General Report on Lands of the Wiluna–Meekatharra Area, Western Australia, 1958

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PART I. INTRODUCTION AND SUMMARY DESCRIPTION OF THE WILUNA–MEEKATHARRA AREA

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I. INTRODUCTION

The area surveyed covers 25,000 sq. miles in Western Australia and has been designated the "Wiluna–Meekatharra area". The boundaries of the area are lat. 26°S. in the north and lat. 27°S. in the south, long. 117°E. on the western side and long. 123°E. on the eastern side.

(a) *Survey Procedure*

The general procedure was similar to that of previous surveys carried out by the Division of Land Research and Regional Survey, with slight modifications imposed by the nature of the country surveyed.

Each survey is carried out by a small team of scientists working in collaboration with the object of scientifically mapping and describing large areas of country. The basic descriptive unit is the land system (Plate 1, Fig. 1), which has been defined as an area or group of areas with a recurring pattern of land forms, soils, and vegetation. The land system maps and descriptions provide a basis for an assessment of the potentiality of the area and for recommendations for further research.

The method of survey is based on the concept that each type of country or land system is expressed on aerial photographs by a distinctive pattern (Plate 1, Fig. 2), so that a map of the land systems can be produced from the photographs. The method presupposes that a complete aerial photographic cover of the area is available. The Wiluna–Meekatharra area had been photographed at a scale of 1:37,500 in 1956.

A first interpretation of the aerial photographs was made in April 1957 as a preliminary to a reconnaissance of the area by some members of the survey team. Distinctive air-photo patterns were noted along possible routes, and traverses were planned to sample the patterns.

The reconnaissance took place in September 1957. The aerial photographs were taken into the field and traverse routes, speedometer mileages, and descriptive notes were marked on them. Distances were plotted to the nearest one-tenth of a mile (approximately one-sixth of an inch on aerial photographs).

The aerial photographs were interpreted in the laboratory by the full survey team during May and June 1958. Approximately 300 query areas were selected along 10 traverse routes and a preliminary attempt was made to designate these selected types of country, mainly in terms of geology and relief.

The main field season followed from July to October 1958. The aerial photographs were marked as in the reconnaissance. In addition, joint records were made of observations at query spots, and a preliminary field mapping of types of country was attempted on the aerial photographs which were traversed. The emphasis on query sampling was called for by the lack of relief, which often necessitated careful levelling.

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The final interpretation of the aerial photographs in the period February to April 1959 resulted in a map showing the 48 land systems described in this report.

During the survey the team spent 4 months interpreting aerial photographs in the laboratory, and approximately 4 months in the field. The approximate total length of traverses was 1500 miles (Fig. 1).

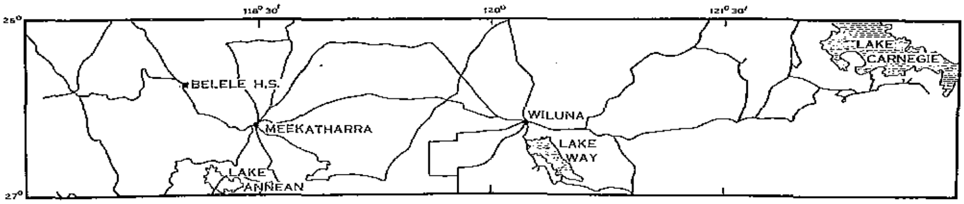

Fig. 1.—Traverse map.

II. Summary Description

(a) Population and Communications

The two towns in the area are Meekatharra (population approximately 300) and Wiluna (population 70). These grew up as gold-mining towns, but since the virtual cessation of mining they have very much decreased in size and now act as distributing and route centres.

Meekatharra is the terminus of the railway line from Perth. It is situated on the Great Northern Highway, 475 miles from Perth, and is a stopping point on the air route from Perth to Port Hedland and Darwin. Wiluna is 112 miles east of Meekatharra, with which it was connected by rail until 1952. It has an infrequent air service to Perth and Meekatharra. Meekatharra and Wiluna form two Road Board Districts and are the centres of secondary road networks. All roads in the area are of graded earth.

(b) Climate

The area is arid, the mean annual rainfall ranging from 7 in. in the west of the area to 10 in. in the east. On the average, monthly rainfall is highest in March and lowest in September. The east of the area receives more summer storms and a higher amount of rain per wet day than the west. Variability of rainfall is high and increases eastwards.

Summers are long and hot, and maximum temperatures commonly exceed 100°F. Winters are mild, but there is a brief frost season which becomes more severe towards the east.

The weather is controlled by a succession of anticyclones moving eastwards. The troughs between these anticyclones occasionally deepen to form rain-bearing depressions, of tropical origin during the summer months and of southern origin during late autumn and winter. Tropical cyclones, which occur in some years, are of considerable importance because they are usually accompanied by widespread heavy rain.

Humidity levels are low and dews are of rare occurrence except during and immediately following periods of rainy weather.

Evaporation from a free water surface is 90 to 110 in. per year. The highly variable rainfall allows the existence of only those perennial species which can withstand periods of several years without sufficient rain to permit growth. It is estimated (Part III) that initial effective rain (sufficient to start plant growth) can be expected to occur about three times a year in the west of the area, with an emphasis on a winter growing season, and about twice a year in the east, where the summer months are relatively important. Subsequent growth periods, as determined by available moisture, are mainly less than 4 weeks and are rather less frequent, particularly towards the east of the area. The actual duration of growth periods varies according to depth of soil and amounts of run-on and/or run-off.

The western parts, with a higher proportion of winter rain and lower evaporation, can expect a more effective growing period than the eastern parts, which receive more of their rain in summer.

A dry spell of 6 to 9 months, commencing not later than the end of August, is to be expected in most years. In the past, droughts have lasted up to 5 years.

(c) *Physical Regions*

The survey area forms part of a broad watershed on the interior plateau of Western Australia and it consists mostly of extensive plains with low hill ranges and plateaux of minor extent (Plate 2, Fig. 1). Its western part drains to the Indian Ocean by the Murchison River, whilst the remainder has an interior drainage with large salt lakes.

Four physical provinces can be distinguished (Part V), and are shown on the map of land forms and physical provinces and regions.

(1) The Murchison plains are drained to the Murchison River. They form the lowest part of the area, descending from about 1450 ft in the south-east to about 1000 ft in the north-west. Most of the province consists of stony plains, alluvial flood-plains, and tributary wanderrie country. It is traversed by the east-trending Jack Hills in the north-west and the Weld Range in the south-west; these are narrow ranges mainly between 250 and 500 ft high.

(2) The Salinaland plains comprise the plateau surface with interior drainage. The plateau attains between 1800 and 2000 ft on the interfluves, which consist mainly of sand plain. The lowlands, generally below 1700 ft, consist of alluvial plains tributary to Lake Way in the south and Lake Carnegie in the north-east. The trunk valleys are occupied by calcreted valley fills in the upper sectors and by salt lakes and dunes in the lower parts. The southern half of the province is diversified by north-trending low hill belts.

(3) The central uplands occupy the north half of the area between Meekatharra and Wiluna. There is a southern plateau rim with summits exceeding 2100 ft in the Glengarry Ranges. The inner lowlands contain a central alluvial tract with extensive calcreted valley fills. This is drained mainly eastwards to Lake Way and partly westwards to the Murchison River. Much of the northern part consists of low basalt hills.

(4) The north-eastern uplands are in the north-east corner of the area. They contain four north-west-trending regions. Discontinuous plateaux with less than 150

ft of relief occur in the south-east. They are separated by an inner lowland from the Princess Ranges, a second upland belt with more than 400 ft of relief. The north-east part consists mainly of Lake Carnegie and its fringing lowlands.

(*d*) *Geology*

The Wiluna–Meekatharra area forms part of the stable Australian shield (Part IV). The outline geology is shown on the accompanying geological map. Most of the area is underlain by Archaean gneiss and granite traversed by remnant belts of steeply dipping metavolcanic greenstone and metasedimentary whitestone. The greenstone, which is mainly schistose, consists predominantly of lava, tuff, and agglomerate, with minor intercalations of metasedimentary lenses, ultrabasic intrusives, and acid volcanics. The whitestone comprises a wide variety of schists diversified by resistant jaspilite and quartzite.

The metamorphic belts trend west-south-west in the west of the area and north–south in the east. The gneisses are regarded mainly as resulting from granitization of the metamorphic belts. Hydrothermal mineralization occurred near the margins of the intrusive bodies.

Proterozoic lavas and sediments (Nullagine "system") were laid down unconformably in shallow basins on the crystalline basement in the north central and north-east parts of the area. They consist mainly of basalt, slate and mudstone, sandstone and quartzite, and thin dolomite. The succession ranges from 600 ft in the centre of the area to possibly 1000 ft in the north-east. These rocks are only gently folded and are not metamorphosed.

Subhorizontal boulder tillite, siltstone, and grit, regarded as Permian in age, overlie the Nullagine and older rocks unconformably in the east of the area. The succession does not exceed 100 ft.

The Wiluna–Meekatharra area has remained land since Palaeozoic time and has undergone no significant deformation. Over much of the area the rocks described above bear remnants of ferruginous and siliceous cappings inherited from a Tertiary phase of deep weathering. They are also extensively buried by surface deposits due to the general tendency to alluviation in low ground owing to increasing aridity and the development of interior drainage from Tertiary times onwards.

Gold-mining was formerly important near Meekatharra and Wiluna and was an important factor in early settlement, but is now restricted to small-scale production from the Meekatharra district (Plate 8, Fig. 2). Small amounts of copper, arsenic, silver, barytes, and ochre have been produced in the area.

(*e*) *History of the Physical Landscape*

The oldest element is the deeply weathered, lateritic land surface known as the old plateau (Part V). This consisted of extensive plains on gneiss and granite, undulating surfaces on Nullagine mudstone and lava, low greenstone hills, and subdued sandstone plateaux. Strong relief was restricted to ranges of whitestone and Nullagine quartzite.

Erosion of the old plateau, probably caused by uplift of the area to its present altitude in late Tertiary time, has formed the younger, new plateau surface. Stripped plains have been formed on granite and gneiss, closer dissection has occurred in undulating and low hilly areas, whilst plateaux and mountain ranges have undergone marginal dissection and stripping. The new plateau surface has been more effectively extended in the Murchison plains, whilst the old plateau survives more extensively in Salinaland.

With a change to a drier climate, extensive alluviation took place in the lowlands and interior drainage to salt lakes was established in the Salinaland plains. Calcreted valley fills formed in many trunk valleys. At the height of aridity, extensive wind sorting of surface deposits led to the formation of sand plain and some dunes. Subsequent amelioration of climate is indicated by stabilization of sand surfaces and renewal of drainage activity.

Stripping and dissection of the higher parts of the area now proceed slowly, whilst transport and deposition are mainly the work of sheet floods on lower slopes and alluvial plains. Wind erosion is important near salt lakes and on saline alluvial flats. The sand plain remains a fairly stable environment with little surface drainage.

(*f*) *Soils*

The outstanding features of the soils of this area are their generally leached nature and the widespread siliceous hard-pan or "cement" (Plate 2, Fig. 2). Apart from the hard-pan, the soils resemble those of other parts of arid Australia.

Leached coarse-grained red earths and red sands are the most extensive soils and are mainly derived from weathered rock on the old plateau. Mainly shallow red earths with massive hard-pan occur on tributary alluvial plains whilst the lower flood-plains also have calcareous and saline soils. Soils derived from fresh rock material are of small extent, and weathering crusts and weathered rock surfaces are widespread. Stone pavements are widespread, even on lower soil-covered slopes with leached soils.

Very sandy soils in sand plain and on wanderrie banks are the only widespread deep soils.

Seven soil groups have been defined on the basis of their unconsolidated "fine earths" and are subdivided on the basis of their substrata, texture, depths, and the presence of a stone pavement or of a nodular horizon.

Alluvial soils are of minor extent in valleys throughout the survey area.

Shallow, stony soils are found extensively on hill slopes and plateau surfaces.

Red sands and clayey sands occupy 6000 sq. miles, principally on sand plain, wanderrie banks, and dunes. They are generally freely-drained acidic or neutral soils and comprise shallow and deeper forms, with hard-pan or on weathered rock, locally with ferruginous nodules.

Red earths occur over 9000 sq. miles. They include deeper, coarser-textured red earths with gradational texture profiles and shallower, finer-textured red earths with uniform texture profiles, commonly with surface seals. Deeper red earths may occupy narrow trenches in the hard-pan in vegetation groves. Red earths are mostly acidic, except in areas with restricted drainage. The red earths are further divided according to whether they occur on weathered or fresh rock, hard-pan, or a calcareous horizon, and by the presence of ferruginous nodules or of a stone pavement.

The calcareous earths are shallow soils with powdery consistence due to dispersed carbonate. They are generally brown when dry, with a stone pavement, and are alkaline although low in total salts.

Texture-contrast soils mainly have a subsoil pan at less than 1 ft depth. In the coarser-textured soils this generally rests on hard-pan, but in finer-textured soils it may pass downwards into horizons with carbonates, gypsum, or weak hard-pan. They are red-brown soils, with varying surface reactions but generally with alkaline subsoils. They are very susceptible to erosion unless protected by a stone pavement.

Red coarse-structured clays occur very locally on alluvial plains derived mainly from dolomite.

These soils occur in soil associations, of which 24 have been recognized. Each association is normally related to one or more landscapes which largely correspond to land units.

The soils are generally shallow because of the occurrence of hard-pan, and infertile because of the pre-weathering of most parent materials.

All soils are likely to be deficient in phosphorus and acid sandy soils will probably lack calcium and potassium. The general availability of nitrogen is likely to be higher than indicated by the low nitrogen contents, which are due to rapid mineralization by alternate wetting and drying.

The best soils for irrigation will probably be deep red earths with fairly coarse surface textures, but such soils are restricted near the principal aquifers.

(*g*) *Vegetation*

The area falls within the Eremean botanical province. The 75 vegetation communities recognized (Part VII) include woodlands, shrublands, and spinifex grasslands (Plate 3, Fig. 1).

The upper layers of most communities are dominated by mulga (*Acacia aneura*). Eucalypts are relatively unimportant, but several mallee species occur in sparse upper storeys in spinifex grasslands on sand plain.

Most communities have well-developed shrub layers with various species of *Eremophila*, and these useful indicator plants have been used with *Acacia aneura* to designate many communities. Halophytic shrublands are extensive, mainly in lower-lying alluvial areas. Chenopods, either as herbaceous shrubs or as forbs, are characteristic of these shrublands, but also form an important part of the understoreys of many communities throughout the area.

Spinifex forms the only extensive grasslands, but valuable perennial tussock grasses, notably the wanderrie grasses *Danthonia bipartita* and *Eragrostis lanipes*, characterize several important communities. *Aristida arenaria* is the commonest of the widespread short annual grasses.

The area is noted for the lush growth of forbs (mostly mulla mullas) and ephemerals (mostly composites) which particularly characterize areas with run-on and which also form a short-lived element in most communities after rain.

(*h*) *Natural Pastures*

With the exception of spinifex, pastures consisting only of grass layers do not exist in this semi-arid area. During dry periods grazing animals find it necessary to depend upon the edible trees and shrubs to a greater or less degree (Plate 3, Fig. 2). Thus, all layers of the vegetation need to be included in any description of natural pastures.

The pastures fall into four types based primarily on their response to the semi-arid climate (Part VIII).

(i) *Pastures Characterized by Ephemeral Drought-evading Plants.*—These short grass pastures respond mainly to winter rains. They are palatable and nutritious when green, when areas receiving run-on may have a lush growth of forbs, but are short-lived and of low nutrient status when dry. Top feed is scanty and overall carrying capacity is generally low, although high for short periods following suitable rains.

Two forms are distinguished. Short grass–mixed forb pastures predominate on shallow red earths on alluvial plains and lower slopes, and also extend into hilly areas, where the denser shrub layer is a useful "carry-over" element during drought seasons. Short grass–chenopod pastures occur on stony plains, where the small annual chenopods give increased drought resistance and more enduring palatability.

(ii) *Pastures Characterized by Perennial Drought-evading Plants.*—These pastures contain valuable tussock grasses which can respond rapidly to rain at all seasons, are palatable and nutritious when green, and can persist for long periods as dry fodder. Top feed is commonly valuable.

The most important of these pastures are *Danthonia bipartita–Eragrostis lanipes* pastures, which are extensive on wanderrie banks and other sandy habitats, and *Eriachne helmsii* pastures, which occur on parts of the sand plain in the Murchison plains, on deeper soils in mulga groves, on sand banks, and on sandy uplands.

(iii) *Pastures Characterized by Drought-resistant Sclerophyllous Grasses.*—These are spinifex grasslands, mainly on sand plain. The spinifex is unpalatable, and the limited value of these pastures resides chiefly in the volunteer herbaceous shrubs and forbs which appear after burning. Top feed is restricted to lower areas with significant run-off.

Hard spinifex pastures predominate on sand plain in the Salinaland plains; feathertop spinifex pastures are more prominent on sand plain in the Murchison plains.

(iv) *Pastures Characterized by Drought-resistant Semi-succulent Low Shrubs.*—These consist of halophytic shrublands and samphire pastures which are palatable and highly nutritious and which respond well to rain at all seasons. They also contain short grasses and numerous forbs which provide seasonal fodder. They are the most valuable pastures in the area.

They comprise samphire pastures in and near salt lakes, low halophytic shrubland pastures, with frankenia on lower saline alluvial flats, and tall halophytic shrubland or bluebush pastures on higher saline alluvial flats.

