depths of the profiles.

The sands of Category A contrast with the clays of Category C and the abrupt change of texture from A to B horizons in the soils of Category B is also clearly shown.

A common feature of solodic and solonetzic soils is the concentration of clay at the top of the B horizon and its decrease in amount with depth in the B, horizon. The graph also shows the difference in texture of the A horizon between a solodic soil (fine sandy loam) and a soil of the Warratong series of solonetzic soils (sand).

Reaction (pH)

The reaction trends within the profiles of the soil groups have been discussed in the previous section, and here in Figure 10 a diagram gives useful comparisons within and between the three categories. A general shift from acidic to alkaline profiles is evident with an increasing amount of clay. However, overlapping does occur, for example, the podzolic deep sand is less acid than the solodic soil (a few solodic soils analysed were of equal acidity to the podzolic deep sand), and the acidic brown clay is more acid than the red-brown earth.

Cation Exchange Capacity and Exchangeable Potassium

The cation exchange capacity of a soil is a measure of the ability of the soil to hold plant nutrients in their exchangeable forms, which plants can use. The sources of cation exchange are the clay minerals and organic matter, and its level of activity depends on the amount and types of these two soil constituents. In soils of Category A (the sands), the cation exchange capacity is higher in the surface horizon than elsewhere in the profile because of the accumulation of organic matter from the decomposition of plant litter. In soils of Category B, the values for the cation exchange capacity are higher in the A_1, horizon than in the A_2, horizon, again because of an accumulation of organic matter, and then they rise to their highest levels in the B horizon because of the high amounts of clay. In soils of Category C, the clays, the cation exchange capacity is high throughout the profile, sometimes rising in the subsoil as the percentage of clay rises. Figure 11 illustrates these features and also compares the cation exchange capacities of the three categories. The sands have very low* values, the clays have moderate to high values and the soils with a sharp contrast of texture in their profiles have low values in the A horizon and moderate values in the B horizon. The very high values in the subsoils of Groups (9) and (10) (calcareous clays) are a reflection of the high levels of exchangeable calcium.

Exchangeable potassium is a useful guide to the fertility of a soil, particularly its ability to support an introduced pasture. Figure 12 illustrates the levels of exchangeable potassium in the surface soils and subsoils of the three categories.

In the surface soils, the sands of Category A have very low values for exchangeable potassium which are well below 0.2 m.e. per cent. This value is critical for the vigorous growth of introduced pastures. As the texture of the surface soil becomes more clayey so the levels of the nutrient increase. The medium textured soils of Category B have levels of exchangeable potassium equal to or up to twice the critical level, whilst the clays of Category C have even higher amounts. The two comparatively low surface values for the clays belong to acidic brown clays and the remaining surface values of the category belong to the calcareous clays of Groups (9) and (10a).

In the subsoils, the values of exchangeable potassium in the sands are even lower than those at the surface. The values in the clay subsoils of Category B are variable but generally they are higher than the values at the surface. In the subsoil clays of Category C, the levels of exchangeable potassium vary considerably and this is related to the soil groups within the category. The cluster of three low values at or near 40 per cent clay belong to the acidic brown clays whilst the two very high subsoil values belong to soils of Group (10a) (the gilgaied self-mulching clays within the wheat belt). The two subsoil values occupying an intermediate position within the category belong to clays of Group (9).

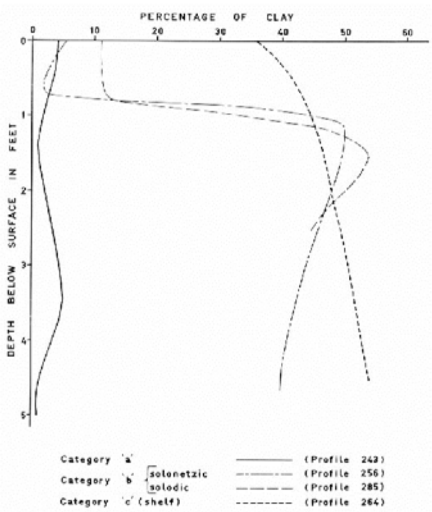

Figure 9 – Changes in the amount of clay with depth for the soil categories.

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* See Table 7 for common values of some analytical features

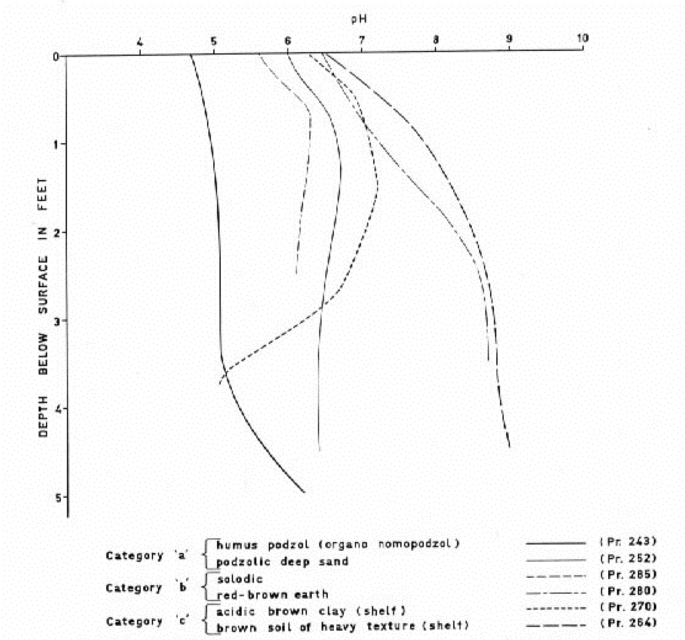

Figure 10 – Changes in pH with depth for soil categories and soil groups

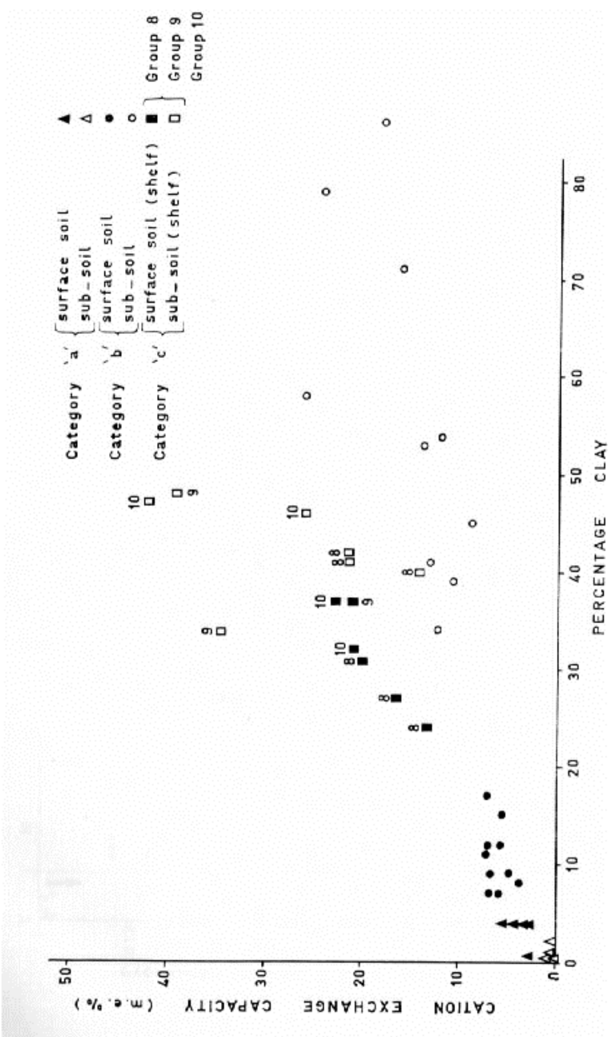

Figure 11 – Cation exchange capacity and percentage of clay for soil categories and soil groups.

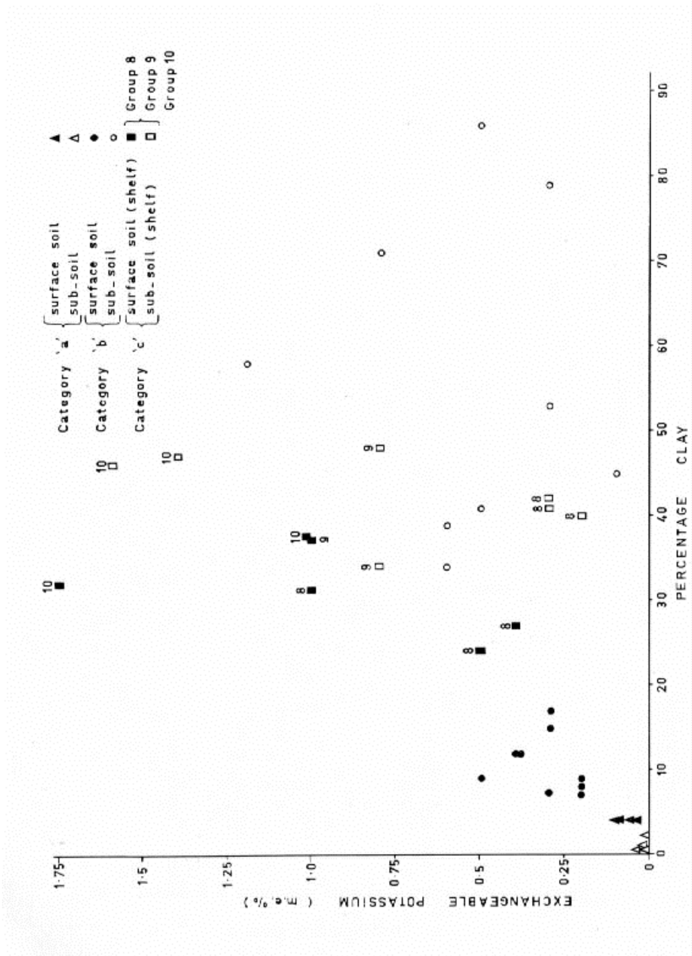

Figure 12 – Exchangeable potassium and percentage of clay for soil categories and soil groups

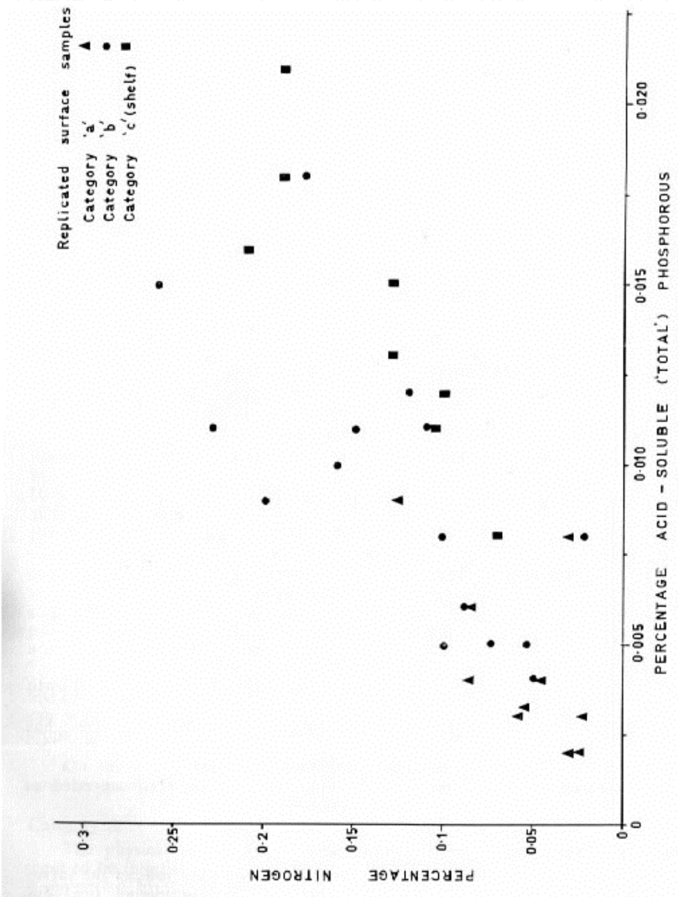

Figure 13 – Levels of nitrogen and phosphorus in the soil categories

Phosphorus and Nitrogen

The analyses of surface samples for acid-soluble phosphorus and total nitrogen show that the soils of the survey, like the great majority of soils in Australia, are poorly supplied with these two plant nutrients. Values for phosphorus rarely exceed 0.015 per cent and for nitrogen 0.2 per cent (Figure 13). Considerable overlapping occurs between the three categories. The sands of Category A mostly have the lowest values, whereas the soils of medium texture in Category B and the clays of Category C extend over the same broad range of values.