(*i*) *Land Systems*

The area has been divided into 48 land systems, each with a recurring pattern of topography, soils, and vegetation (Plate 1, Fig. 1). These land systems, which are described in detail in Part II and are shown on the land system map, provide a basic inventory of natural resources.

The erosional land systems are classified according to the history of the land surface on which they occur as well as by relief. In this way, inherited as well as younger soil landscapes are explained. The depositional land systems are classified according to the nature of the deposits, thus emphasizing major contrasts in soils and vegetation.

In this summary, the main features of topography, soils, and vegetation, including pastures, are given for each group of land systems. Distinctive characteristics of individual land systems are then stated.

(i) *Undulating Terrain Forming Part of the Old Plateau.*—These land systems consist of rounded crests and broad shallow valleys with between 10 and 40 ft of relief on various weathered rocks. The gentle slopes and stripped crests have shallow red earths or stony soils and mainly open mulga communities forming short grass–mixed forb pastures. More valuable perennial pastures with dense mulga, edible shrubs, and tussock grasses are found on sandy, gravelly soils on more stable crests, and on deeper red earths in mulga groves.

Dural land system is strongly undulating with minor rocky crests.

Fisher land system is moderately undulating with fewer rocky areas.

Lorna land system is gently undulating, with hard spinifex pastures on sand plain in the lower parts.

Diamond land system is very gently undulating with fairly extensive sandy crests.

(ii) *Surfaces Formed by Dissection of the Old Plateau*

(1) *Mountain and Hill Ranges.*—These land systems are characterized by steep rocky slopes, with 150–500 ft of relief, formed partly in weathered rock. Soils are mainly lacking or are shallow and stony, but shallow red earths occur on drainage flats. The vegetation consists largely of open mulga with various edible shrubs and annuals forming short grass–mixed forb pastures of low but enduring carrying capacity.

Weld land system consists of narrow whitestone mountain ranges.

Princess land system comprises broader quartzite ranges with fairly dense mulga communities.

Yagahong land system forms greenstone hill ranges and their lower slopes.

Gabanintha land system consists of whitestone hill ranges, but includes extensive lower slopes, mainly with shallow red earths.

(2) *Sandstone Plateaux.*—These are mainly small rocky plateaux, 50–150 ft high, with escarpments or stony slopes of moderate steepness. Soils are mainly shallow and stony and are commonly lacking on steep slopes. Typically, the vegetation consists of open mulga with variable shrub and ground layers, mainly classed as short grass–mixed forb pastures.

Glengarry land system has undulating plateau summits carrying useful perennial grass pastures with fairly dense mulga on shallow stony sands.

Lynne land system comprises small plateaux separated by saline alluvial tracts with tall halophytic shrubland pastures on texture-contrast soils.

Doman land system consists of subdued uplands having gentler lower slopes with red earths supporting mulga groves.

Wongawol land system consists partly of rocky plateaux and partly of stony lowlands with scalded tracts and very sparse vegetation.

(3) *Low Hills*.—These land systems are formed on various partly weathered rocks dissected into hills up to 75 ft high, with minor lateritic cappings. Soils are mainly shallow and stony, with gravelly sands on lateritic remnants and red earths on lower slopes and alluvial plains. The vegetation consists typically of open mulga with variable shrubs and grasses, including spinifex, but with closer mulga cover in drainage plains. These are mainly short grass–mixed forb pastures.

Wiluna land system consists of rounded greenstone hills.

Killara land system consists of basalt hills with significant sandy or stony crests carrying some feathertop spinifex pastures.

Sodary land system comprises rounded ridges and small uplands. In addition, there are moderately extensive saline alluvial tracts with texture-contrast soils and degraded halophytic shrubland pastures.

(4) *Duricrusted Plateaux and Benches*.—These land systems have formed by dissection of weathered rocks with silcrete cappings, and have prominent escarpments up to 150 ft high. They have mainly stony, shallow soils with moderately dense mulga and a close shrub layer, forming typical upland short grass–mixed forb pastures.

Tooloo land system consists of small plateaux. Lower slopes and adjoining flats have shallow texture-contrast soils with halophytic shrubland pastures.

Boondin land system forms rocky benches with limestone foothills traversed by saline alluvial flats carrying halophytic shrubland pastures.

(5) *Breakaways and Plains*.—In these land systems there has been extensive stripping of lateritized rock, leaving plains with shallow stony soils, traversed by unchannelled alluvial flats with shallow red earths. The vegetation consists of open mulga, denser and with more edible shrubs near drainage lines. The stony plains support short grass–chenopod pastures whilst the red earth flats have less enduring, short grass–mixed forb pastures.

Sherwood land system consists of very extensive stony granitic plains backed by low breakaways with stunted mulga and native pine (Plate 1, Fig. 1).

Violet land system is gently undulating terrain. Lateritic remnants form broad low crests with sandy or gravelly soils and dense mulga, mainly in feathertop spinifex pastures. Lower slopes and drainage floors have short grass–mixed forb pastures on shallow red earths, with groves of denser mulga and perennial grass pastures on deeper soils.

Millrose land system consists partly of stony plains and partly of red earth flats, but also contains extensive wanderrie banks with perennial *Danthonia bipartita–Eragrostis lanipes* pastures on red clayey sands.

(iii) *Surfaces Eroded below the Old Plateau*.—In these land systems, lateritic cappings are lacking and there are extensive stony surfaces formed on relatively fresh rock. Variations in rock resistance account for the three relief classes into which the land systems are grouped.

(1) *Uplands.*—These are rocky hills with up to 100 ft relief, mainly with open mulga, but they also include minor fringing plains or lower slopes with shallow red earth. They carry short grass–mixed forb pastures.

Norie land system consists of granite domes and fringing pediments.

Treuer land system is a stony sandstone tableland, bounded on one side by steep escarpments and on the other passing into gentler slopes with groved mulga on shallow red earths.

(2) *Low Hills and Plains.*—The extensive plains have shallow, stony soils and support open mulga communities in short grass–chenopod pastures. The stunted mulga of the rocky hills and the denser mulga communities on shallow red earths on alluvial flats comprise short grass–mixed forb pastures.

Mindura land system consists of undulating stony granitic plains with clusters of low granite domes.

Edenhope land system consists of plains sloping from low ridges and hills. The upper parts of these plains are stony; the lower parts support short grass–mixed forb pastures with groved mulga on shallow red earths.

(3) *Plains.*—These land systems have extensive shallow stony soils with sparse mulga in short grass–chenopod pastures. They are traversed by alluvial flats with shallow red earths and sparse mulga and shrubs in short grass–mixed forb pastures.

Koonmarra land system consists of stony granitic plains.

Yarrameedie land system consists of stony granitic piedmont plains, with unusual development of short grass–mixed forb pastures and mulga groves on shallow red earths in lower parts due to dispersal of through-going drainage.

Windidda land system consists of flat plains with narrow stony limestone tracts. Open mulga in short grass–mixed forb pastures predominates, but there are also well-developed mulga groves with *Danthonia bipartita–Eragrostis lanipes* pastures, and clay flats supporting *Eragrostis xerophila* pastures. Short grass–chenopod pastures are restricted to minor flood-plains.

Kalyaltcha land system consists mainly of stony plains traversed by alluvial flats with texture-contrast topsoils and halophytic shrubland pastures.

(iv) *Depositional Surfaces.*—Alluvial plains and aeolian sand surfaces comprise 30% of the survey area.

(1) *Calcreted Valley Fills.*—These land systems form tracts up to 5 miles wide in trunk valleys. They consist partly of low calcrete tables with shallow, stony calcareous earths and very open mulga with a calciphilous ground flora forming short grass–mixed forb pastures. Between and flanking the tables are alluvial red earth flats with open mulga in short grass–mixed forb pastures, passing down-valley into saline alluvial plains with texture-contrast soils and halophytic shrubland pastures.

Cunyu land system has mainly red earth plains with short grass–mixed forb pastures.

Mileura land system has extensive texture-contrast soils with halophytic shrubland pastures.

(2) *Mainly Non-saline Alluvial Plains.*—These are tributary drainage plains, mainly subject to sheet flow and with shallow red earths supporting open mulga in short

grass–mixed forb pastures. *Danthonia bipartita–Eragrostis lanipes* and other perennial grass pastures occur in favoured areas, such as sandy soils on wanderrie banks and deeper red earths in mulga groves.

Jundee land system consists of shallow red earths with widely spaced thin mulga groves.

Trennaman land system has extensive sandy tracts and wanderrie banks.

Yanganoo land system has deeper red earth soils and denser mulga in thick groves, with some feathertop spinifex pastures in sandier soils transitional to sand plain.

Cole land system has mulga groves in upper sectors, and wanderrie banks and sand plain with hard spinifex pastures in its lower parts.

Yandil land system consists very uniformly of shallow red earths with short grass–mixed forb pastures.

Ero land system has well-developed wanderrie banks and mulga groves, but also contains lower areas of saline alluvia with texture-contrast soils and halophytic shrubland pastures.

Wadjinyanda land system consists of flood-plains with severely degraded shallow red earths and depauperate mulga communities.

Mitchell land system has relatively extensive sandy soils supporting both hard spinifex and perennial tussock grass pastures in its upper parts, and minor areas of saline alluvium with texture-contrast soils and halophytic shrubland pastures in its lower parts.

(3) *Partly Saline Alluvial Plains*.—These land systems form the lower drainage plains, with fine-textured, mainly saline alluvium, and texture-contrast soils with extensive halophytic shrubland pastures. They have generally been subject to severe wind and water erosion.

Barwidgee land system consists of stony plains, salt pans, and sand dunes.

Beringarra land system consists of degraded flood-plains flanked by plains of non-saline alluvium with shallow red earths and sparse mulga in short grass–mixed forb pastures.

(4) *Alluvial Plains with Wind Modification*.—Belele land system consists of extensive wanderrie banks with moderately deep red clayey sands and open mulga with *Danthonia bipartita* pastures (Plate 1, Fig. 2; Plate 4, Fig. 2). Intervening alluvial tracts have shallow red earths with short grass–mixed forb pastures.

(5) *Sand Plain and Dunes*.—Aeolian sand surfaces comprise 20% of the survey area. They consist mainly of sand plain with deep red clayey sands and spinifex pastures. There are tracts of denser mulga in areas receiving run-on. Minor areas of dunes have deep red sands.

Bullimore land system consists of sand plain with hard spinifex pastures.

Kalli land system consists of sand plain mainly with feathertop spinifex pastures, but with areas of *Eriachne helmsii* pastures.

Yelma land system consists mainly of sand plain with hard spinifex pastures and red earth plains with short grass–mixed forb pastures.

Waguin land system is mainly sand plain, but also contains fairly extensive rocky areas and stony plains with short grass–chenopod pastures.

Heppingstone land system is a dune field with hard spinifex pastures.

(*j*) *Pasture Lands*

By grouping together land systems with similar patterns of pastures, nine pasture lands have been established (Part VIII). These are grouped into five types of country on the basis of broad similarity of physical environment and of pasture content, and are ranked in order of pastoral value.

(i) *Saltbush Country*.—This comprises halophytic shrubland, salt lakes and halophytic shrubland, and short grass–forb pastures with minor halophytic shrubland, mainly on saline alluvial plains, and it contains extensive pastures characterized by drought-resistant semi-succulent shrubs (Plate 4, Fig. 1). These nutritious and durable pastures have been degraded by heavy grazing, with loss of perennial shrubs and severe wind and water erosion.

(ii) *Wanderrie Country*.—This country includes both open and dense mulga with wanderrie shrubland, both of which contain valuable perennial as well as short grass–mixed forb pastures on shallow soils (Plate 4, Fig. 2). There is useful top feed. These pasture lands have relatively high potential carrying capacity, but uncontrolled selective grazing has extensively reduced the perennial grasses and there has been widespread soil deterioration on the short grass plains.

(iii) *Short Grass–Forb Country*.—This country comprises two pasture lands, namely alluvial plains with short grass–mixed forb pastures and stony plains with short grass–chenopod pastures (Plate 5, Fig. 1). These contain extensive low-value pastures which give a short-lived response of short annual grasses and forbs, mainly after winter rains. The stony plains have slightly more durable pastures owing to the presence of chenopods. Top feed is scanty throughout. These pasture lands have been extensively degraded, with widespread sealing and localized erosion of shallow soils.

(iv) *Hill Country*.—This consists of hill pastures with stunted mulga shrubland (Plate 5, Fig. 2). The pastures consist mainly of short grass–mixed forb pastures, but with an unusually dense and varied shrub layer which can support low stocking densities even in drought conditions. This pasture land may therefore be regarded as a useful grazing reserve. Uncontrolled grazing has caused depletion of the shrub layer.

Relief is rarely strong enough to render large areas inaccessible to grazing.

(v) *Spinifex Country*.—This comprises spinifex sand plain, with both hard spinifex and feathertop spinifex pastures (Plate 6, Fig. 1). The sclerophyllous grasses are unpalatable and the carrying capacity of this pasture land is low. The chief value of the pastures is in the transitory growth of more palatable species following burning. Spinifex country is least-developed, pastorally, in the area.

(*k*) *Water Supply*

Surface waters are of little importance to the pastoral industry because of low rainfall and ephemeral sheet run-off with restricted channel development (Part IX).

The pastoral industry is dependent on ground water from more than 1000 wells and bores, mainly yielding less than 4000 gal/day (Plate 7, Fig. 1). The main source of shallow ground water is the extensive alluvial cover, with the calcreted valley fills in trunk valleys particularly pre-eminent. There is generally adequate supply for stock at shallow depth, but the water-table beneath sand plain commonly lies deeper, whilst in upland areas ground water is restricted to narrow alluvial tracts. Ground water commonly becomes too saline for stock in the lower parts of alluvial plains near salt lakes, and more locally in areas of weathered rock.

The proportion of country effectively watered for stock, on the basis of a $2\frac{1}{2}$-mile grazing radius from water points on sheep stations and a 5-mile radius on cattle stations, decreases from 70% in the west of the area to 30% in the east. This is partly due to the earlier development of the west and to the remoteness of the east, but it also reflects the lower pastoral value of much of the eastern part.

In contrast with the general availability of stock water, it is likely that supplies for irrigation will be limited. If a yield of 5000 gal/hr is adopted as a minimum requirement, only the calcreted valley fills, mainly Cunyu land system, are likely to provide adequate supplies on any scale. Tributary alluvial plains underlain by hardpan will yield such amounts locally.

In the lower parts of many of the calcreted valley fills, ground water is too saline for irrigation, whilst in others saline waters occur in discontinuous tracts. Most of the other main aquifers yield fair-quality water only.

Calculated potential recharge in catchments with fair-quality waters exceeds 25,000 ac. ft./yr only in Yalgar River and in West Creek, and these are possibly the only areas capable of supporting group schemes. Localized individual schemes, subsidiary to the pastoral industry as at present, may develop in catchments with smaller recharge or on tributary alluvial plains marginal to aquifers with saline ground water.

(*l*) *The Pastoral Industry*

The pastoral industry depends on a sparse, xerophytic native vegetation and must remain essentially extensive (Part X). Stocking rates and pasture management must be adjusted to low and uncertain rainfall and to recurrent drought.

Terrain imposes few limitations on the industry and extensive plains allow rational layout of station roads and fences but certain uplands may be inaccessible to cattle, whilst large salt pans and dune fields may similarly remain undeveloped (Plate 2, Fig. 1). Extensive sand plain has probably restricted pastoral development in Salinaland.

Ground water for stock supplies is adequate except in some saltbush country.

Shallow, infertile soils accentuate drought conditions, causing widespread death of top feed, and soil sealing accentuates the ephemeral character of many pastures (Plate 6, Fig. 2). Serious soil erosion has occurred on degraded saltbush country.

The Murchison plains were settled between 1880 and 1910, mainly by development along the saltbush flats. The Wiluna area was settled later; sheep stations were not established here until the 1920s and cattle stations still predominate further east. Gold-mining played an important part in development by bringing settlements, communications, and markets.

Sheep numbers in the survey area have fluctuated widely in common with other pastoral areas of Western Australia. They reached a maximum in the early 1930s, but fell by about 50% during the 1936–41 drought and have only recovered to a small degree.

Sheep and cattle stations are held under pastoral lease from the Crown. The sheep stations range from 100,000 ac to the maximum of 1,000,000 ac, and are boundary fenced and subdivided into paddocks watered with wind pumps from wells or bores (Plate 7, Fig. 2). Stocking rates average 1 sheep to 40–50 ac, but vary between pasture lands and with seasons. There is little prospect of an early return to the 1930 rates of 1 sheep to 15–20 ac.

Generally, equal numbers of ewes and wethers are held; the wethers are sold at 5 yr, but ewes generally remain on the station. There is little conscious management for breeding and 50% lambing percentages are considered normal.

Narrowing profits of recent years have not led to improved management, and there has been little effort to come to terms with the environment or to conserve natural resources.

Cattle properties are even more vulnerable owing to lack of range management. Most of them allow free range at all times and there is no control of breeding, which prevents improvement of herds. Further subdivision is a prerequisite of improvement of cattle stations.

At present there is little to choose between the two types of pastoral enterprise, as each yields an average annual gross return of about 1*s.* 6*d.* per acre.

To some degree, the present condition of the natural pastures reflects the sequence of settlement. Saltbush and wanderrie country in the Murchison plains shows maximum deterioration from continuous over-stocking and uncontrolled grazing and the adjoining short grass–forb country is also severely degraded, but the less desirable hill country and spinifex country are less affected. Equivalent pastures in the later-settled areas further east are less degraded but there is a common trend towards deterioration and degradation, shown by subclimax vegetation, loss of more palatable perennials, and soil erosion and sealing (Plate 6, Fig. 2).

For increased production, management must recognize the requirements of pasture species for survival and propagation. The methods to be adopted vary between pasture lands, but many involve the use of deferred grazing techniques.

Improvement of saltbush country depends on the return of perennial shrubs, which requires complete protection during the first two seasons and subsequent protection at intervals to allow seed production and recovery after periods of stress. Furrowing and seeding of scalded areas may be necessary.

Recovery of wanderrie country will be aided by the relatively deep soils with high water storage. Protection for six months is required for regeneration and establishment of the better perennial grasses, but rejuvenation of palatable shrubs will require longer protection, as in saltbush country.

Short grass–forb country should be grazed when growth is available in order to spell other pastures. Rejuvenation of shrub components is rendered difficult by shallow, sealed soils and the low value of the pastures does not justify this consideration except in favoured areas with run-on.

Hill country, although of low carrying capacity, can serve as a useful drought reserve because of enduring nutritious shrubs. It should be allowed to recuperate after prolonged drought.

Spinifex country should be burned to encourage volunteer species and then utilized at as high a rate as possible. There is no advantage in deferring the grazing of these species.

Improved production of perennial grasses and shrubs, fully accessible to sheep, results from tree-clearing in areas of dense mulga.

Relocation of fences due for renewal so as to enclose pasture lands more coherently would facilitate such management practices.

Some further development of the industry could result from increased stock waters, particularly on better pasture lands in the east of the area. It is doubtful if unwatered areas serve any useful purpose as drought reserves since stock are less capable of wide foraging at times of stress. There is scope for water-harvesting in catchment areas and water-spreading in areas of deeper soils such as wanderrie banks and mulga groves.

Ground water sufficient for irrigation occurs extensively, particularly in Cunyu land system, and this could be more widely used to grow supplementary feed (Plate 8, Fig. 1). Lucerne, probably in combination with winter oats, can be produced relatively cheaply in the area and should be used for flock maintenance during drought and as a supplement for short periods to improve lambing percentages and weaner survival.

(*m*) *Photographs*

The photographs have been arranged in sequence to tell a descriptive story, beginning with an illustration of a land system, then showing aspects of geology, land forms, soils, and vegetation, the types of pastoral country, and examples of pastoral and past mining settlement. This follows the arrangement in Part I of the report, and text reference to these photographs is made only in Part I.

III. Acknowledgments

The cooperation of the following authorities is acknowledged. The Western Australian Department of Agriculture made available D. G. Wilcox for the period of the survey and the Western Australian Geological Survey made available J. Sofoulis for the same period. C.S.I.R.O. Division of Soils seconded W. H. Litchfield.

The preparation of all the maps, diagrams, illustrations, and the manuscript was done by the staff of the Division. The guidance and criticism of G. A. Stewart, Chief of the Division, is gratefully acknowledged.

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PART II. LAND SYSTEMS OF THE WILUNA–MEEKATHARRA AREA

By J. A. MABBUTT,* N. H. SPECK,* R. L. WRIGHT,* W. H. LITCHFIELD,†
J. SOFOULIS,‡ and D. G. WILCOX§

The area has been mapped and described in 48 land systems, each of which is "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation"||.

The land systems and their component units are described in tabular form and illustrated by block diagrams which also show generalized geology or by sketch plans where relief is very small. The relief scale of the block diagrams is exaggerated in varying amount, and no attempt is made to depict true relative areas of land units. The stated areas of land units are based on random sampling on air photos and are merely an approximate guide.

The land systems are arranged in geomorphological groups as described in Part V and as portrayed on the land system map. Individual land systems can be located by referring to the index.

Further information about the land systems is given in Parts IV–VII, and there is frequent cross-reference to these more detailed accounts. For instance, the heading of the geomorphological description is the same as that under which the land system is described in Part V. The main soils are named as in Part VI, with reference by number–letter designation to the dominant soil association and its equivalent soil landscape. The vegetation communities are numbered and described under the same names as in Part VII.

Under land use is included reference to the pasture land of which the land system forms part. Nine such pasture lands, defined on major pastoral characteristics, are described in Part VIII and are shown on the pasture lands map. Generalized information on stock water, based on Part IX, is also given under land use.

No climate information is given in the land system descriptions, since there is insufficient climatic contrast within the area to differentiate the land systems on this basis.

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|| CHRISTIAN, C. S., and STEWART, G. A. (1953).—General report on survey of Katherine–Darwin region, 1946. C.S.I.R.O. Aust. Land Res. Ser. No. 1.

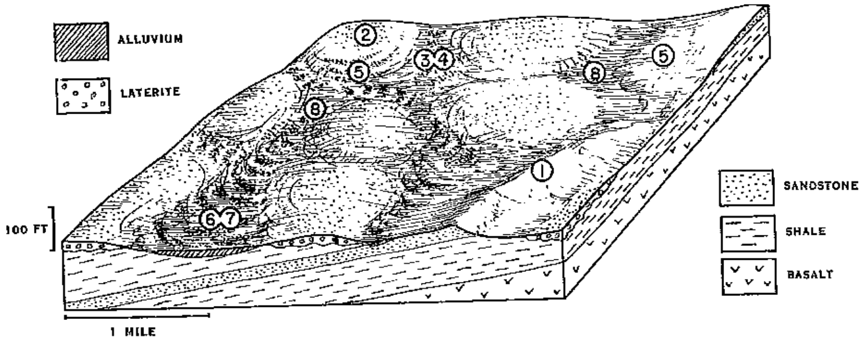
(1) Dural Land System (850 sq. miles)

Strongly undulating terrain with mulga, in the centre of the area.

Geology.—Weathered, gently dipping basalt and interbedded mudstone, shale, and sandstone of Upper Proterozoic age (Nullagine "system").

Geomorphology.—Undulating terrain forming part of the old plateau: strongly undulating tracts with rounded stable crests and lightly stripped slopes, with rockier areas on sandstone; a diffuse pattern of shallow upper valleys, and branching alluvial trains elsewhere; drainage floors and minor channels in areas of through-going drainage or stronger dissection; relief mainly below 40 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved by controlled stocking; improvement possible in units 3, 5, and 6 by clearing, water-spreading, and introductions; drought resistance moderate; adequate stock water of good quality.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	100	**Steeper slopes and crests:** narrow crests attaining 75 ft high; stony slopes, 5–20% and up to ¼ mile long, with rock outcrops and minor breakaways	Very shallow, stony soils between rock outcrops. Rock outcrop and 2	Mulga with gidgee and other *Acacia* spp., inedible shrubs, sparse perennial grasses, forbs, and short annual grasses: *A. aneura* alliance (30, 42); also below breakaways 64
2	250	**Rises:** flat or gently rounded crests 20–40 ft high, up to 1½ miles wide and 3 miles long, with marginal slopes less than 1%; undissected surfaces with lateritic gravel	Reddish gravelly sands on lateritic weathering crusts. 3*d*	Open mulga with scattered gidgee and mallee, sparse perennial grasses, spinifex, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (30, 32); also 5
3	50	Shallow valleys through unit 1: typically ¼ mile wide and up to 3 miles long, gradients 1 in 200 to 1 in 500; unchannelled floors with gentle marginal slopes	Red earths of irregular depth on hard-pan. Principally 4*i*, locally 4*h* with 4*j*, 4*h*	**Groves:** mulga with mostly unpalatable shrubs, sparse perennial grasses, forbs, and short annual grasses: *A. aneura* sub-alliance (27, 28)
4	100			**Intergroves:** similar to unit 2, but more open
5	150	**Gentle lower slopes:** concave, attaining 3% and up to 1 mile long; lightly stripped surfaces with stony upper sectors and with colluvial mantles in lower parts	Principally shallow stony red earths, some clayey sands, on weathered rock, ferricrete, or hard-pan; deeper red earths in groves. 4*b*, locally 4*i*	Diffuse mulga groves with edible shrubs and soft spinifex. Intergroves more open, with less spinifex and more grasses: *A. aneura–Eremophila leucophylla* sub-alliance (5)
6	50	**Alluvial fans:** up to 1 mile long, gradients 1 in 50 to below 1 in 250	Red earths of irregular depth on hard-pan, as in units 3 and 4. Principally 4*i*, locally 4*h* with 4*j*	**Groves:** dense mulga with some edible shrubs and variable, sparse grass layers: *A. aneura* sub-alliance (27, 28, 33); also 3
7	100			**Intergroves:** open mulga, as in unit 6, and also *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
8	<50	**Drainage floors:** mainly up to 150 yd wide, gradients 1 in 100 to 1 in 250; central zones up to 100 yd wide, with minor channels and small flood-banks	Shallow fine-textured red earths on hard-pan. 4*h*	Open mulga and curara with inedible shrubs, forbs, and short annual grasses; increases in density along channels; *A. aneura–A. tetragonophylla* sub-alliance (10, 11)

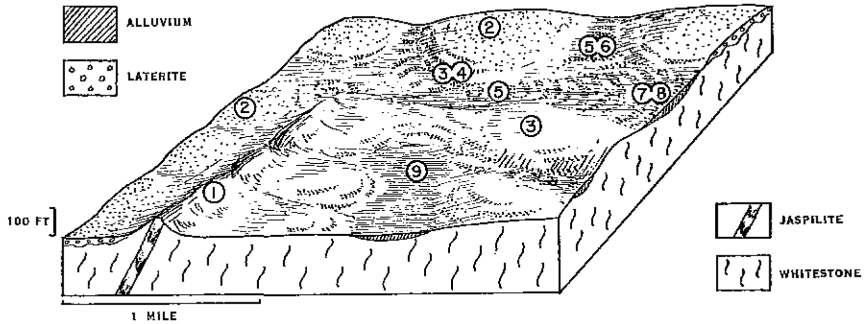
(2) Fisher Land System (150 sq. miles)

Undulating terrain with mulga, in the east of the area.

Geology.—Weathered, steeply dipping feldspathic schist (whitestone) of Archaean age.

Geomorphology.—Undulating terrain forming part of the old plateau: strike belts up to 3 miles wide, with low, rounded interfluves and a diffuse pattern of shallow upper valleys passing downslope into alluvial drainage floors and plains; well-defined channels in areas with through-going drainage; relief mainly below 25 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved by controlled stocking; some improvement possible in units 3, 5, and 7 by clearing, check banks, and introductions; drought resistance moderate; stock water little developed, but probably adequate.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	10	Ridges: up to 50 ft high, 200 yd wide, and 1 mile long; narrow crests with outcrops of lateritized rock; stony slopes, 5–25%	Outcrop with little adjacent soil. Rock outcrop and 2	Feathertop spinifex with very open mulga and gidgee, sparse shrubs, and forbs: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (5)
2	50	Stable crests and slopes: rounded, elongate rises up to 25 ft high and 1 mile wide, slopes less than 2%; undissected surfaces with lateritic gravel	Presumably reddish gravelly sands on lateritic weathering crusts. 3*d*	Similar to unit 1, but with more open spinifex and a greater density of mulga, with edible shrubs and perennial grasses
3	10	Stripped crests and slopes: crests up to ½ mile wide and slopes up to ½ mile long, attaining 5%; surfaces subject to sheet-flow, with stony upper sectors, and with colluvial mantles in lower parts	Principally shallow stony soils on hard-pan, locally on weathered rock on upper slopes. 4*b*, 4*i*	Groves: mulga and gidgee with inedible shrubs, palatable and unpalatable perennial grasses, forbs, and short annual grasses: *A. aneura*–*Eremophila fraseri* sub-alliance (8)
4	50			Intergroves and upper slopes: similar to unit 3, but with dead mulga and with grass layers almost absent
5	<10	Shallow valleys through unit 2: up to ¼ mile wide, gradients about 1 in 250; unchannelled floors with gentle concave marginal slopes	Shallow red earths on hard-pan, deeper in groves. 4*i*	Groves: mulga and other *Acacia* spp. with sparse edible shrubs, spinifex, palatable perennial grasses, and forbs: *A. aneura* sub-alliance (28)
6	<10			Intergroves: similar to unit 5, but with less dense tree and shrub layers
7	<10	Alluvial fans: up to 1 mile long and ¾ mile wide, gradients 1 in 250 to 1 in 500		Groves: mulga with dense shrubs, palatable and unpalatable perennial grasses, and forbs: *A. aneura* sub-alliance (28)
8	10			Intergroves and non-groved areas: similar to unit 7, but with a sparser shrub layer and more spinifex
9	10	Drainage floors: unchannelled surfaces up to ¼ mile wide, gradients below 1 in 250	Red earths on hard-pan or gravel at irregular depths. 4*h*	Open mulga with a moderately dense shrub layer, forbs, and short annual grasses: *A. aneura*–*A. tetragonophylla* (curara) sub-alliance (10)

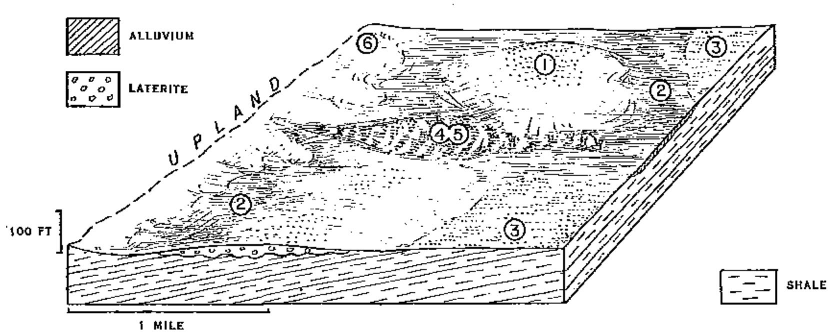
(3) Lorna Land System (180 sq. miles)

Gently undulating, sandy plains with mulga and spinifex, mainly in the east of the area.

Geology.—Weathered, gently dipping mudstone and shale of Upper Proterozoic age (Nullagine "system") and Quaternary aeolian sand.

Geomorphology.—Undulating terrain forming part of the old plateau: gently undulating plains with sand plain in the lowest parts, forming belts up to 5 miles wide; small alluvial fans and ill-defined, unchannelled drainage depressions formed by dispersed run-on from adjacent areas; relief below 20 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved by controlled stocking; units 3 and 6 will produce valuable pastures with rain following burning; stock water undeveloped, but probably adequate.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	**Rises:** gently rounded or flattish crests up to 20 ft high and up to 1 mile in extent; concave marginal slopes, up to 1%	Red clayey sands on lateritic weathering crusts or weathered rock. 3*d*, 3*c*	Dense mulga with edible shrubs, palatable and unpalatable perennial grasses: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (3)
2	50	**Depressions receiving run-on:** typically elongate and up to ½ mile wide	Presumably mainly deep red earths. 4*d*	Mulga with dense shrubs (some edible), palatable and unpalatable perennial grasses, forbs, and annual grasses: *A. aneura–Eremophila leucophylla* sub-alliance (1)
3	30	**Sand plain:** slightly hummocky, loose or lightly firmed surfaces	Presumably deep red clayey sands. Mainly 3*h*	Spinifex with sparse trees and various shrub layers; forbs and annuals numerous after a burn: *Eucalyptus kingsmillii* (mallee)–*A. aneura* alliance (50, 52, 57)
4	10	**Alluvial fans and trains:** slopes up to 1 mile long subject to sheet-flow, gradients 1 in 250 to 1 in 500	Red earths of irregular depth to hard-pan. Presumably mainly 4*h* with 4*j*	**Groves:** mulga with some edible shrubs and various sparse grass layers: *A. aneura* sub-alliance (27, 28, 30)
5	20			**Intergroves:** as in unit 4, but more open; also 10
6	20	**Uneven lower hill slopes:** receiving some run-on	Presumably shallow red earths. 4*b*	Spinifex with mulga and clumps of tall mallee: probably 51

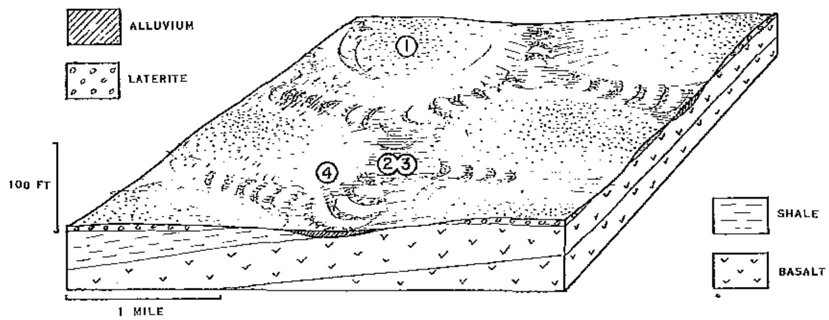
(4) Diamond Land System (180 sq. miles)

Gently undulating plains with mulga and dense shrubs, in the centre of the area.

Geology.—Weathered, gently dipping basalt and interbedded mudstone and shale of Upper Proterozoic age (Nullagine "system").