Table 7 - Common surface values for some soil analytical features

C/N ratio	Common range for Victorian soils is 10 to 13 (Leeper 1964) and for N.Z. soils 10 to 15 (Metson 1956).
Available phosphorus	A common figure for Victorian soils is 10 p.p.m. (Leeper 1964).
Acid-soluble phosphorus	Common range for Victorian soils is 0.02 to 0.03 per cent (Leeper 1964). An average for Australia has been calculated as 0.03 per cent (0.07 per cent P.0., Wild 1958).
Cation exchange capacity.	N.Z. figures give a medium range of 12 to 25 m.e. per cent (Metson 1956).
Base saturation	N.Z. figures give a medium range of 40 to 60 per cent (Metson 1956).
	Critical surface values related to pasture growth.
Chloride	0.1 per cent adversely affects pasture growth (Cope 1958).
Exchangeable potassium	Potassium deficiency in introduced pastures has been associated with a content of 0.2 m.e. per cent or less (Blackburn 1959b).
Exchangeable calcium	Less than 5.0 m.e. per cent has been suggested as a low figure (Leeper 1964).

Soils of the Area and Land-Use

This section shows the relationship between the data on the soils of the survey and the use of the soils for primary production. In considering this, due emphasis must also be given to the other features of the environment that affect land-use, namely, climate and topography, particularly as they influence the water-holding properties of sands, loams and clays.

The growth of plants depends primarily upon the following five factors the amount of light received, a range of suitable temperatures, and the availability of air, of water and of plant nutrients. The availability of air and water is determined by the physical properties of soil in conjunction with climate and topography, and the availability of plant nutrients is determined by the chemical properties of soil such as the amount and types of clay minerals and organic matter and the degree of alkalinity and acidity.

The important physical properties of the soil are the texture and structure of each horizon because these affect the infiltration of water and air, the water storage capacity of the soil, and the strength of the forces holding the water in the soil pores (which determines how readily plants can take up the water). These features are well illustrated by comparing the behaviour of sandy soils and clayey soils under a range of climates.

Sands are loose and very permeable thus allowing water to move down the profile quickly. Also, they have low contents of water at wilting point and field capacity* and a low storage capacity for available water. Because of this, sands can yield water to plants at low contents of water but the reserves are very limited. By contrast, clays have much higher contents of water at wilting point and field capacity and a higher moisture storage capacity. Clays, therefore, require higher contents of water before the water is available to plants but the reserves are much greater than in sands. The significance of these differences between sands and clays depends largely on the amount of rain received. In areas of low rainfall, crops and pastures in sandy soils can make use of light falls of rain because the moisture content is quickly raised above the wilting point, whereas the same falls of rain cannot be used by plants in clay soils because the moisture content may still be below the wilting point. In areas of moderate to high rainfall, where the constant replenishment of water keeps the supply above the high wilting point, clays are most useful.

Texture and structure can further exert an influence on the amount and availability of soil water through an impeding horizon of poorly structured clay or coffee-rock hardpan. Such a layer influences the position and movement of water within the soil and its importance in any area is determined largely by the climate and topography. Thus in poorly drained areas such a layer often causes waterlogging during the wet season whereas on freely drained sites under the

* Field capacity is the moisture content after excess water has drained away. Wilting point is the moisture content at which plants wilt. The difference is the amount of available water. Each of these values is much lower in sands than in clays.

same rainfall, and also in areas of lower rainfall, it holds up water to the roots of pasture plants so prolonging their growing season into early summer. These aspects are considered again more fully later in this section.

Within the area of survey, the nutrient status of the soil is also related to texture. The clays have greater chemical reserves than the sands and therefore can withstand for much longer periods the constant withdrawal of nutrients by crops and pastures. This results in simpler fertilizer treatments.

On the basis of these relationships, the three categories of soil groups can now be considered in terms of their land-use potential.

Category A

The physical and chemical data concerning the soils of Category A show them to be infertile soils with a low potential for development and this assessment is supported by the experience of farmers and agronomists.

The nomopodzols are highly acid and have insufficient supplies of those nutrients required by pasture species. Agronomic experiments on these soils, both within and outside the survey area, have indicated that deficiencies of phosphorus, nitrogen, potassium, copper and zinc have to be rectified, and the high acidity reduced with lime, before vigorous introduced pastures can be established (Drake and Kehoe 1954, 1963 Newman 1956, 1959 Newman and Makeham 1960 Gibbons and Downes 1964). The leptopodzols and podzolic deep sands are similar to the nomopodzols except that they are less acid and generally do not require lime.

Once the nutrient deficiencies of these soils are overcome by the addition of the necessary fertilizers, the limiting factor to their successful and economic use is their low capacity to store water. Most areas of podzols and podzolic deep sands within the survey area receive on the average less than 30 inches of rain each year and many of the sites are in areas of less than 20 inches. Water reserves are depleted if rain falls at long intervals so that the soil rapidly dries out as the falls of rain become less frequent in late spring and early summer. Even the deep subsoil may become dry. Thus a major problem to overcome is the difficulty of maintaining plant life during the long period of moisture stress, and this applies particularly to the establishment of seedlings in the top few inches of the soil.

Most attempts at land development on these soils have used shallow-rooted annuals and perennials. More success is likely if deep-rooted perennials such as lucerne and perennial veldt grass are used because they have more chance of tapping any reserves of water that may be in the deep subsoil.

The suitability of these soils for plantations of pine trees *(Pinus radiata)* requires some consideration.