Geomorphology.—Undulating terrain forming part of the old plateau: very gently undulating watersheds of moderate extent; rounded, stable crests and lightly stripped lower slopes, with a sparse, branching pattern of unchannelled, shallow valleys; relief below 10 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved by controlled stocking; improvement possible in unit 2 by clearing, check banks, and introductions; drought resistance moderate; stock water undeveloped, probably adequate.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	80	Rises: flattish or very gently rounded crests up to 10 ft high and 1½ miles wide, extending up to 3 miles along the strike; concave marginal slopes, 0·5–1%; undissected surfaces with some pebble gravel	Presumably reddish gravelly sands on lateritic weathering crusts. 3*d*	Mulga and other *Acacia* spp. with a dense shrub layer, palatable and unpalatable perennial grasses, patches of feathertop spinifex, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (27); also 3
2	10	Valleys: unchannelled drainage depressions up to ½ mile wide, gradients 1 in 200 to 1 in 500; flat floors and concave marginal slopes up to 0·5%	Red earths of irregular depth on hard-pan. Principally 4*i*, 4*h* with 4*j*	Groves: diffusely groved mulga with edible and inedible shrubs, some palatable perennial grasses, and forbs: *A. aneura* sub-alliance (27, 28)
3	20			Intergroves: as for unit 2, but with slightly more open mulga, fewer shrubs, and more perennial grasses
4	70	Stripped slopes: up to ½ mile long, 0·5–2%; stony, little-dissected surfaces with a few rock outcrops	Principally shallow, stony soils on hard-pan or weathered rock, deeper red earths in groves. Principally 4*b*, locally 4*h* with 4*j*, 4*i*	Open mulga with a dense shrub layer, palatable and unpalatable perennial grasses, and forbs: *A. aneura* sub-alliance (30). Denser tree and shrub layers in groves

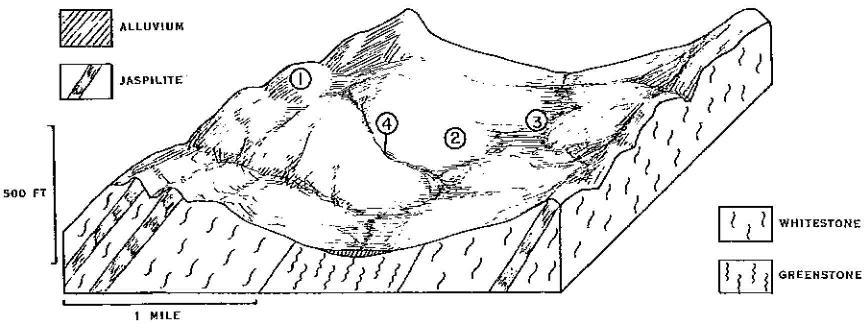
(5) Weld Land System (100 sq. miles)

Rocky whitestone ranges in the west of the area.

Geology.—Steeply dipping hematitic and siliceous jaspilite and weathered quartz-hornblende-schist and chlorite-mica-schist (whitestone and some greenstone) of Archaean age.

Geomorphology.—Surfaces formed by dissection of the old plateau—mountain and hill ranges: mountain ranges in strike belts up to 5 miles wide; narrow ridges with steep slopes and rocky crests formed by jaspilite; watersheds, with a moderately dense, rectangular pattern of incised tributary valleys and narrow alluvial drainage floors; relief mainly below 500 ft.

Land Use.—Hill pastures with stunted mulga shrubland: unit 1 partly inaccessible; elsewhere, ephemeral growth after rain should be stocked; drought resistance low; limited stock water of good quality in unit 3.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	**Mountain ranges**: ridges 150–300 ft high and ¼ mile wide, locally culminating in subconical hills more than 500 ft high, or merging in bevelled uplands up to 2 miles in extent; rocky crests with lateritic ironstone; upper slopes, above 20%, stony but with smoother profiles; small benches with lateritized rock surfaces and breakaway margins; lower sectors, 5–20%, dissected into spurs up to 400 yd wide and 15 ft high, with rounded crests and concave marginal slopes up to 5%	Outcrop with little adjacent soil. Rock outcrop and 2	Open mulga and other *Acacia* spp. with sparse shrubs and forbs; much bare rock: *Acacia aneura* (mulga)–*Eremophila fraseri* sub-alliance (9); also 21, 22
2	40	**Lower slopes**: concave, 1–5% and up to 200 yd long, forming interfluves with slightly convex crests up to 800 yd wide and 5 ft high, and concave marginal slopes up to 100 yd long, attaining 1%; stony surfaces, with rock outcrop and minor calcrete crusts	Shallow, stony soils on hard-pan or rock. 2. Locally shallow calcareous earths. *5a*	Low mulga and other *Acacia* spp. with forbs and sparse short annual grasses: *A. aneura*–*A. linophylla* sub-alliance (39)
3	<10	**Drainage floors**: mainly up to 100 yd wide, gradients ranging from 1 in 250 in strike valleys to above 1 in 50 in tributaries	Gravel and red earths on hard-pan or gravel at irregular depths. 4*h*	Moderately dense mulga with sparse unpalatable shrubs, annual chenopods, and short annual grasses: *A. aneura*–*A. tetragonophylla* (curara) sub-alliance (10); also 39
4	<10	**Channels**: multiple channels up to 15 ft wide and incised to 2 ft, into bedrock in upper sectors or into hard-pan in lower sectors	Bed-loads range from sand to cobbles on bedrock in upper sectors, and from sand to grit on hard-pan in lower sectors	As in unit 3, but denser

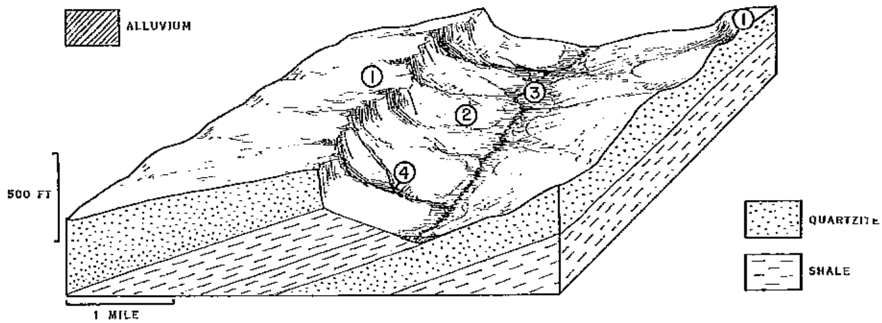
(6) Princess Land System (180 sq. miles)

Rocky sandstone ranges with dense mulga, in the north-east of the area.

Geology.—Gently dipping massive quartzite and interbedded mudstone and shale of Upper Proterozoic age (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—mountain and hill ranges: mountain ranges in strike belts about 5 miles wide; parallel cuestas and plateaux, and strike vales eroded on softer rocks; moderately dense, rectangular pattern of incised, parallel tributary valleys and alluvial drainage floors following strike; relief up to 400 ft.

Land Use.—Hill pastures with stunted mulga shrubland: unit 1 partly inaccessible; elsewhere, ephemeral growth after rain should be stocked; drought resistance low; stock water little developed, partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	80	Mountain slopes and summit ridges: 200–400 ft high, up to 2 miles wide, and extending up to 5 miles along the strike; dip slopes up to 1½ miles long, and broadly rounded upland summits up to ½ mile in extent, slopes generally less than 10%; lower dip slopes locally dissected into flat-crested spurs up to ½ mile wide and 50 ft high; indented escarpments, 5–35%, with minor structural benches; basal scree slopes, 10%; many rock outcrops	Outcrop with little adjacent soil. Rock outcrop and 2	Dense mulga with mostly inedible shrubs, unpalatable perennial grasses, and numerous forbs: *Acacia aneura* (mulga) sub-alliance (30, 31)
2	70	Lower slopes: concave, 1–5% and up to 1 mile long, dissected up to 30 ft into rounded spurs up to ¾ mile wide, with concave marginal slopes attaining 5%; upper parts have numerous outcrops, lower parts are masked with colluvium	Outcrop and shallow stony soils, possibly with some thin hard-pan crusts on rock. Principally 4*b*, local rock outcrop and 2	Dense mulga with scattered gidgee and mallee, inedible shrubs, clumps of feathertop spinifex, forbs, and short annual grasses: *A. aneura* sub-alliance (27, 30)
3	20	Drainage floors: typically up to 150 yd wide, locally attaining 400 yd in lowest sectors; gradients 1 in 50 to 1 in 200	Gravel and red earths on hard-pan or gravel at irregular depths. 4*h*	Dense mulga and other *Acacia* spp. with mostly edible shrubs, abundant herbage, and short annual grasses: *A. aneura* sub-alliance (35)
4	10	Channels: up to 20 ft wide and 5 ft deep, gradients 1 in 50 to 1 in 200	Bed-loads range from sand to cobbles on hard-pan or bed-rock	As in unit 3, but forming a dense fringe

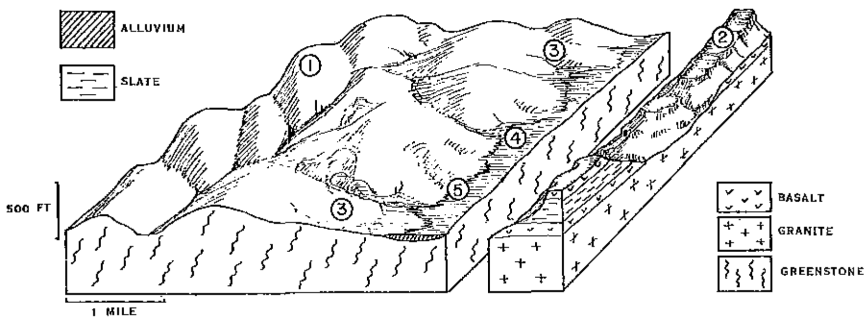
(7) Yagahong Land System (60 sq. miles)

Greenstone hill ranges with open mulga, in the west of the area.

Geology.—Schistose metamorphosed gabbroic and amphibolitic lava (greenstone) of Archaean age; flat-lying Upper Proterozoic slate and basalt (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—mountain and hill ranges: hill ranges of basic schist; closely dissected by a rectangular pattern of drainage tributary to transverse alluvial floors; small, marginally dissected plateaux formed on slate and basalt; relief up to 350 ft.

Land Use.—Hill pastures with stunted mulga shrubland: units 1 and 2 partly inaccessible; ephemeral growth after rain should be stocked; drought resistance low, unit 3 prone to erosion; stock water undeveloped.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	20	**Hills and ridges:** narrowly rounded crests up to 200 ft high; concave slopes, 5–20%, with stony surfaces and many outcrops; lower slope sectors locally dissected 10–25 ft into rounded spurs and narrow valleys with 5–10% slopes	Outcrop with little adjacent soil. Rock outcrop and 2	Very open, stunted mulga with sparse inedible shrubs and short annual grasses: *Acacia aneura* sub-alliance (30)
2	10	**Plateaux:** rocky summits up to 350 ft high and 1 mile in extent, deeply and narrowly dissected in part; escarpments with sheer rock faces, structural benches, and short scree slopes up to 25%		Moderately dense mulga and other *Acacia* spp. with inedible shrubs and forbs and short annual grasses: *A. aneura* (mulga)–*A. craspedocarpa* sub-alliance (15)
3	20	**Lower slopes:** concave, 1·5–5% and up to 400 yd long; mainly dissected into interfluves up to ½ mile wide and 10 ft high, with gently rounded stony crests and concave margins up to 200 yd long, attaining 2%; surfaces subject to sheet-flow and locally masked with colluvium	Shallow, stony soils on hard-pan or rock. *4b*. Possibly locally, shallow calcareous earths. *5a*	Very sparse, stunted mulga with shrubs absent and with sparse short annual grasses: *A. aneura* sub-alliance (21)
4	<10	**Drainage floors:** mainly up to 50 yd wide, gradients above 1 in 100; central channelled zones may occupy whole floors in upper sectors	Gravel and red earths on hard-pan or gravel at irregular depths. *4h*	Open mulga with edible and inedible shrubs and forbs and sparse annual grasses: *A. aneura* sub-alliance (22)
5	<10	**Channels:** multiple runnels, up to 5 ft wide and 1 ft deep, with intervening low stony flood-banks	Bed-loads range from grit to cobbles on hard-pan and gravel, or on bedrock locally in upper sectors	As in unit 4, but forming a dense fringe

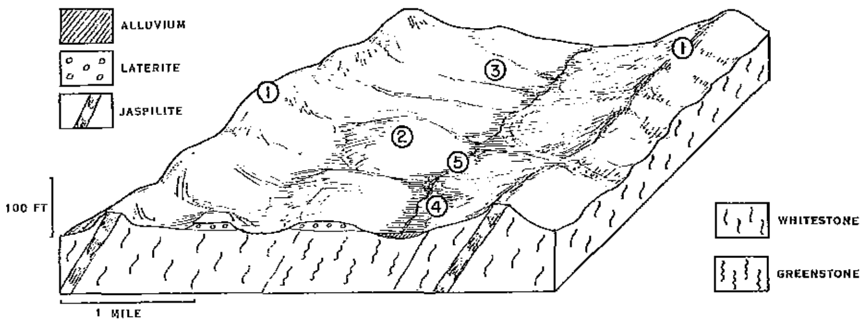
(8) Gabanintha Land System (300 sq. miles)

Whitestone hill ranges with very open mulga.

Geology.—Selectively weathered, steeply dipping quartz-feldspar schist, basic lava, and hematitic and siliceous jaspilite (whitestone with some greenstone) of Archaean age.

Geomorphology.—Surfaces formed by dissection of the old plateau—mountain and hill ranges: strike belts up to about 5 miles wide, with rocky jaspilite ridges, rounded crests with laterite cappings, and extensive lower slopes; strike-controlled or rectangular pattern of incised drainage of moderate density; relief 50–200 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be stocked; drought resistance low; adequate stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	100	Ridges: 50–200 ft high and up to 2 miles long; narrow crests with lateritic ironstone; stony upper slopes, above 15%, with rock ledges; concave mid-slopes, 5–15%, with cobble mantles dissected to 25 ft into rounded spurs up to ½ mile wide, with concave margins, 5–15%	Outcrop with adjacent very shallow, stony soils. Rock outcrop and 2	Mulga with scattered larger trees, moderate ground cover of feathertop spinifex and other perennial grasses: *Acacia aneura* (mulga) sub-alliance (32, 33, 34)
2	10	Rounded hills: up to 75 ft high; flat or gently sloping cappings of pisolitic ironstone or lateritized rock, locally with breakaway margins 5–25 ft high; smooth hill slopes, 5–15%, decreasing to less than 5% on upper sectors below breakaways; all slopes are cobble-mantled, with calcrete crusts locally	Outcrop with very shallow stony soils, and reddish sands on lateritic weathering crusts. Rock outcrop and 2, 3*d*	Open mulga and other *Acacia* spp. with sparse shrubs, forbs, and short annual grasses: *A. aneura–A. linophylla* sub-alliance (39)
3	150	Lower slopes: concave, 0·3–5% and up to 500 yd long, dissected into interfluves up to ½ mile wide and 10 ft high, with flattish crests and concave margins attaining 1%; stony, with calcrete crusts locally	Shallow soils, including red earths and texture-contrast soils on hard-pan or weathered rock. 4*b*, 6*a*	Very open, low mulga with sparse shrubs, forbs, and short annual grasses; commonly degraded: *A. aneura* sub-alliance (21, 22, 34)
4	20	Drainage floors: up to 150 yd wide, transverse slopes up to 1·5%; surface strew from sand to small cobbles; locally with multiple channels and low flood-banks	Gravel and red earths on hard-pan or gravel at irregular depths. 4*h*	Very open mulga with unpalatable shrubs and sparse, unpalatable grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
5	20	Channels: up to 30 ft wide and 4 ft deep, gradients 1 in 150 to 1 in 200	Bed-loads range from sand to small cobbles, mainly on hard-pan breccia	As in unit 4, but forming a denser fringe

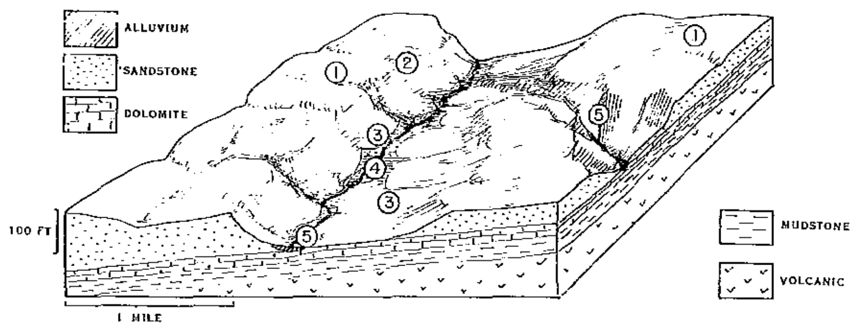
(9) Glengarry Land System (650 sq. miles)

Stony plateaux with mulga and soft spinifex, in the centre and north-east of the area.

Geology.—Partly weathered, gently dipping Upper Proterozoic sandstone and quartzite, with interbedded mudstone and shale, and dolomite (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—sandstone plateaux: prominent plateaux, bevelled ridges, and smaller hills, with steep, rocky slopes and minor lowland tracts, forming dissected watersheds up to 10 miles wide in centre of area; incised, moderately dense, strike-controlled drainage; also as narrower, lower tracts with radial drainage in east of area; relief mainly below 100 ft, locally up to 200 ft.

Land Use.—Hill pastures with stunted mulga shrubland; units 1 and 2 partly inaccessible; elsewhere, ephemeral growth after rain should be stocked; some stock water in unit 4.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	250	**Summits**: strongly undulating surfaces up to 1 mile wide, extending up to 3 miles along the strike, regional slopes up to 2%; locally dissected up to 30 ft, with valley slopes up to 5%; stony surfaces with rock outcrops	Very shallow, stony red clayey sands. 3*b*	Dense mulga, gidgee, and other *Acacia* spp., with scattered tall mallee in some areas, many shrubs, some feathertop spinifex, and other perennial grasses: *Acacia aneura* (mulga) sub-alliance (33)
2	150	**Hill slopes**: concave, mainly up to 15%; small breakaways and benches up to 20 ft high on massive quartzite or silicified rock, and minor steep slopes in kaolinized rock; stony surfaces, in part gullied to 30 ft depth	Outcrop with little adjacent soil. Rock outcrop and 2	Open mulga with dense shrubs, unpalatable perennial grasses, forbs, and short annual grasses: *A. aneura* sub-alliance (30, 31)
3	180	**Lower slopes**: concave, 1–5% and up to 500 yd long; stony, lightly dissected surfaces with rock outcrops in upper parts	Shallow, stony soils on hard-pan or rock. 4*b*	Open mulga and dense shrubs, patches of soft spinifex and short annual grasses: *A. aneura* sub-alliance (27)
4	40	**Drainage floors**: up to 300 yd wide, gradients 1 in 50 to 1 in 150; mainly with channelled central tracts up to 100 yd wide; concave marginal slopes up to 0·5%, with lightly sealed alluvial surfaces and stony patches	Red earths, locally deep and without hard-pan. 4*d*, 4*h*	Mulga of variable density, with edible and inedible shrubs, various perennial grasses with clumps of spinifex, abundant herbage, and short annual grasses: *A. aneura* sub-alliance (35)
5	30	**Channels**: up to 30 ft wide and 6 ft deep, braiding locally, gradients 1 in 15 to 1 in 150	Bed-loads range from sand to boulders on hard-pan or bed-rock	Similar to unit 4, but with fewer perennial grasses

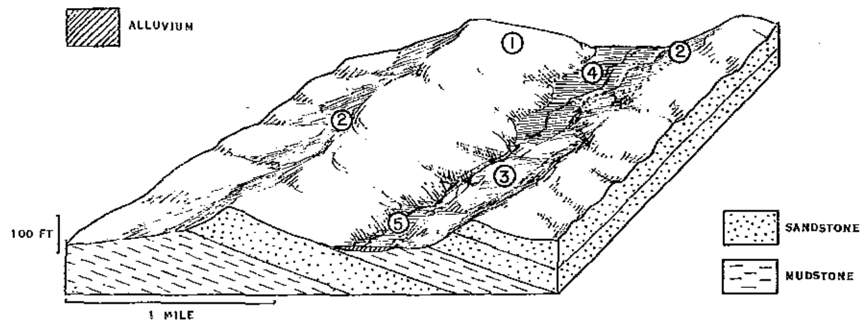
(10) Lynne Land System (250 sq. miles)

Stony plateaux with open mulga, in the centre and north-east of the area.

Geology.—Partly weathered, gently dipping Upper Proterozoic quartzite, sandstone, and feldspathic grit (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateaux—sandstone plateaux: strike belts up to 4 miles wide, with plateaux and bevelled ridges, rocky slopes, and narrow, flanking lowlands; occurring as parallel ridges separated by strike valleys with alluvial flood-plains, or as single ridges with a radial pattern of incised valleys; relief up to 150 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth in units 1–3 after rain should be stocked; palatable pastures in units 1 and 4 should be preserved by controlled stocking; drought resistance moderate; unit 4 subject to severe water and wind erosion; a little stock water in unit 4, but commonly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	60	**Summits:** up to 150 ft high, in strike belts up to 1 mile wide; gently sloping or rounded surfaces with slopes less than 5%; very stony, with many rock outcrops	Outcrop and shallow stony soils. Rock outcrop and 2	Open mulga and other *Acacia* spp. with moderately dense inedible shrubs and palatable and unpalatable perennial grasses: *Acacia aneura* (mulga) sub-alliance (33)
2	70	**Hill slopes:** mainly 5–20%, with ledges and upper breakaways up to 20 ft high formed by quartzite or silicified strata; dissected into rounded spurs up to 50 ft high and ¼ mile wide, with marginal slopes up to 15%		Stunted mulga with sparse shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (29, 30)
3	70	**Lower slopes:** concave, 0·5–3·5% and mainly up to ½ mile long; stony surfaces with minor rock outcrops and extensive colluvial mantles; locally dissected to 5 ft	Shallow, stony soils on rock, locally on hard-pan crusts. 4*b*	As in unit 2, but increasing in density downslope
4	30	**Flood-plains and tributary alluvial drainage floors:** up to 500 yd wide, gradients 1 in 250 to 1 in 1000; levees up to 1 ft high, with back slopes about 0·5%; severely scalded surfaces with multiple shallow runnels, either throughout or in central zones up to 100 yd wide	No records; probably mainly texture-contrast soils. 6*b*	Very sparse mulga with shrub layers of saltbush and bluebush and with forbs and succulents: *A. aneura–Kochia pyramidata* (bluebush) alliance (60)
5	20	**Channels:** up to 50 ft wide and 5 ft deep	Bed-loads mainly sand, with low banks of pebble gravel	Dense fringing community of *Acacia* spp. with some tall eucalypts and shrubs: 72; also 60

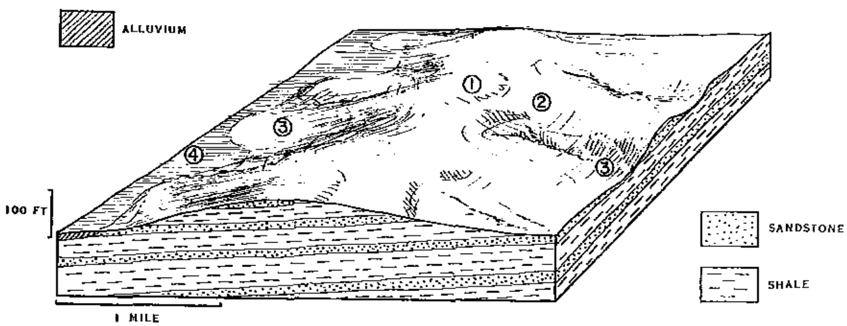
(11) Doman Land System (120 sq. miles)

Low, stony uplands with open mulga, in the north-east of the area.

Geology.—Partly weathered, gently dipping interbedded shale and sandstone of Upper Proterozoic age (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—sandstone plateaux: subdued plateaux and rounded uplands in strike belts up to 4 miles wide; fairly extensive, undissected summits; gentle bounding slopes, stony in upper parts and with colluvial mantles in lower sectors, dissected by a sparse or moderately dense radial drainage; relief mainly up to 75 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be stocked; drought resistance low; stock water undeveloped.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	30	**Summits:** mainly up to 75 ft high, 1½ miles wide; rounded or gently sloping, with slopes less than 5%; very stony surfaces with many rock outcrops	Outcrop and shallow stony soils. Rock outcrop and 2	Probably mulga and other *Acacia* spp. with moderately dense inedible shrubs and palatable perennial grasses: *Acacia aneura* (mulga) sub-alliance (33)
2	40	**Hill slopes:** up to 1 mile long and mainly above 5%; dissected into stony spurs up to ½ mile wide and 25 ft high		Stunted mulga with sparse shrubs and short annual grasses: *A. aneura* sub-alliance (27, 29, 30)
3	40	**Lower slopes:** concave, 0·25–3·5% and up to ½ mile long; extensively masked with colluvium	Principally shallow stony soils; locally red earths of irregular depth to hard-pan near groves. 4*b*, locally 4*i*	Locally groved pattern of mulga with inedible shrubs, palatable and unpalatable perennial grasses, clumps of spinifex, and short annual grasses: *A. aneura* sub-alliance (29)
4	10	**Alluvial drainage floors:** up to 100 yd wide, gradients less than 1 in 200; flat floors with multiple shallow runnels	Presumably red earths on hard-pan or gravel at irregular depths. 4*h*	Fringing community of mulga and scattered larger trees with shrubs and assorted perennial grasses

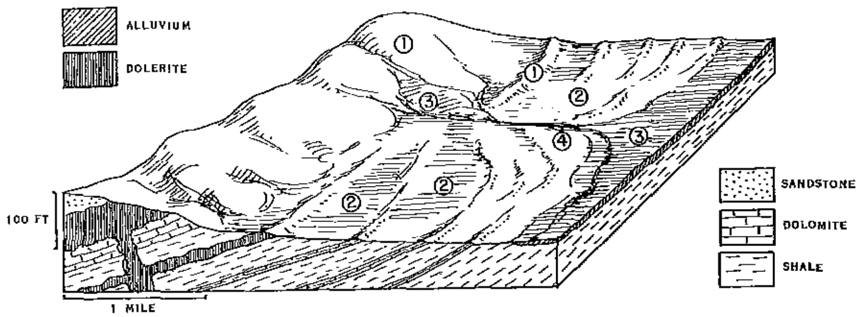
(12) WONGAWOL LAND SYSTEM (120 SQ. MILES)

Uplands and degraded rocky lowlands with stunted mulga, in the north-east of the area.

Geology.—Slightly weathered, gently dipping, interbedded sandstone, shale, and dolomite of Upper Proterozoic age (Nullagine "system"), with dolerite sills and dykes.

Geomorphology.—Surfaces formed by dissection of the old plateau—sandstone plateaux: strike belts up to 10 miles wide, with plateaux and rounded uplands; plains traversed by low dolerite ridges, with intervening shale depressions with clay pans; moderately dense, strike-controlled drainage, with a dense branching pattern of incised tributary valleys on upland flanks, and with narrow alluvial flood-plains; relief up to 100 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be stocked; drought resistance low; unit 2 subject to severe degeneration and erosion; little stock water, mainly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	90	**Rocky slopes and upland surfaces:** flattish summits up to 100 ft high and 1½ miles wide; upland margins dissected into spurs with gently rounded crests up to 50 ft high and ¼ mile wide; also, narrow strike rises up to 20 ft high and 300 yd wide; stony or boulder-strewn slopes up to 10%, with small rock ledges in upper parts	Outcrop and shallow stony soils. Rock outcrop and 2	Very stunted mulga with sparse shrubs and forbs and short annual grasses: *Acacia aneura* (mulga) sub-alliance (21)
2	20	**Strike depressions:** flat, sealed surfaces up to 200 yd wide, with extensive clay pans	Scalded surfaces, including shallow alluvial and stony soils on rock	Bare ground
3	10	**Flood-plains and tributary alluvial fans:** fans up to ½ mile long, gradients 1 in 100 to 1 in 250; discontinuous flood-plains up to ¼ mile wide; sealed surfaces with stone patches throughout	No records	Open mulga and *Acacia* spp. with very sparse shrubs and forbs and short annual grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
4	<10	**Channels:** up to 20 ft wide and 1 ft deep; gradients above 1 in 100	No bed-load	Fringing community of open mulga with sparse shrubs and forbs and short annual grasses

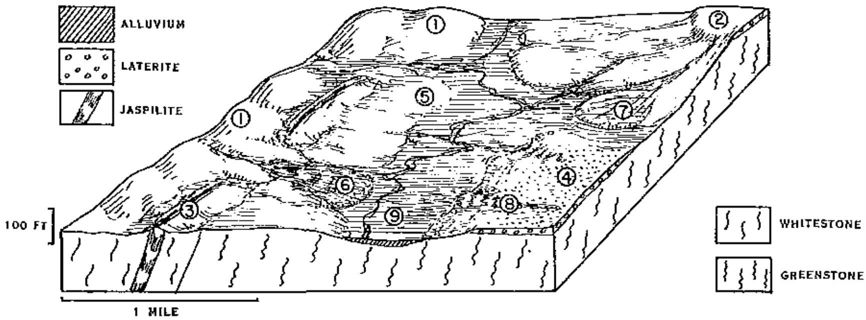
(13) Wiluna Land System (700 sq. miles)

Greenstone hill belts and stony lower slopes.

Geology.—Archaean: weathered, steeply dipping metavolcanic and metasedimentary schist with minor hematitic and siliceous jaspilite (greenstone with some whitestone).

Geomorphology.—Surfaces formed by dissection of the old plateau—low hills: strike belts up to 10 miles wide; dissected higher parts, with minor stable surfaces, rounded hills with laterite cappings, and ridges; undulating lower parts with stony slopes; fairly dense drainage, with alluvial strike valleys and incised, branching tributaries; relief up to 75 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be stocked, and chenopods and palatable grasses in units 5 and 7 encouraged by controlled stocking; low drought resistance; degradation in unit 5; adequate stock water in unit 9 but with some salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	200	**Rounded hills:** 25–75 ft high and up to 1 mile wide; stony slopes up to 15%, decreasing to 5% in upper parts; lower slopes dissected into rounded spurs up to 20 ft high	Shallow, gravelly and stony soils on laterite or hard-pan. Rock outcrop and 2, minor 3*d*, 4*b*	Open mulga and gidgee with sparse unpalatable shrubs, forbs, and short annual grasses: *Acacia aneura* (mulga)–*A. tetragonophylla* (curara) (11) and *A. aneura* (22, 23) sub-alliances
2	60	**Laterite cappings:** rounded or sloping surfaces up to 400 yd in extent, with much ironstone gravel; marginal breakaways up to 15 ft high	Outcrop with little adjacent soil. Rock outcrop and 2	Fairly dense mulga and gidgee with open shrubs, forbs, clumps of spinifex, and other perennial grasses: *A. aneura* sub-alliance (24, 31); also 42
3	30	**Strike ridges:** narrow, rocky crests up to 75 ft high and 1 mile long; concave slopes, 5–25%		Sparse trees, shrubs, chenopods, and short annual grasses: *A. aneura* sub-alliance (21)
4	50	**Stable crests and slopes:** up to 1 mile in extent, with up to 30 ft of relief; rounded crests, and smooth concave slopes, 1·5–7%	Reddish gravelly sands on lateritic weathering crusts. 3*d*	Dense mulga with a moderately dense shrub layer, feathertop spinifex, and unpalatable perennial grasses: *A. aneura* sub-alliance (34)
5	200	**Lower slopes:** concave, up to 400 yd long, 0·5–5%; partly dissected into interfluves up to 10 ft high and ½ mile wide, with concave margins up to 200 yd long, attaining 1%	Shallow, stony soils, including red earths, calcareous earths, and texture-contrast soils; deeper red earths in groves. 4*b*, 6*a*, 4*i*	Open mulga with unpalatable shrubs, perennial grasses, sparse forbs, and short annual grasses: *A. aneura* sub-alliance (22); also 7. Groves of denser mulga and shrub layers: *A. aneura* sub-alliance (28)
6	20	**Alluvial fans and plains:** up to 1½ miles long and 500 yd wide, gradients above 1 in 100	Red earths of irregular depth on hard-pan. 4*i*	Groved mulga with unpalatable shrubs and forbs (chenopods): *A. aneura* sub-alliance (27)
7	20		Stony texture-contrast soils with coarse-structured clay soils around gilgais. 6*c*	Very open mulga with palatable shrubs, herbage, and chenopods: *A. aneura* sub-alliance (60, 68); denser mulga and other *Acacia* spp. around gilgais: *A. aneura–A. sclerosperma* sub-alliance (18)
8	30	**Shallow valleys through unit 4:** up to 200 yd wide and 2 miles long, gradients about 1 in 100, ill-defined central drainage tracts	Mainly red earths; locally alluvial soils on hard-pan or gravel at irregular depths. 4*h*, minor 4*h* with 4*j*, 1*d*	Dense groves of mulga and other *Acacia* spp.: *A. aneura–A. craspedocarpa* sub-alliance (15); intergroves of more open mulga: *A. aneura* sub-alliance (21)
9	70	**Drainage floors:** up to 100 yd wide, gradients above 1 in 300; multiple shallow channels		Dense mulga, edible and inedible shrubs, forbs, short annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (11); also fringing community (73)

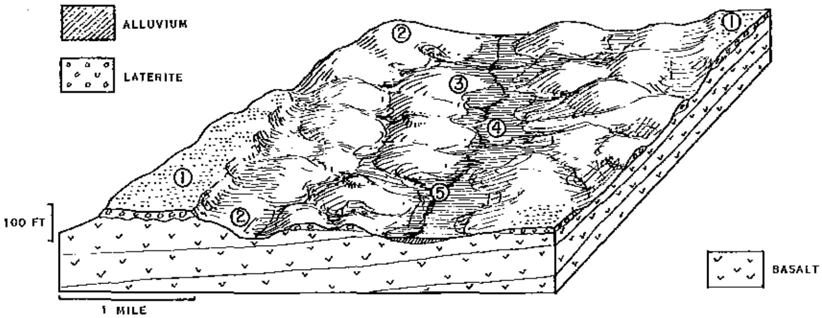
(14) Killara Land System (540 sq. miles)

Broken basalt hill lands with open mulga, in the centre of the area.