There is only one mature plantation within the survey area growing in these soils. Its growth supports the general Victorian experience that deep, white, acidic sands (that is, the nomopodzols and podzolic deep sands) are either unsuitable sites or marginal sites for profitable pine plantations because of their infertility. Research indicates that deficiencies of phosphorus, nitrogen and zinc in these soils must be overcome before a satisfactory growth rate can be achieved. At Longford in East Gippsland, Hall (1961) found that *Pinus radiata* seedlings gave significant field and pot responses to phosphorus and nitrogen and also pot responses to copper. The same problem occurs in similar soils in the lower south-east of South Australia. Thomas (1957) considered that a nitrogenous fertilizer had to be added with superphosphate to overcome the poor response to superphosphate alone shown by *Pinus radiata.* Even with these treatments, plantations established in nomopodzols cost more money, require longer rotations and yield less timber than plantations of the same age in more fertile soils.

Leptopodzols are more fertile than nomopodzols as indicated by the chemical analyses and by the darker and stronger colours in the sub-surface horizons. Successful commercial plantations have been established for some years in these soils at Dartmoor in south-western Victoria and at Longford.

The deep sandy profile of the podzols satisfies the need of pines for a well-drained soil. The low water-holding capacity of these soils is no problem in areas where the rainfall is both high (above 28 inches) and evenly distributed throughout the year because the soil is regularly replenished with water. However, where the rainfall is considerably lower and a dry summer is a feature of the climate, the low water-holding capacity is a serious handicap and the podzols are of doubtful value irrespective of their fertility status because of the water stress placed on the pines.

Category B

The land-use features of this category include some of the advantages and disadvantages of both Categories A and C.

Solodic, solonetzic, and red-brown earth soils have greater supplies of plant nutrients than the podzols and podzolic deep sands but generally lower supplies than the clay soils of Category C. Phosphorus and nitrogen are deficient in all soils of Category B. Molybdenum is deficient in many areas of solodic soils that have developed on granitic rocks and Ordovician sedimentary rocks. A potassium deficiency often exists in the deeper A horizons of the granitic solodic soils and the Warratong series of solonetzic soils. Lime is necessary on the more acid soils of this category (Newman 1955, quotes a surface pH of less than 5.5). The close proximity of the clay subsoil to the plant roots raises the overall nutrient status of these soils by supplementing the supplies in the A horizon.

In the areas of medium and low rainfall, these soils have a more favourable water status for pasture growth than either of the other categories, because they have medium to coarse textures in the A horizon and clay subsoils that are neither too close to ground level nor too far below it. That is, pastures can make use of light falls of rain, the clay holds up water to the roots and cultivation is easy. For these reasons the solonetzic soils oil the northern plains are more suitable for pasture improvement than the neighbouring podzols and grey and brown soils of heavy texture.

In the areas of higher rainfall, solodic soils are the only examples of this category to be found and they, too, are suitable for pasture improvement. However, two of their main problems on flat land are waterlogging and salting, both resulting in part from accessions of drainage waters and the proximity of the impermeable clay to the ground surface. Conversely, the wetness of the flat land becomes an advantage as the dry season approaches because the pastures are able to grow for a longer period than on higher land and perennial species rather than annual species become a proposition. By contrast, the slopes of the undulating and rolling plains are comparatively dry sites because water readily drains away and the shallow A horizons dry out much sooner on these areas than on the flats below.

There are no plantations of *P. radiata* in the soils of this category within the area of the survey. However, published reports of investigations in Victoria and South Australia indicate that the main causes of pine failure in these soils are a result of the firm, impermeable clay subsoil close to the ground surface. In poorly-drained areas, failure results from waterlogging in the winter (Poutsma and Simpfendorfer 1962), and in hilly areas, failure results from soil dryness in the summer (Boomsma 1949). The much greater amounts of plant nutrients in these soils, compared with the soils of Category A. has tended to divert attention from the possibility of nutrient deficiencies being a cause of pine failure. However, experiments in the Adelaide Hills of South Australia have shown that pines growing in lateritic, red, and yellow podzolic soils respond noticeably to additions of superphosphate (Thomas 1957, Lewis and Harding 1963).

Category C

Most of the clays in this category are neutral to alkaline and well supplied with plant nutrients. Phosphorus and nitrogen are the only deficiencies and these are readily overcome by the use of superphosphate and a leguminous pasture.

The physical features of these soils vary among the groups. The clays of Groups 8, 9 and 11 (that is, the shelf soils) are poorly structured and this is their chief obstacle to easy utilization. On drying out in summer they become very hard and structureless and develop a coarse cracking pattern as they shrink. In winter they swell and have a low permeability to water and so they become waterlogged. Cultivation is therefore difficult and can be attempted only when the soil is at the right degree of wetness.

By contrast, the gilgaied grey soils of heavy texture (Group 10a) have a better structure and a softer consistence, particularly as they dry out in summer, and they are readily cultivated for wheat growing. Their ability to self-mulch has been aided by the spread of the puff material over the paddocks as the gilgais were levelled to make cultivation easier.

All soils in this category have a disadvantage common to clay soils, that is, they require a high content of water to be above wilting point. This is of less concern in the higher rainfall areas than in the drier parts of the survey where pastures on these soils cannot readily make use of light showers of rain during the summer and autumn.

6. NATIVE VEGETATION

Classification of the Vegetation

This study of the vegetation is not regarded as an end in itself but is related to the soil and land-use aspects of the survey. The interactions of climate, topography and soil affect the potential, hazards and problems of land-use, and over limited areas, these interactions are consistent. Consequently, because native vegetation is an expression of these interactions, it can be used over such limited areas to indicate the potential of land for development.

An attempt was made to assess the form, composition and distribution of the native vegetation as it was before white men disturbed it. It was not always possible to do this because in some places clearing and fires have radically altered the original vegetation. On the plains, the usual approach was to observe the plant communities surviving in road reserves between the paddocks, particularly those reserves where no road has ever been made. These plant communities are, in many places, the best available indicators of the form and composition of the original vegetation. In the pastoral areas, both standing timber and stumps in the paddocks also give an indication of the density of the vegetation at settlement. In the wheat-growing areas, almost all the timber has been removed to make way for cereal crops. The Reserved Forests and unoccupied Crown lands in and around the mountains have communities that have been least affected by man, although forestry operations and bush fires have caused some alteration.

The system of vegetation classification of plant communities proposed by Beadle and Costin (1952) has been used in this work with the addition of two sub-formations not described by these authors.

Beadle and Costin make use of two concepts to classify plant communities, those of floristics and structure. The floristics of a plant community refers to the species present, and the chief unit of classification is the association. The association is a natural grouping of species, qualitatively consistent, and usually takes its name from the dominant species in the tallest layer. Where a lower layer is equally important, a combination of names from both layers is used in naming the association.

The associations recorded in the survey are omitted in this chapter because their large number does not allow a ready handling of the information. However, they are presented in the full table of classification in Appendix IIB. The purpose of this chapter is achieved by bulking the associations into larger and fewer floristic units called alliances.

The alliance is a group of floristically-related associations of similar structure. It takes its name from the dominant species of its component associations. The alliance is a "synthetic" floristic unit, that is, a convenient bulking of related associations for a particular purpose, which, in this survey, was to correlate the native vegetation with soils and land-use.

The structure of a plant community refers to the form and shape of the species and their spatial arrangement relative to each other. Formation and sub-formation are the two units of structural classification used here. Examples of the formation are grassland, heath, woodland and sclerophyll forest. Examples of the sub-formation are savannah woodland, tall woodland, dry sclerophyll forest and wet sclerophyll forest.

Table 8 summarises the classification by indicating the formations, sub-formations and alliances. The following pages describe the sub-formations and alliances, and the common names of the species are used, with the scientific names in parentheses. Appendix IIA gives the scientific names and their authorities as well as the common names.

Grassland

In some areas, for example, north-east of Glenthompson and west of Maroona, man-made grasslands have been created by the almost total removal of the trees. However, in this classification, only those grasslands believed to have been developed under the natural environments are considered. Such grasslands are restricted to two areas, around Willaura and between Dunkeld and Cavendish, both of which are part of the basalt plain.

The dominant species are wallaby grasses *(Danthonia spp.)* and spear grasses *(Stipa spp.)* and these form the only alliance recognized.

Heath

Heaths are found mainly in and around the Grampians on the dip slopes of the ranges, in the valleys between the ranges and on the lowermost outwash slopes adjacent to the plains. There are also small areas of heath in the north-western parishes. The average height of this sub-formation is between two and three feet but some examples are stunted (less than twelve inches high).

Plate 15 – In this harsh environment, with the upper dip slope of Mt William in the foreground, there is only a dry heath community with some stunted eucalypts

Three alliances are recognized. The first is the prickly tea-tree-silver banksia *(Leptospermum juniperinum-Banksia marginata)* alliance that is found in sites too wet for trees. A number of other species present in the alliance is listed in Appendix IIA. The second alliance is the desert banksia *(B. ornata)* alliance and it is found in the north-western parishes on undulating deposits of deep sand. The third alliance is the shiny tea-tree-Grampians fringe-myrtle *(Leptospermum nitidum-Calytrix sullivanii)* alliance. It occurs on some of the dip slopes in the ranges of the Grampians where the soil is too shallow and dry for tree growth.

Table 8 – Abridged classification of native vegetation

Structure		**Floristics** (See text and Appendix IIA for scientific names)
Formation	**Sub-Formation**	**Alliance**
Grassland	Grassland	Wallaby grasses – spear grasses – brome grasses
Heath	Heath	Prickly tea-tree – silver banksia Desert banksia Shiny tea-tree – Grampians fringe-myrtle
Scrub	Wet	Cross-leaf honey-myrtle
	Dry	Grampians gum – long leaf box
Mallee	Dry	Blue mallee - broombush
Woodland	Heath	Brown stringybark - desert banksia Yellow gum – apple box Manna gum – bracken Long leaf box
	Short	Long leaf box – red stringybark
	Savannah	Red gum – yellow box – apple box Buloke Black box
	Tall	Grey box – buloke Yellow box – yellow gum – grey box Red gum
Sclerophyll Forest	Dry	Brown stringybark – messmate – long leaf box Messmate –apple box Swamp gum
	Wet	Mountain grey gum - messmate

Wet Scrub

This sub formation is restricted to the edges of streams that flow out of the Grampians, particularly the headwaters of the Wannon and Glenelg Rivers. The scrub is ten to twelve feet high and commonly comprises the one species, cross-leaf honey-myrtle *(Melaleuca decussata.)*

Dry Scrub

Dry scrubs occur in sites within the ranges that are similar to the sites of the shiny tea-tree-Grampians fringe-myrtle (heath) alliance, but the presence of stunted eucalypts places the community within the scrub formation. The eucalypts are Grampians gum *(Eucalyptus alpina),* long leaf box *(E. goniocalyx,* formerly *E. elaeophora)* and brown stringybark *(E. baxteri)* and the alliance is named the Grampians gum-long leaf box alliance.

Dry Mallee

A small area of mallee vegetation occurs in undulating country south-west of Horsham. The species are also found in the Mallee and marginal Mallee areas in north-western Victoria. They are peppermint box *(E. porosa),* blue mallee *(E. fruticetorum)* and Kamarooka mallee *(E. froggattii)* Broombush *(Melaleuca uncinata)* forms a conspicuous understorey. The community has been called the blue mallee-broombush alliance.

Plate 16 – A dry scrub of Grampians gum and heath species growing on a dip slope in the Grampians

Heath Woodland

This sub-formation is not found in Beadle and Costin's classification. It consists of a woodland of trees, either loosely interlacing or separate, underneath which is a dense and continuous heath ground layer. Five alliances are recorded.

The most extensive alliance is the brown stringybark-messmate *(E. obliqua)* apple box *(E. aromaphloia)* alliance which is found on the outwash slopes surrounding the Grampians ranges and the western Black Range and also in the valleys within the mountains. The important eucalypts are brown stringybark, messmate and apple box, with peppermint *(E. vitrea)* of lesser importance. The species present in the heath understorey are the same as those mentioned within the prickly tea-tree-silver banksia (heath) alliance and are listed in Appendix IIA.