Geology.—Weathered, gently dipping Upper Proterozoic basalt (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—low hills: strike belts up to 5 miles wide, with undulating stable watersheds, extensive hills, and stony slopes; dense pattern of incised, branching tributaries and narrow alluvial drainage floors, mainly transverse to strike; relief 25–75 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be stocked; adequate stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	Stable interfluves: undulating surfaces with rounded rises up to 15 ft high and 1½ miles in extent, and undissected slopes, less than 2%; traversed by shallow unchannelled drainage zones up to 50 yd wide and 3 ft deep; extensive veneer of lateritic pebbles	Reddish gravelly sands on lateritic weathering crusts. 3*d*	Very open mulga and gidgee with edible shrubs, patches of spinifex, sparse forbs, and short annual grasses: *A. aneura* (mulga)–*Eremophila leucophylla* sub-alliance (4)
2	200	Stripped, dissected surfaces: gently sloping margins of unit 1, up to ¼ mile wide, or accordant low hill crests; stony surfaces capped with lateritic gravel or ferruginized rock, marginally dissected up to 25 ft, with breakaways up to 10 ft high and gullied concave hill slopes, 3–20%	Weathered rock surfaces with some shallow, stony soils, locally on hard-pan crusts; very locally shallow calcareous earths. Rock outcrop and 2, 4*b*	Open mulga with mostly inedible shrubs and unpalatable perennial grasses, including clumps of spinifex: *A. aneura* sub-alliance (34)
3	200	Lower slopes: concave, up to ½ mile long, and attaining 3%; partly dissected up to 5 ft, with marginal slopes up to 1%; stony upper sectors with minor outcrops; lower parts masked with colluvium	Shallow red earths with stone pavement on hard-pan; deeper red earths in groves. 4*i*	Open mulga and other *Acacia* spp. with moderately dense inedible shrubs, forbs, and short annual grasses; locally in a diffuse grove pattern: *A. aneura* sub-alliance (21, 30)
4	60	Drainage floors: up to ¼ mile wide, gradients 1 in 100 to 1 in 500; concave marginal slopes up to 1%; upper sectors have central channelled zones up to 100 yd wide, lower sectors are unchannelled	Red earths of irregular depth on hard-pan or gravels. 4*h*	Moderately dense mulga and edible and inedible shrubs, unpalatable perennial grasses, abundant herbage, and short annual grasses; locally in a diffuse grove pattern: *A. aneura*–*A. tetragonophylla* (curara) (10) and *A. aneura* (27) sub-alliances
5	30	Channels: up to 10 ft wide and 3 ft deep; narrowly incised into bedrock in unit 2, with gradients 1 in 50 to 1 in 150; multiple channels incised into hard-pan in unit 4	Bed-loads mainly coarse sand to pebbles	Dense mulga and other *Acacia* spp. with edible shrubs, spinifex and unpalatable perennial grasses, forbs, and short annual grasses: *A. aneura*–*A. craspedocarpa* sub-alliance (15)

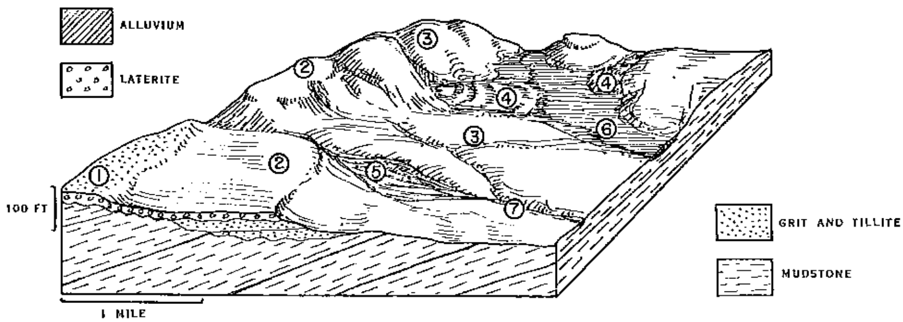
(15) Sodary Land System (400 sq. miles)

Stony uplands and plains and bluebush flats, in the north-east of the area.

Geology.—Partly weathered, gently dipping, thinly bedded Upper Proterozoic mudstone and shale (Nullagine "system"), overlain by deeply weathered, flat-lying (?)Permian feldspathic grit and boulder tillite.

Geomorphology.—Surfaces formed by dissection of the old plateau—low hills: rounded ridges and small uplands, with minor summit remnants of weathered grit; extensive stony lowlands with broad, partly saline alluvial plains; dense pattern of incised branching upper valleys; relief up to 100 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth in unit 3 after rain should be stocked, palatable pasture in units 2 and 5 preserved by controlled stocking; drought resistance low; erosion hazard in unit 5; check banks possible in unit 4; stock water little developed, but partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	<10	**Stable summits:** undulating stony surfaces up to ¾ mile in extent, with up to 20 ft of relief, slopes less than 2%; rounded interfluves up to ½ mile wide, and valleys up to ¼ mile wide	No records; possibly reddish, gravelly sands on laterite. 3*d*. Otherwise, shallow stony soils on weathered rock or hard-pan crusts. 4*b*	Open mulga with inedible shrubs and unpalatable perennial grasses: *Acacia aneura* (mulga) sub-alliance (30, 33)
2	50	**Partly stripped summits:** up to 2 miles in extent, regional slopes less than 3%, marginal slopes up to 10%; stony surfaces, with outcrops of weathered rock; marginal breakaways up to 10 ft	Outcrop and shallow stony soils on weathered rock or hard-pan crusts. 4*b*, also rock outcrop and 2	Low, dense *Acacia* spp. with sparse shrubs and unpalatable perennial grasses: *A. aneura* sub-alliance (36)
3	250	**Stripped summits and slopes:** rounded crests up to 50 ft high; upper slopes mainly 5–20%, attaining 40% in weathered rock below breakaways; concave lower slopes, 0·5–3·5% and up to ¼ mile long, lightly dissected stony surfaces with rock outcrops in upper parts and colluvial mantles downslope		Open mulga with scattered gidgee and mallee, sparse shrubs, sparse unpalatable perennial grasses, forbs, and short annual grasses: *A. aneura* sub-alliance (34)
4	20	**Alluvial fans:** up to ⅓ mile wide, gradients above 1 in 250	Red earths of irregular depth on hard-pan. 4*h* with 4*j*	Groved mulga with edible shrubs, forbs, and short annual grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10, 11)
5	50	**Alluvial plains derived from weathering zones:** upper sectors less than 200 yd wide, gradients about 1 in 150; lower sectors up to 1 mile in extent, gradients less than 1 in 250	Shallow texture-contrast soils on hard-pan, locally with gilgais. 6*d*, locally 6*c*	Open mulga with sparse shrubs (mostly chenopods), patches of herbage, and short annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (10); also 21, 60
6	20	**Drainage floors:** up to 300 yd wide, with channelled central tracts up to 100 yd wide; gradients less than 1 in 250	Red earths on hard-pan or gravel at irregular depths. 4*h*	Dense mulga with inedible shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (21, 25)
7	<10	**Channels:** 30 ft wide and incised to 3 ft into hard-pan or bedrock	Ill-sorted bed-loads ranging from sand to cobbles	A fringe of dense mulga and other *Acacia* spp.: probably 35

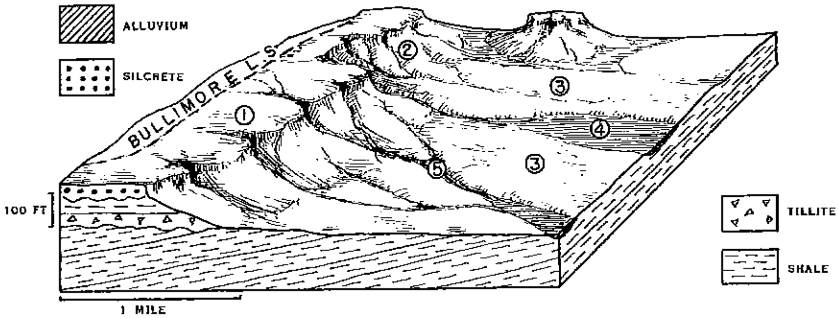
(16) Tooloo Land System (120 sq. miles)

Plateaux with steep, stony slopes with saline soils, in the east of the area.

Geology.—Kaolinized, flat-lying (?)Permian feldspathic grit and siltstone boulder tillite, with silcrete duricrust, overlying gently dipping Upper Proterozoic shale and mudstone (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—duricrusted plateaux and benches: dissected belts up to 4 miles wide, consisting of small plateaux with flat rocky summits with silcrete duricrust, and steep, dissected slopes; closely spaced gullies on hill slopes, tributary to drainage floors with saline alluvium; relief up to 150 ft.

Land Use.—Hill pastures with stunted mulga shrubland: units 2–4 support palatable halophytes and are prone to degeneration but are isolated and hence difficult to preserve, so should be sacrificed; ephemeral growth after rain in units 1 and 6 should be heavily stocked; stock water undeveloped, probably restricted, and saline in part.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	30	Summits: up to 150 ft high and 1½ miles in extent, slopes generally less than 5%; silcrete duricrusts with a mantle of derived boulders	Stony pavements of silcrete with little soil. Rock outcrop and 2	Open mulga with inedible shrubs, spinifex and other unpalatable perennial grasses, and forbs: *Acacia aneura* (mulga) sub-alliance (32, 34)
2	30	Hill slopes: marginal breakaways up to 30 ft high; concave slopes in weathered rock, 15–50%; loose, stony surfaces, closely dissected up to 15 ft, with valley slopes up to 35%		Low open halophytic shrubland with sparse tall shrubs, forbs, and annual chenopods: *A. aneura–Kochia pyramidata* (bluebush) alliance (64)
3	40	Lower slopes: concave, up to 5% and ¾ mile long; partly dissected into flat-crested spurs up to 15 ft high, ¼ mile wide, marginal slopes up to 3%; upper parts stony; less dissected lower parts with colluvial mantles	Presumably texture-contrast soils	Halophytic shrubland with forbs and annual chenopods; locally with groves of mulga and other *Acacia* spp.: *A. aneura–K. pyramidata* alliance (64); also 29
4	10	Alluvial fans and valley tracts: fans up to 400 yd long, gradients about 1 in 100; tracts up to ¼ mile wide, gradients less than 1 in 100; braiding shallow runnels; some gilgais in lower sectors	Shallow, gritty texture-contrast soils on hard-pan, 6*d*	Low halophytic shrubland with annual chenopods and short annual grasses: *A. aneura–K. pyramidata* alliance (64)
5	<10	Incised channels: up to 10 ft wide and 2 ft deep, gradients 1 in 25 to 1 in 100	Bed-loads are ill-sorted and range from sand to boulders, commonly on bedrock	Fringing community of mulga and other *Acacia* spp.: probably *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)

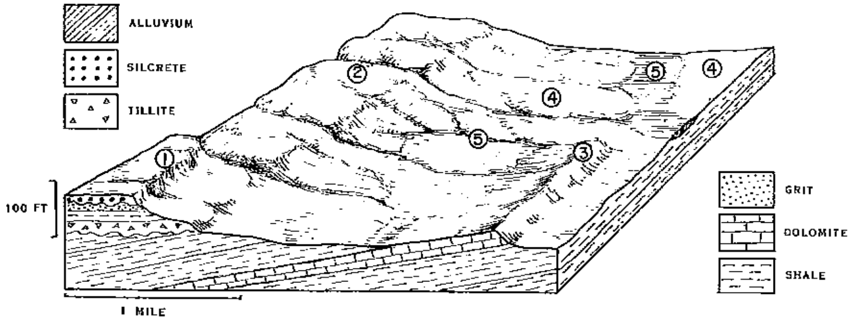
(17) Boondin Land System (300 sq. miles)

Broken uplands and stony plains with bluebush flats, in the east of the area.

Geology.—Weathered, flat-lying (?)Permian feldspathic grit and siltstone boulder tillite, with minor silcrete duricrust, overlying gently dipping Upper Proterozoic shale, dolomite, and mudstone (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—duricrusted plateaux and benches: belts up to 5 miles wide, consisting of dissected uplands and spurs with summit remnants of silcrete duricrust; limestone foothills; lowlands with saline alluvial drainage floors; moderately dense pattern of incised branching tributary valleys; relief up to 100 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be heavily stocked; units 4 and 5 prone to degeneration and erosion; stock water little developed, probably adequate in units 5 and 6, although partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	10	**Summit remnants:** duricrusted, flat or gently sloping rocky summits up to $\frac{1}{2}$ mile in extent, local slopes up to 5%; boulder mantle; marginal breakaways up to 30 ft high	Stony pavements of silcrete with little soil. Rock outcrop and 2	Moderately dense mulga and gidgee with a dense shrub layer, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (30, 32, 33)
2	130	**Spurs, uplands, and hill slopes:** eroded below unit 1; flattish or slightly rounded stony crests, 50–100 ft high and up to $\frac{3}{4}$ mile in extent; main hill slopes are concave, attaining 50% in weathered rock below breakaways; spur margins are mainly convex, up to 15%		Moderately dense mulga, gidgee, and other *Acacia* spp., with a dense shrub layer, feathertop spinifex and other perennial grasses, sparse forbs, and short annual grasses: *A. aneura* sub-alliance (30)
3	<10	**Limestone foothills:** ridges about 50 ft high and $\frac{1}{4}$ mile long; benched, rocky slopes	Outcrop and very shallow, stony calcareous soils. Rock outcrop and 2	Sparse mulga and *Acacia* spp. with few edible shrubs, calciphilous forbs, and short annual grasses: *A. aneura–A. sclerosperma* sub-alliance (18)
4	100	**Lower slopes:** concave, up to 3 miles long and attaining 5%; dissected into interfluves up to 10 ft high and $\frac{1}{2}$ mile wide, with concave marginal slopes, 0·5–1%	Stony soils, including shallow texture-contrast soils on hardpan. 6*a*	Open mulga with inedible shrubs, forbs, chenopods, and short annual grasses: *A. aneura* sub-alliance (29)
5	40	**Drainage floors:** up to $\frac{1}{2}$ mile wide, gradients 1 in 100 to 1 in 250; central channelled tracts up to 200 yd wide; stony surfaces with scalds and clay pans	Presumably principally texture-contrast soils. Either 6*b* or 6*d*	Probably tall halophytic shrubland, with sparse trees, chenopods, herbage, and short annual grasses: *A. aneura–Kochia pyramidata* (bluebush) alliance (63)
6	20	**Channels:** up to 25 ft wide and 5 ft deep	Bed-loads of coarse sand	Fringing community, probably of *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)

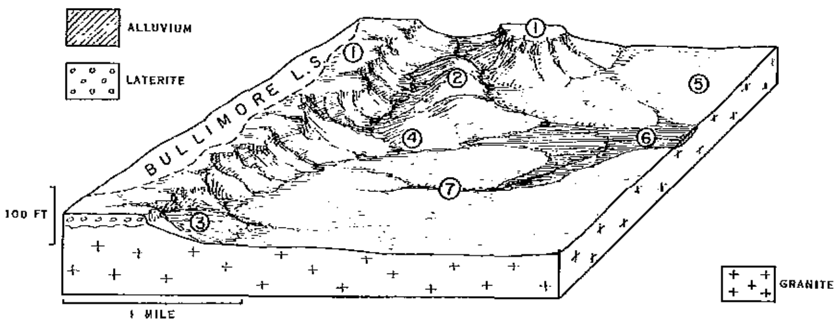
(18) Sherwood Land System (2200 sq. miles)

Widespread stony granite plains with laterite breakaways.

Geology.—Weathered and unweathered Archaean gneiss and granite.

Geomorphology.—Surfaces formed by dissection of the old plateau—breakaways and plains: marginal breakaways formed in mottled zone; escarpments and alluvial fans in or derived from kaolinized rock; stony plains and small hills eroded in little-weathered rock; moderately dense, branching or rectangular, joint-controlled drainage with prominent alluvial drainage floors; relief up to 50 ft.

Land Use.—Stony plains with short grass–chenopod pastures: ephemeral growth could be heavily stocked, or perennial chenopods in unit 5 regenerated if rested; moderate drought resistance; unit 3 prone to shallow gullying; stock water plentiful in unit 6, but locally saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	150	**Stripped lateritized surfaces:** up to ⅓ mile wide, slopes less than 2%; rocky pitted surfaces locally with silcrete or ironstone gravel; escarpments up to 50 ft high, with breakaways up to 15 ft high in hardened rock, 5–10 ft cavernous zones, and rocky scree slopes, 10–40%	Outcrop with little adjacent soil. 2	Stunted mulga with scattered native pines; much bare rock: *Acacia aneura* (mulga)–*Callitris hugelii* (native pine) sub-alliance (43)
2	50	**Hills:** domes up to 30 ft high; bare rock surfaces with joint clefts and benches		Very open mulga and other *Acacia* spp. with sparse shrubs and grasses; much bare rock: *A. aneura* sub-alliance (26)
3	250	**Alluvial fans:** up to ½ mile long, locally extending as valley tracts up to 1 mile downslope; gradients 1 in 25 to 1 in 200; shallow distributary channels	Mainly shallow, gritty texture-contrast soils on hard-pan, locally brown alluvial sands. 6*d*	Stunted, very open mulga with shrubs sparse or absent, but with numerous annual bluebush species and short annual grasses; scattered denser clumps of mulga: *A. aneura*–*A. tetragonophylla* (curara) sub-alliance (10); also 21
4	200	**Hill-foot slopes:** concave, 1·5–5% and up to ¼ mile long; rock outcrops in upper sectors, shallowly dissected thin detrital mantles in lower sectors	Gritty red clayey sands on rock. 3*a*	Very open mulga with sparse shrubs and short annual grasses: *A. aneura*–*Eremophila fraseri* (6) and *A. aneura* (21) sub-alliances
5	1300	**Plains:** slopes less than 1·5%, forming convex or flat-crested interfluves up to ¾ mile wide, 2 miles long, and 10 ft high; stony crests with rock outcrops, and less stony, concave marginal slopes up to 200 yd long and attaining 1·5%	Very shallow stony soils on weathered rock, locally with a thin hard-pan crust. 2	Open mulga with sparse shrubs, chenopods, and short annual grasses: *A. aneura*–*A. tetragonophylla* sub-alliance (10)
6	150	**Drainage floors:** up to 250 yd wide, gradients 1 in 100 to 1 in 250, locally passing into alluvial flood-plains up to ¾ mile wide, gradients 1 in 250 to 1 in 500; flat, or with marginal slopes up to 0·5%	Red earths on hard-pan or gravels at irregular depths, locally alluvial soils. 4*h*, minor 1*d*	Dense mulga and other *Acacia* spp. with edible shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (35)
7	100	**Channels:** mainly up to 10 ft wide, and incised to 1 ft into hard-pan or bedrock	Bed-loads range from sand to small cobbles	As in unit 6, but forming dense fringe

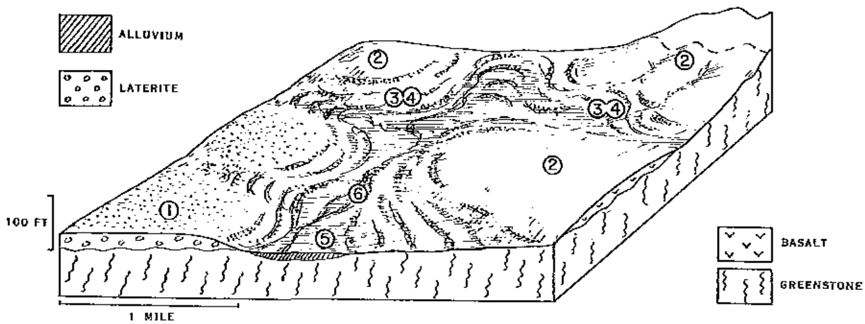
(19) Violet Land System (850 sq. miles)

Widespread undulating plains with dense mulga.

Geology.—Weathered, steeply dipping, Archaean basic schist (greenstone) and gently dipping Upper Proterozoic basalt (Nullagine "system").

Geomorphology.—Surfaces formed by dissection of the old plateau—breakaways and plains: gently rounded, stable or lightly stripped crests and extensive lower slopes; sparse pattern of parallel, through-going alluvial drainage floors; little channel drainage except in uppermost sectors; relief up to 30 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved through controlled stocking; check banks and removal of upper storey would improve unit 3; adequate stock water in units 3–6.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	150	**Stable interfluves:** 10–30 ft high and up to 1½ miles in extent; undissected, gently rounded or sloping crests and concave lower slopes, 1–5%; widespread ironstone gravel	Mainly reddish gravelly sands on lateritic weathering crusts. 3*d*	Dense mulga and gidgee and scattered clumps of mallee with edible shrubs, palatable and unpalatable perennial grasses, and numerous forbs; *Eucalyptus kingsmillii* (mallee)–*Acacia aneura* (mulga) alliance (54); also 4, 57
2	200	**Stripped interfluves:** generally up to 15 ft high and 1 mile in extent locally forming spurs up to 50 ft high and sloping up to 5% from adjacent higher ground; flat or gently rounded crests, locally with dissected laterite cappings; concave margins, 0·5–3%, attaining 10% below cappings; stony, with minor rock outcrops	Shallow, stony soils on ferruginized rock, ferricrete, or hard-pan; very shallow near outcrop. Principally 4*b*, rock outcrop and 2	Dense mulga and other *Acacia* spp., unpalatable shrubs, feathertop spinifex, and other perennial grasses: *A. aneura–A. linophylla* sub-alliance (41)
3	100	**Lower slopes:** concave, 0·2–2% and up to 2 miles long; forming interfluves up to 5 ft high and 1 mile wide, with marginal slopes 0·5–1% and up to 400 yd long; undissected surfaces subject to sheet-flow and masked with colluvium	Red earths of irregular depth on hard-pan. 4*i*, 4*h* with 4*j*	**Groves:** mulga and gidgee with a dense layer of edible and inedible shrubs, palatable perennial grasses, and forbs: *A. aneura* sub-alliance (21, 27); locally 28
4	350			**Intergroves:** similar to unit 3, but more open and with a higher proportion of inedible species
5	50	**Drainage floors:** up to 400 yd wide, gradients 1 in 200; flat central floors, unchannelled, except locally in upper sectors; marginal slopes 0·5–1%	Red earths on hard-pan or gravel at irregular depths. 4*h*	Dense mulga and scattered tall eucalypts with shrubs, perennial grasses, herbage, and short annual grasses: 72
6	10	**Channels:** multiple shallow runnels with low flood-banks		

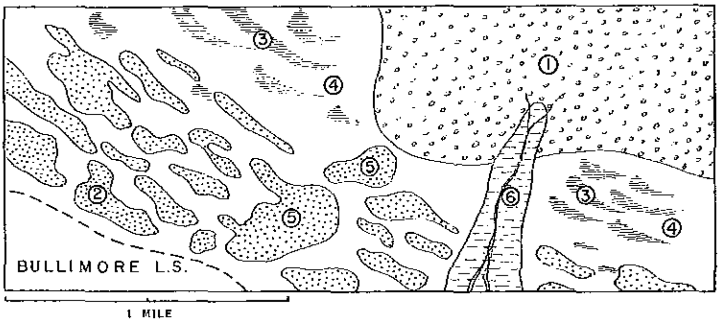
(20) Millrose Land System (280 sq. miles)

Stony plains with wanderrie banks, in the east of the area.

Geology.—Quaternary aeolian sand and alluvium on partly weathered Archaean gneiss and granite.

Geomorphology.—Surfaces formed by dissection of the old plateau—breakaways and plains: stony higher parts; lower slopes mantled with colluvium, with wanderrie banks and vegetation groves; small sand plain remnants; surface drainage mainly sheet-flow, locally confined to branching, shallow alluvial floors; relief up to 10 ft.

Land Use.—Open mulga with wanderrie shrubland: palatable pastures in units 2 and 3 should be preserved; ephemeral growth after rain in units 1, 4, and 6 should be heavily stocked; check banks possible in unit 3; adequate stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	60	Stony plains: rises or interfluves up to 10 ft high and 1 mile wide; convex or flat crests with minor rock outcrops, slopes generally less than 0·25%; concave margins, locally attaining 1%	Very shallow soils on weathered rock, locally with a thin hard-pan crust. 2	Stunted mulga with sparse shrubs and short annual grasses: *Acacia aneura* (mulga) sub-alliance (22), commonly very degraded
2	80	Wanderrie banks: mainly up to 50 yd wide, locally developing into irregular patches up to 300 yd in extent; less than 6 in. high; hummocky surfaces with 1 ft relief; alternating with unit 4	Red clayey sands on hard-pan. 3*g*	Wanderrie-type open mulga with edible shrubs, palatable perennial grasses, and minor clumps of spinifex: *A. aneura–Eremophila leucophylla* sub-alliance (1)
3	20	Surfaces subject to sheet-flow: average gradient 0·2%	Principally shallow red earths, of irregular depth in and near vegetation groves. 4*h*, 4*h* with 4*j* and presumably 4*i*	Groves: mulga with various shrub layers, some palatable perennial grasses, chenopods, and scattered clumps of spinifex: *A. aneura–Eremophila leucophylla* sub-alliance (1); also 10, 60
4	100			Intergroves and wanderrie flats: very open, stunted mulga with unpalatable shrubs, and short annual grasses and scattered clumps of spinifex: *A. aneura–Eremophila fraseri* sub-alliance (6)
5	10	Sand plain: patches up to ½ mile in extent, commonly aligned downslope; hummocky surfaces	Coarse-textured soils, mainly red clayey sands. 3*h*	Spinifex with mulga and scattered mallee, numerous shrubs, forbs, and annual grasses: *Eucalyptus kingsmillii* (mallee)–*A. aneura* alliance (51, 52); also 59
6	10	Drainage floors: up to ⅓ mile wide, gradients above 1 in 500; flat floors traversed by small channels locally	Red earths on hard-pan. 4*h*	Stunted mulga with few shrubs and sparse short annual grasses; much bare ground: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)

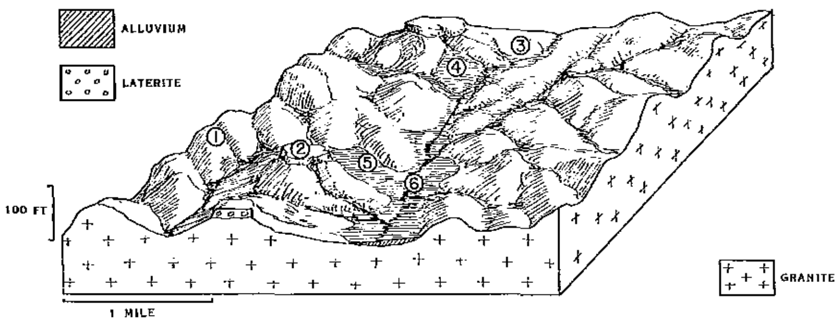
(21) NORIE LAND SYSTEM (40 SQ. MILES)

Low granite hills with stunted mulga, in the west of the area.

Geology.—Massive Archaean granite with minor laterite capping.

Geomorphology.—Surfaces eroded below the old plateau—uplands: clustered domes and small rounded uplands with minor laterite cappings, forming watersheds up to 4 miles in extent; penetrated by narrow lowlands, and closely dissected by a rectangular, joint-controlled drainage with narrow alluvial floors; relief up to 75 ft.

Land Use.—Hill pastures with stunted mulga shrubland: unit 1 partly inaccessible; elsewhere, ephemeral growth after rains should be stocked; drought resistance low; stock water undeveloped and probably restricted, with small ephemeral surface waters.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	15	**Hills:** up to 75 ft high, comprising rounded uplands up to 2 miles in extent, and groups of domes and tors; extensive rock surfaces broken by joint benches and clefts with boulder debris	Outcrop with little adjacent soil. Rock outcrop and 2	Very open mulga and other *Acacia* spp. with scattered and sparse perennial and annual grasses; much bare rock: *Acacia aneura* (mulga) sub-alliance (26)
2	<5	**Tabular laterite cappings:** pitted, rocky surfaces up to 200 yd in extent, with breakaway margins up to 10 ft high		Stunted mulga with some native pines; much bare rock: *A. aneura–Callitris hugelii* (native pine) sub-alliance (43, 44)
3	15	**Lower slopes:** concave, 1·5–3% and up to 400 yd long; rock outcrops in upper sectors, lightly dissected detrital mantles in lower parts	Shallow soils including gritty red clayey sands on rock. Rock outcrop and 2, 3*a*	Open mulga with denser clumps of other *Acacia* spp., sparse shrubs, and short annual grasses: *A. aneura–A. craspedocarpa* sub-alliance (15)
4	<5	**Alluvial fans:** up to 200 yd long, locally continued downslope as valley tracts up to 100 yd wide; gradients 1 in 50 to 1 in 100; lightly sealed surfaces	Mainly red earths on hard-pan at irregular depths; minor shallow texture-contrast soils on hard-pan. 4*h* with 6*d*	Open mulga with unpalatable shrubs, short annual grasses, and chenopods: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
5	<5	**Drainage floors:** up to 50 yd wide, gradients above 1 in 150	Gravel and red earths on hard-pan or gravel at irregular depths. 4*h*	Mulga with scattered larger trees, sparse shrubs, and short annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (13)
6	<5	**Channels:** up to 20 ft wide and 1 ft deep	Bed-loads of coarse grit on hard-pan or rock	As in unit 5, but denser

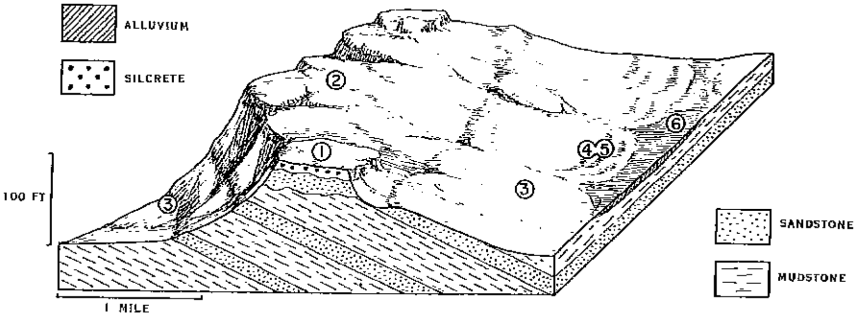
(22) TREUER LAND SYSTEM (150 SQ. MILES)

Stony uplands with open mulga, in the east of the area.

Geology.—Gently dipping Upper Proterozoic mudstone, shale, and sandstone (Nullagine "system"), locally overlain by weathered, flat-lying (?)Permian feldspathic grit.

Geomorphology.—Surfaces eroded below the old plateau—uplands: a cuesta up to 5 miles wide; upper dip slopes with secondary ridges and minor summit remnants of weathered grit; lower dip slope plains traversed by an open pattern of branching or subparallel shallow drainage floors; prominent escarpment, deeply dissected by a dense, rectangular pattern of minor valleys; relief up to 100 ft.

Land Use.—Hill pastures with stunted mulga shrubland: ephemeral growth after rain should be heavily stocked; check banks possible in unit 4; stock water undeveloped, but probably limited and partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	<10	**Remnant summit surfaces:** gently sloping silcrete cappings with dissected breakaway margins up to 25 ft high	Stony pavements of silcrete with little soil. Rock outcrop and 2	Probably open mulga with inedible shrubs, spinifex and other unpalatable perennial grasses, and forbs: *Acacia aneura* (mulga) sub-alliance (32, 34)
2	30	**Uplands:** upper dip slopes up to 2 miles long, broken by shallow valleys into tracts up to 1 mile wide and consisting of alternating low escarpments, up to 30 ft high, and dip slopes less than 5% and up to ½ mile long; dissected major escarpments up to 100 ft high, slopes 20–60%, with minor structural benches; stony surfaces with rock outcrops	Shallow, stony soils. Rock outcrop and 2	Probably open mulga with dense shrubs, unpalatable perennial grasses, patches of feathertop spinifex, and short annual grasses: *A. aneura* sub-alliance (27, 30, 31)
3	60	**Lower slopes:** concave, 1–5% up to 1½ miles long on lower dip slopes, and ¾ mile long at foot of major escarpments, where they are partially dissected into flat-crested spurs up to 15 ft high and ¾ mile wide; stony surfaces with little rock outcrop	Shallow stony soils, including red earths on hard-pan. 4*b*	Open mulga, gidgee, and other *Acacia* spp., with a rich shrub layer and short annual grasses: *A. aneura* sub-alliance (30)
4	<10	**Plains:** slopes generally less than 1%, up to 1 mile long and 3 miles wide; subject to sheet-flow and masked with colluvium	Red earths of irregular depth to hard-pan. 4*h* with 4*j*	**Groves:** dense mulga with some edible shrubs and variable sparse grass layers: probably *A. aneura* sub-alliance (27, 28); also 3
5	30			**Intergroves:** as unit 4, but more open; also 10
6	20	**Drainage floors:** unchannelled floors up to 200 yd wide, gradients 1 in 100 to 1 in 200	Red earths on hard-pan or gravel at irregular depth. 4*h*	Dense mulga with abundant shrubs and short annual grasses: *A. aneura* sub-alliance (35)

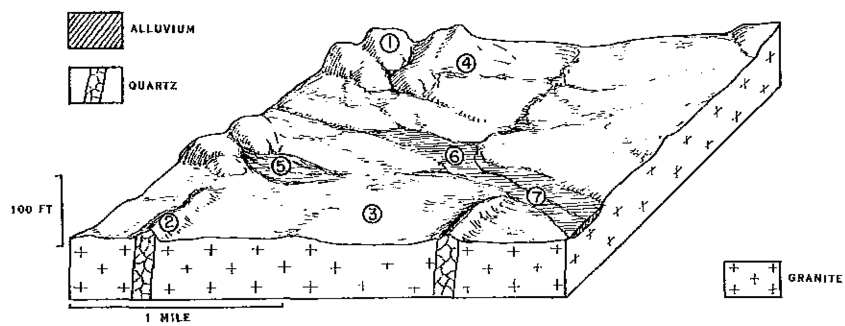
(23) MINDURA LAND SYSTEM (750 SQ. MILES)

Stony plains with low granite hills, in the west of the area.

Geology.—Massive Archaean granite and gneiss with minor quartz reefs.

Geomorphology.—Surfaces eroded below the old plateau—low hills and plains: broad interfluves or piedmont tracts with clustered or scattered low hills and minor quartz reef ridges; moderately dense, radial pattern of alluvial drainage floors with joint-controlled tributaries; relief mainly up to 25 ft, hills up to 50 ft high.

Land Use.—Stony plains with short grass—chenopod pastures: ephemeral growth after rain should be heavily stocked; possibly important as a catchment for areas downslope; stock water in units 3, 6, and 7.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	70	**Hills:** up to 50 ft high and 1¼ miles in extent; bare, exfoliating surfaces broken by joint clefts and benches with rock debris	Outcrop with little adjacent soil. Rock outcrop and 2	Very open mulga and other *Acacia* spp. with sparse shrubs, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (21, 26)
2	10	**Ridges:** narrow crests up to 25 ft high and ¼ mile long, with rocky slopes, 10–20%		Open, stunted mulga with mostly unpalatable shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (22); also 40
3	450	**Undulating plains:** interfluves up to 25 ft high and ½ mile wide; gently rounded crests with regional slopes attaining 1%, concave margins steepening to 2%; stony surfaces with rock outcrops	Very shallow, stony soils on rock, locally with a thin hard-pan crust; shallow calcareous earths locally. 2, 5*a*	Open, stunted mulga with unpalatable shrubs, forbs, and short annual grasses: *A. aneura–Eremophila fraseri* sub-alliance (6); also 22
4	100	**Hill-foot slopes:** concave, 2–3% and up to 250 yd long; rock outcrops in upper sectors, channelled detrital mantles in lower sectors	Gritty red clayey sands on rock. 3*a*	
5	30	**Alluvial fans:** up to 400 yd long, gradients about 1 in 50	Shallow, gritty texture-contrast soils on hard-pan. 6*d*	Open mulga, gidgee, and other *Acacia* spp. with unpalatable shrubs, forbs, and short annual grasses: 23
6	50	**Drainage floors:** mainly up to 100 yd wide in lowest sectors, gradients 1 in 150 to 1 in 200; and central channelled tracts, stony marginal slopes up to 1%	Red earths on hard-pan or gravel at irregular depth. 4*h*. Locally, alluvial soils. 1*d*	Dense mulga, gidgee, and other *Acacia* spp. with unpalatable shrubs, forbs, and short annual grasses: 35
7	50	**Channels:** multiple channels, up to 20 ft wide and 2 ft deep		As in unit 6, but forming a fringing community

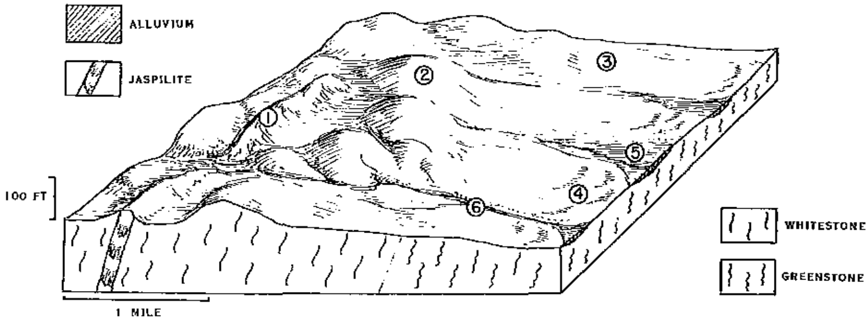
(24) Edenhope Land System (40 sq. miles)

Undulating stony plains with low hills, mainly in the west of the area.