The brown stringybark-desert banksia alliance occurs in the north-western parishes and is intermingled with the desert banksia (heath) alliance. Desert banksia is the dominant shrub in the understorey. The reason for the presence of trees of brown stringybark in some areas of deep sand and not in other areas is not known. The soils and land-forms are the same in each case.

In small scattered areas over the plains south of Horsham is another heath woodland community dominated by yellow gum *(E. leucoxylon),* with yellow box *(E. melliodora)* a sub-dominant. Near Quantong, apple box replaces yellow gum as the main species. The heath understorey has not the wealth of species found in the heath woodlands of the Grampians. The common members are silver banksia, a number of tea-tree species, daphne heath *(Brachyloma daphnoides),* twiggy guinea flower *(Hibbertia virgata),* cypress pine *(Callitris preissii)* and black rapier sedge *(Lepidosperma carphoides).* This community is named the yellow gum-apple box alliance.

A heath woodland community of very restricted but characteristic occurrence is manna gum (E. *viminalis)* and bracken *(Pteridium esculentum)* which grows on sandy lunettes in the south and south-east of the survey. The names of these two species are given to the alliance.

The fifth community included within the heath woodlands is the long leaf box alliance which is found only in the Illawarra and Ledcourt districts west of Stawell. The common members of the heath layer are flame heath *(Astroloma conostephioides), woolly* tea-tree *(Leptospermum lanigerum),* and daphne heath.

Plate 17 – The dry mallee sub-formation clearly showing the understorey of broombush.

Short Woodland

The short woodland does not appear in Beadle and Costin's scheme. It has been recognized to accommodate those woodlands in which the trees are loosely interlacing or slightly discontinuous, are short (20 to 30 feet in height) and ill which the depth of the crown greatly exceeds the length of the bole.

This sub-formation is found in the eastern parts of the survey on the upper slopes of rolling and hilly country, and the dominant eucalypts are long leaf box and red stringybark (E. *macrorrhyncha)* with yellow gum and yellow box as minor species. The alliance has been named after the two dominant eucalypts.

Plate 18 – An example of a heath woodland sub-formation with its well-developed heath layer. The eucalypts are long leaf box and yellow gum.

Savannah Woodland

Savannah woodlands are widespread throughout the central and southern plains, and the various communities are dominated by red gum (E. *camaldulensis).* In a number of areas it is the only eucalypt. Yellow box and sheoke (Casuarina stricta) are of secondary importance and the minor eucalypts are apple box, swamp gum *(E.* ovata) and yellow gum. The native pastures forming the ground layer are composed mainly of wallaby and spear grasses. Red gum-yellow box-apple box alliance is the name given to this group of communities.

In the most northerly areas of the survey, remnants of buloke (Casuarina *luehmanni) savannah* woodlands remain after their almost total clearance for wheat farms. Buloke is the only tree and the alliance has been named after it. In the same area there are a few small stands of black box *(E.* largiflorens) that have remained uncleared and the third alliance in this sub-formation has been named after this species.

Shrub Woodland

The shrub woodlands occupy a transitional position between the heath woodlands and dry sclerophyll forests of the Grampians and the tall woodlands and savannah woodlands of the plains. Generally yellow box and yellow gum are the main eucalypts and manna gum and red gum are associated species. However, in the Moora Valley within the Grampians, red gum is dominant and yellow box is of secondary importance.

Common members of the sub-dominant shrub layer are black wattle (*Acacia mollissima*), blackwood (*Acacia melanoxylon*) and silver banksia. These shrubs are tall (15 to 25 feet) and are regarded as a sub-dominant layer of small trees. The alliance has been named the yellow-box-black wattle alliance.

Tall Woodland

This sub-formation occurs widely over the central and northern plains and three alliances have been recognized.

The grey box (E. hemiphloia)-buloke alliance is widespread in the areas of gilgaied brown and grey clays. Grey box and buloke form the main association. in the alliance and black box is present also in the far north-western parishes. The yellow box-yellow gum-grey box alliance is restricted to sandy soils and these three eucalypts occur in a number of combinations with each other to form different associations. The red gum alliance occurs within the same general area as the other two alliances but it is confined to wet situations such as creek banks and swamp margins. Within the communities of this alliance, red gum is often the only species although yellow box, yellow gum and grey box are also present in some places.

Dry Sclerophyll Forest

The dry sclerophyll forests occur mostly over the ranges of the Grampians and western Black Range and extend down onto the outwash slopes below the ranges where they intermingle with the heath woodlands. They grow in a wide range of habitats and hence their form and height varies. They can be tall and moist and so grade into the wet sclerophyll forests, or they can be short and dry and so grade into the heath woodlands, short woodlands and dry scrubs. Also, there is a number of small areas of this sub-formation scattered over the central western and north-western plains. Four alliances are recorded.

The brown stringybark-messmate-long leaf box alliance is found on the sandstone ranges, mainly in a short, dry form, although in a few favourable sites the trees are tall and well formed.

Plate 19 – An example of the tall, dry sclerophyll forest. The trees are taller and have a better shape than they have in most parts of the ranges.

The messmate-apple box alliance occurs on the outwash slopes surrounding the ranges where it exists with the brown stringybark-messmate-apple box (heath woodland) alliance. The main differences between these two alliances are the spacing and form of the trees which are most likely a reflection of the comparative dryness and wetness of their respective sites. The dry sclerophyll forest alliance tends to predominate on the middle and upper portions of the outwash slopes, and the heath woodland alliance is most common on the lowest and flattest sections of the slopes. The heath understoreys of the two alliances are both continuous and tall (three to four feet in height) and they have many species in common.

The third alliance of this sub-formation is the brown stringybark alliance which exists in small, scattered areas on the plains west of the Grampians. Brown stringybark is the dominant and sometimes only eucalypt. The important difference between this and the other two alliances is the sparse and stunted heath layer which often has only the three following species :-flame heath, daphne heath and woolly tea-tree.

Swamp gum alliance is the fourth floristic grouping within the dry sclerophyll forests and it is confined to wet situations, such as creeks and drainage lilies, in the valleys and on the outwash slopes of the Grampians. Other eucalypts are messmate and manna gum, and common members of the heath layer are prickly tea-tree and species of honey-myrtle *(Melaleuca decussata* and *Melaleuca squamea).*

Wet Sclerophyll Forest

Only in moist, sheltered gullies within the Grampians has a wet sclerophyll forest developed. Mountain grey gum *(E. cypellocarpa* formerly *E. goniocalyx)* and messmate belong to the dominant tree layer and in the sub-dominant tree layer are such species as blackwood, hazel pomaderris *(Pomaderris apetala)* and dogwood *(Cassinia sp.).* The ground layer includes clematis *(Clematis aristata),* soft tree-fern *(Dicksonia antarctica),* hairy correa *(Correa aemula)* and shield fern *(Polystichum aculeatum).* This plant community is called the mountain grey gum-messmate alliance.

Ecological and Land-Use Relationships of the Classification

A community of plants is often more useful than its individual species for indicating soils and the potential of land for development. This is because many of the species can live with other species in other communities whereas the grouping that forms the community in question is found only in, and is indicative of, a limited range of habitat. Also, the structure of a plant community as well as its floristics is often a guide to the type of habitat. For example, yellow box, yellow gum and grey box individually grow in a number of sites and with other species, but when classified together as a tall woodland alliance they indicate one type of soil in a particular part of the survey. In the same area, grey box is associated with a different soil when it is grouped into a tall woodland alliance with buloke. Yellow gum is associated with a third kind of soil when it forms a heath woodland alliance with apple box and some heath species.

The environmental and land-use relationships of the alliances are briefly described here and also later in the report within the context of the land-systems where the alliances occur.

ALLIANCES USEFUL FOR ASSESSING LAND-USE POTENTIAL –

Alliances that indicate both the type of soil and its wetness or dryness

Prickly tea-tree-silver banksia (heath) alliance.
Brown stringybark-messmate-apple box (heath woodland) alliance.
Messmate-apple box (dry sclerophyll forest) alliance.
Desert banksia (heath) alliance.
Brown stringybark-desert banksia (heath woodland) alliance.

These alliances are indicative of the nomopodzols and leptopodzols in and around the Grampians and in the north-western parishes of Kalingur, Tooan and Jilpanger. The iron leptopodzols in sandy lunettes (Nekeeya series) and the clay leptopodzols near Stawell (Illawarra series) are excluded from this relationship.

More precisely, it is the heath layer of each alliance that is associated with the podzols because the eucalypts grow in other soils. Where the heath layer is tall and dense the soils are sandy, moderately to highly acidic and well-drained, and they lack the reserves of nutrients necessary for pasture species.

The first three alliances listed above occur in and around the Grampians. Here the sequence from dry sclerophyll forest to heath reflects an increasing wetness of site. As the sites change from dry to wet, the tree density is reduced and the sub-formation changes from dry sclerophyll forest to heath woodland. The heath sub-formation occurs in the wettest sites where the trees do not grow. In many cases the wetness of the heaths arises from the proximity of the clay subsoil to the surface as well as from the low topography.

The dry sclerophyll forest and heath woodland alliances represent areas that are of marginal value for profitable attempts at primary production. The infertility and low moisture storing capacity of the podzols have been discussed in the previous chapter. Another disadvantage is the high cost of clearing the land because of the density of the trees and the ability of the heath species to regenerate. The areas of heath are much more favourable for pasture development because they are wet enough for late season annual species and even for perennials, and in many sites a clay subsoil provides a source of nutrients within reach of the roots. Also the absence of trees keeps the clearing costs down to a minimum. However, few of the heath areas are large enough to warrant development.

The two alliances with desert banksia occur together in the relatively dry north-western corner of the survey area. They both grow in iron leptopodzols that have developed in undulating deposits of deep sand.

Yellow gum-apple box (heath woodland) alliance.
Like the five alliances above, the heath layer of this alliance indicates deep, well-drained, acidic sands, in particular the podzolic deep sands. Of the species in the heath layer, twiggy guinea flower is a consistent indicator of the soil and may be the only species present where the taller, woody heath species are absent because of clearing. The alliance grows on the sand dunes scattered over the southern Wimmera plains. Podzolic deep sands have problems of pasture nutrition and management that are similar to those of the podzols and a further reference to this is made within the discussion of the Warratong land-system.

Manna gum-bracken (heath woodland) alliance.
Like the previous alliances, this alliance is correlated with deep, well-drained, acidic sands, in particular with the iron leptopodzols (Nekeeya series) that have developed in sandy lunettes in the south-eastern and southern parts of the survey. The Nekeeya. series have problems of pasture nutrition and management that are similar to those of the other podzols and a further reference to this is made within the discussion of the Parrie Yalloak land-system.

Alliances that indicate particular types of soil

Blue mallee-broombush (dry. mallee) alliance.
The blue mallee-broombush alliance grows in very shallow solonetzic soils in which there is no more than six inches of sand overlying a heavy clay subsoil. The dominant shrub within the community is broombush.

Although solonetzic soils are widespread elsewhere under other plant communities, they are more fertile, less inclined to erode and have different colour profiles than the soils under the mallee vegetation. For these reasons a separation within the solonetzic group is recognized.

Long leaf box (heath woodland) alliance.
This alliance occurs to the west of Stawell on the upper slopes of gently undulating rises. It is indicative of the Illawarra series of clay leptopodzols. Within the same area, long leaf box forms a short woodland alliance with red stringybark so that daphne heath and the other species in the heath layer can be regarded as the indicators of the Illawarra series.

Yellow box-black wattle (shrub woodland) alliance.
Yellow box-yellow gum-grey box (tall woodland) alliance.
Grey box-buloke (tall woodland) alliance.
Black box (savannah woodland) alliance.
Buloke (savannah woodland) alliance.

There are two main kinds of soils on the northern and central-western plains of the survey, namely, gilgaied calcareous clays (soils of Groups 9 and 10a) and red and brown solonetzic soils. The first two of the five alliances listed above grow in the solonetzic soils and the other three alliances grow in the gilgaied clays. In the parishes of Lowan, Carchap and Connangorach, buloke also grows in gilgaied solonetzic soils that differ from the clays of Group (9) only in having two or three inches of sandy loam as the topsoil in the shelf.

The yellow box-black wattle alliance forms a narrow zone of transition between areas of heath woodlands and dry sclerophyll forests growing in the podzols, on the one hand, and areas of tall woodlands and savannah woodlands growing in gilgaied clays or solodic soils on the other. Such a transition is noticeable along the margins of the outwash slopes surrounding the Grampians.

Each of the eucalypts which make up the yellow box-yellow gum-grey box alliance varies in its incidence according to the depth of the sandy A horizon in the solonetzic soils. Yellow gum tends to be dominant over the other two eucalypts where the A horizon is deepest, whereas grey box tends to be dominant where the A horizon is shallowest. Generally yellow box occupies an intermediate position, being in shallower soils than yellow gum and in deeper soils than grey box.

Brown stringybark (dry sclerophyll forest) alliance.
The significant land-use relationship of the brown stringybark alliance is the absence or poor development of the heath layer, that is, the heath plants are sparse and stunted (less than about twelve inches in height). In this situation the heath indicates a soil with clay close to the surface, within about twelve inches. Areas with this alliance are therefore more suitable for pasture development than the areas of podzols where the heath layer is tall and continuous.

Alliances that indicate comparatively wet soils

Cross-leaf honey-myrtle (wet scrub) alliance.
Red gum (tall woodland) alliance.
Swamp gum (dry sclerophyll forest) alliance.

These alliances indicate sites that are wetter than the surrounding areas. For example, over the northern plains the red gum alliance is restricted to locally wet sites such as creek banks and swamp margins. The surrounding drier sites are

occupied by the grey box-buloke and yellow box-yellow gum-grey box (tall woodland) alliances, and the buloke and the black box (savannah woodland) alliances.
Individual trees of yellow box, yellow gum and grey box are often sub-dominant members of the red gum alliance so that the presence of red gum is an indication of a wet site where late season annual pastures and sometimes perennial pastures are found at low elevations at the bases of the dip slopes in comparatively sheltered sites.

A distinction should be drawn here between the red gum tall woodlands and the red gum savannah woodlands that occur in the southern parts of the survey area. The savannah woodlands occur in areas of higher rainfall and are located at all positions on the landscape so that they do not indicate locally wet sites.

Tall, wet scrubs of cross-leaf honey-myrtle occur along the banks of streams flowing out of the Grampians. In the Moora Valley, the scrubs fill numerous sluggish drainage lines that form the headwaters of the Glenelg River.

The swamp gum alliance borders small creeks that flow across the outwash slopes of the Grampians. Also it is sometimes found close to the bigger streams, behind the honey-myrtle scrub, where the soil is not as wet as it is under the scrub.

THE HABITATS OF SOME OF THE REMAINING ALLIANCES-

Shiny tea-tree-Grampians fringe-myrtle (heath) alliance.
Grampians gum-long leaf box (dry scrub) alliance.
Brown stringybark-messmate-long leaf box (dry sclerophyll forest) alliance.
Mountain grey gum-messmate (wet sclerophyll forest) alliance.

These alliances are grouped together because they are found only on the sandstone ranges where they form a sequence of plant communities and habitats, from the heath alliance in the driest and most rigorous habitat to the wet sclerophyll forest alliance, in the wettest and most sheltered habitat.

Shiny tea-tree-Grampians fringe-myrtle alliance occurs on those dip slopes in the mountains that are formed of extensive areas of smooth, undissected rock. Here there are scattered pockets of shallow lithosols in which the heath communities grow. A few stunted eucalypts are often present. The conditions of habitat which characterise this alliance are a shallow, sandy soil low levels of soil moisture and plant nutrients the restriction of root growth because of the proximity of the rock and the very high summer temperatures of the rock surface and, to a lesser degree, of the shallow soil. Exposure to the weather is not a necessary part of the habitat of the component species because these heaths are found at low elevations at the bases of the dip slopes, in comparatively sheltered sites.

Grampians gum-long leaf box alliance is very similar in species and habitat to the previous community the important difference is that stunted eucalypts are in sufficient numbers to form a dry scrub sub-formation. The slightly less rigorous habitat is a result of the more extensive and deeper layers of soil. Dry scrubs occur on smooth and dissected dip slopes and on scarp faces over the cuesta land-form. Their height and density vary with the degree of harshness of the local environment. Those scarp faces pointing to the east provide the most sheltered sites and there the scrubs attain their best development.

The most extensive plant community over the mountains is the brown stringybark-messmate-long leaf box (dry sclerophyll forest) alliance. Mostly it is a comparatively short, scrubby variant of the sub-formation, found on dip and scree slopes throughout the mountains. In a few locations where the soil is deeper and the aspect favourable, a taller, wetter variant has developed.

As the habitats in the mountains become more sheltered and moist, with deeper soils, the species within the understorey change to those having morphological features that indicate a moderate water supply and a humid atmosphere. Soft, thin leaves and thin cuticles are examples of such features. The mountain grey gum-messmate (wet sclerophyll forest) alliance represents the end of the sequence, and numbered amongst the species of the lower layers within the community are ferns of various kinds and creepers such as clematis. The wet sclerophyll forests are restricted to a few narrow gullies in the central part of the Grampians where the average annual rainfall is 34 to 35 inches. Delley's Dell below Mt. Rosea has a good example of this plant community.

Long leaf box-red stringybark (short woodland) alliance.
The long leaf box-red stringybark alliance is found mainly on steep slopes and crests in the rolling and hilly country composed of Ordovician sedimentary rocks. The soils are stony, shallow and excessively drained. In the Ledcourt area, the long leaf box-yellow gum association within the alliance is typically found on the highest positions of the

gently undulating plain. The soils in these positions are shallow, reddish sandy clay loams that differ from the solonetzic soils surrounding them.