Geology.—Steeply dipping quartz-feldspar schist and massive or schistose amphibolite (whitestone with some greenstone) of Archaean age.

Geomorphology.—Surfaces eroded below the old plateau—low hills and plains: piedmont strike belts with spurs, aligned rounded low hills, and gentle lower slopes; moderately dense pattern of transverse alluvial drainage floors and branching or strike-directed tributaries: relief up to 40 ft.

Land Use.—Stony plains with short grass–chenopod pastures: ephemeral growth after rain should be heavily stocked; plentiful stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	<5	**Ridges:** narrow rocky crests up to 25 ft high and ½ mile long; boulder-covered slopes, 10–25%	Outcrop and very shallow, stony soils. Rock outcrop and 2	Open mulga and other *Acacia* spp. with very sparse shrubs, forbs, and short annual grasses: *Acacia aneura* (mulga)–*A. linophylla* sub-alliance (40)
2	5	**Rounded hills:** up to 40 ft high, ¼ mile wide, and extending up to 2 miles along the strike; convex crests and concave slopes, up to 10%; stony surfaces with rock outcrops	Outcrop and shallow, stony soils, including calcareous earths. Rock outcrop and 2, 4*b*	Stunted mulga with sparse unpalatable shrubs, forbs, and short annual grasses: *A. aneura–Eremophila fraseri* (6) and *A. aneura* (21) sub-alliances
3	15	**Lower hill slopes:** concave, 1–5% and up to 1 mile long, dissected into spurs and interfluves up to 15 ft high and 1 mile wide, with flattish or gently rounded stony crests with low outcrop ridges, and concave marginal slopes up to 200 yd long, attaining 1·5%		
4	10	**Plains:** concave slopes, 0·25–1% and up to 2 miles long, forming interfluves up to 5 ft high and 1½ miles wide, with concave marginal slopes up to 200 yd long, attaining 1%; flattish, stony crests subject to sheet-flow and masked with colluvium	Principally shallow red earths, of irregular depth near groves. 4*b*, minor 4*i*	Locally thinly groved mulga and other *Acacia* spp., with sparse unpalatable shrubs and short annual grasses; intergroves very sparsely vegetated: *A. aneura–A. linophylla* (39) and *A. aneura–A. tetragonophylla* (curara) (10) sub-alliances
5	5	**Drainage floors:** up to 150 yd wide, locally attaining 300 yd in lower sectors, gradients 1 in 50 to 1 in 200; flat floors with channelled zones and low flood-banks	Red earths on hard-pan or gravel at irregular depth. 4*h*	Moderately dense mulga and other *Acacia* spp. with very sparse shrubs, forbs, and short annual grasses: *A. aneura–A. craspedocarpa* sub-alliance (15)
6	<5	**Channels:** multiple channels up to 10 ft wide and 2 ft deep		As in unit 5, but forming a denser fringe

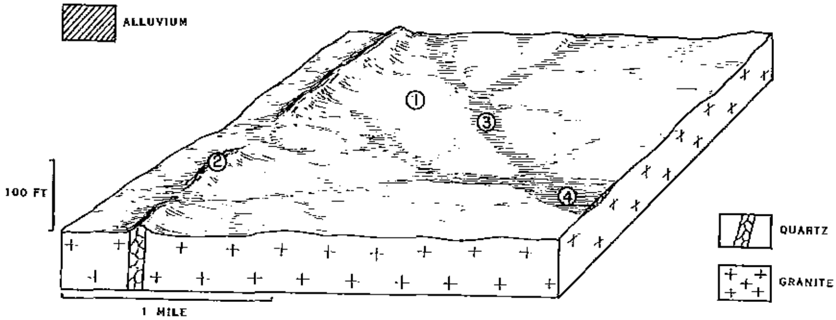
(25) Koonmarra Land System (600 sq. miles)

Stony plains with stunted mulga, in the west of the area.

Geology.—Massive gneiss and granite of Archaean age, with minor quartz reefs.

Geomorphology.—Surfaces eroded below the old plateau—plains: broad, stony interfluves with minor quartz reef ridges; through-going drainage, with a moderately dense pattern of subparallel alluvial floors with branching tributaries; relief mainly below 10 ft.

Land Use.—Stony plains with short grass–chenopod pastures: ephemeral growth after rain should be heavily stocked; possibly important as a catchment for areas downslope; plentiful stock water in units 1, 3, and 4, locally saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	500	**Plains:** interfluves up to 1 mile wide and 10 ft high; flat or gently convex stony crests with minor rock outcrops, regional slopes 0·1–0·5%, locally steepening to 2·5% on spurs from adjacent higher ground; less stony, concave margins up to 200 yd wide, steepening to 1%	Very shallow stony soils on weathered rock, locally with a thin hard-pan crust. 2	Stunted, sparse mulga with unpalatable shrubs and short annual grasses: *Acacia aneura* (mulga) sub-alliance (22)
2	<10	**Ridges:** narrow crests up to 400 yd long; rocky slopes, 10–20%	Outcrop with little adjacent soil. Rock outcrop and 2	Sparse low *Acacia* spp., shrubs, and forbs; much bare rock: *A. aneura–A. linophylla* sub-alliance (39)
3	50	**Drainage floors:** up to 200 yd wide, gradients 1 in 150 to 1 in 500; traversed by a complex of shallow drainage runnels with flood-banks of sand	Principally shallow red earths on hard-pan, locally on gravel and minor alluvial soils. 4*h*, minor 1*d*	Sparse mulga with mostly unpalatable shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (22, 23)
4	50	**Flood-plains:** up to 400 yd wide, gradients less than 1 in 500; flat, unchannelled cross-sections, with sealed, locally scoured surfaces and scattered cobbles		Sparse mulga with unpalatable shrubs and short annual grasses; much bare ground: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10); also 14

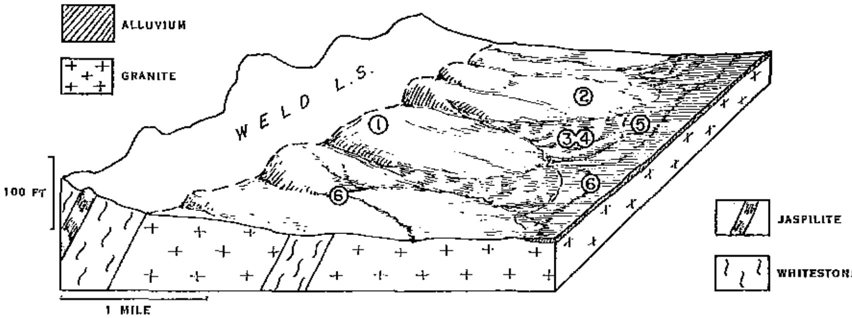
(26) Yarrameedie Land System (80 sq. miles)

Stony slopes with open mulga, in the west of the area.

Geology.—Gneiss and granite of Archaean age, with thin remnants of metamorphic rocks.

Geomorphology.—Surfaces eroded below the old plateau—plains: piedmont tracts up to 3 miles wide; higher parts consist of spurs and stony slopes traversed by fairly closely-spaced alluvial drainage floors; this drainage disperses into alluvial plains in lower parts; relief up to 25 ft.

Land Use.—Stony plains with short grass–chenopod pastures: ephemeral growth after rain should be heavily stocked; possible improvement in unit 3 by removing upper storey; adequate stock waters.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	10	**Hill spurs**: up to ½ mile wide, 1 mile long, and 25 ft high; rounded or bevelled stony crests steepening from 1% to 3% towards backing ridges; concave marginal slopes, 3–8%; rock outcrops and minor breakaways in weathered rock in higher parts	Outcrop with little adjacent soil. Rock outcrop and 2	Open mulga with sparse edible shrubs, forbs, and short annual grasses: *Acacia aneura* (mulga)–*A. linophylla* sub-alliance (39)
2	40	**Lower slopes**: concave, less than 1%, forming interfluves up to 1 mile wide and 10 ft high, with flat or gently rounded crests; surfaces receive sheet-flow and are partly masked with colluvium	Very shallow, stony soils on hard-pan or rock; locally, shallow calcareous earths; red earths of irregular depth near groves. 2, 4*i*, 5*a*	Open mulga with inedible shrubs, forbs, and short annual grasses: *A. aneura* sub-alliance (22). Locally, mulga groves with denser tree and shrub layers
3	<10	**Alluvial fans**: up to 2 miles wide and 2 miles long, gradients 1 in 200 to 1 in 500; sealed, stony surfaces	Red earths of irregular depth on hard-pan. 4*i*	**Groves**: mulga, gidgee, and other *Acacia* spp. with edible and inedible shrubs, sparse forbs, and short annual grasses: *A. aneura* sub-alliance (22, 23)
4	20			**Intergroves**: sparse low mulga and other *Acacia* spp., with shrubs and forbs and short annual grasses. As above but much sparser
5	10	**Flood-plains**: up to 250 yd wide, gradients mainly 1 in 150 to 1 in 500; uneven or sloping floors in upper, channelled sectors, with banks of sand and gravel; flatter floors in unchannelled lower sectors, with shallow runnels and low flood-banks	Shallow, fine-textured red earths on hard-pan. 4*h*	Sparse mulga with unpalatable shrubs and short annual grasses; much bare ground: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10); also 14
6	<10	**Drainage channels**: up to 20 ft wide and incised to 3 ft into rock or hard-pan breccia; gradients above 1 in 150	Bed-loads range from grit to large cobbles	As in unit 5, but forming a denser fringe

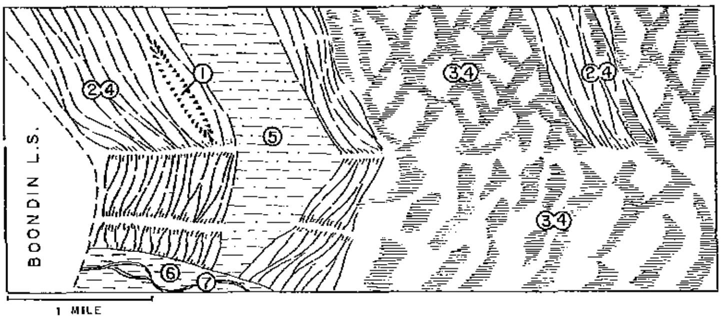
(27) Windidda Land System (80 sq. miles)

Stony limestone plains with mulga groves and grasslands, in the north-east of the area.

Geology.—Gently dipping, thinly interbedded shale and dolomitic limestone of Upper Proterozoic age (Nullagine "system").

Geomorphology.—Surfaces eroded below the old plateau—plains: belted outcrop plains up to 5 miles wide, with stony limestone outcrop bands and minor ridges; slightly lower, soil-covered flats on joint belts and narrow shale bands; clay plains on broader shale bands; sparse pattern of transverse drainage with alluvial flood-plains; regional slopes less than 0·5%, relief mainly less than 5 ft.

Land Use.—Open mulga with wanderrie shrubland: palatable pastures in units 2, 3, 5, and 6 should be preserved by controlled stocking; units 2, 3, and 5 prone to degradation; adequate stock water in unit 4.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	<5	**Ridges:** short ridges up to 15 ft high and ⅛ mile wide; stony slopes up to 5%, with much outcrop	Outcrop with little adjacent soil. Rock outcrop and 2	Dense, low *Acacia* spp. with sparse shrubs and forbs: *Acacia aneura* (mulga)–*A. sclerosperma* sub-alliance (19)
2	10	**Limestone outcrop bands:** stony bands up to 30 yd wide and up to 1 ft above unit 3; much outcrop	Outcrop with adjacent shallow, stony calcareous earths. Rock outcrop and 2, 5*b*	Open mulga with edible shrubs and abundant herbage (most species calciphilous): *A. aneura–A. sclerosperma* sub-alliance (18)
3	10	**Plains:** strike belts and joint tracts up to 50 yd wide; sealed, scalded, partly stony surfaces; narrow, hummocky zones with small linear depressions on margins	Shallow, stony fine-textured calcareous earths over dolomite and shale. 5*b*	**Groves:** mulga with edible shrubs and abundant herbage: *A. aneura–E. leucophylla* sub-alliance (4)
4	40			**Intergroves:** vegetation mainly limited to sparse chenopods and forbs: *A. aneura–Kochia pyramidata* (bluebush) alliance (62)
5	10	Plains up to ½ mile wide; flatter central tracts, slopes less than 0·2%; margins up to 200 yd wide, slopes greater than 0·2%, with incipient linear gilgais; patches of fine stone	Deep, red coarse-structured clay soils, with cracking surfaces. 7	Grassland with scattered halophytes and chenopods: *A. aneura–K. pyramidata* alliance (69)
6	<5	**Flood-plains:** severely scalded surfaces up to ¼ mile wide, transverse slopes 0·2%; levees up to 1 ft high and 50 ft wide	Various soils, including alluvial soils. 1*d*	Very open community of *Acacia* spp. with chenopods, forbs, and short annual grasses: *A. aneura–A. sclerosperma* sub-alliance (18)
7	<5	**Channels:** up to 50 ft wide and incised to 5 ft into alluvium or calcreted sands and gravels; gradients below 1 in 500	Bed-loads range from coarse sand to small cobbles	Fringing community of eucalypts and mulga with dense shrubs and assorted grasses: 72

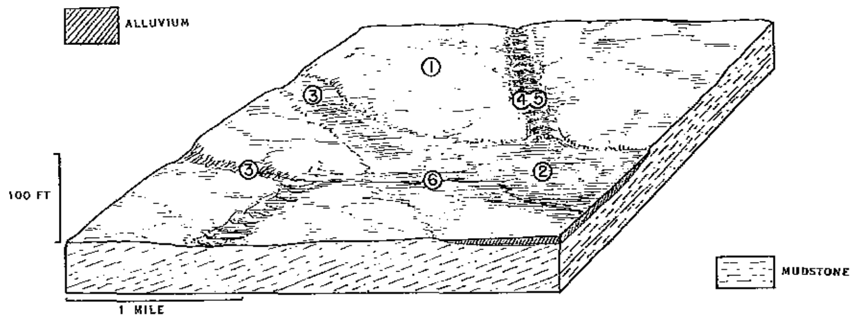
(28) Kalyaltcha Land System (280 sq. miles)

Stony plains with bluebush flats, in the north-east of the area.

Geology.—Gently dipping Upper Proterozoic mudstone and shale (Nullagine "system") with areas of Quaternary saline alluvium.

Geomorphology.—Surfaces eroded below the old plateau—plains: stony plains; drainage of moderate or low density, with through-going subparallel or branching saline alluvial plains, and unchannelled valley tracts widening into alluvial drainage floors down-valley; relief about 5 ft.

Land Use.—Halophytic shrubland: palatable pastures in units 2, 3, 4, and 6 should be preserved by controlled stocking; prone to degradation and erosion; stock water partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	140	Erosional plains: regional slopes less than 1% and up to 2 miles long, dissected into interfluves up to ¾ mile wide and 5 ft high, with concave marginal slopes, 0·5–1%; stony surfaces with some colluvial mantle in lower parts	Presumably shallow, stony soils. 4*b*	Open, stunted mulga with shrubs sparse or absent, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (21)
2	80	Alluvial plains: up to 1 mile wide, gradients mainly less than 1 in 250; intensely scalded, sealed surfaces, with small clay pan depressions, low sand and gravel hummocks, and intensely channelled drainage zones up to 200 yd wide	Texture-contrast soils, including shallow soils on hard-pan. 6*d*	Tall halophytic shrubland with sparse trees, chenopods, patches of herbage, and short annual grasses: *A. aneura–Kochia pyramidata* (bluebush) alliance (63, 68)
3	40	Drainage floors: up to ½ mile wide, gradients above 1 in 250; stony surfaces, locally with shallow channelling	Presumably red earths on hard-pan or gravel at irregular depth. 4*h*	Open mulga with scattered shrubs, chenopods, short annual grasses, and succulents: *A. aneura* sub-alliance (29)
4	<10	Alluvial valley tracts: gradients above 1 in 250	Principally shallow red earths; of irregular depth near groves. 4*h*, 4*h* with 4*j*	Groves: mulga of variable density, with edible and inedible shrubs, palatable and unpalatable perennial grasses, minor clumps of spinifex, and abundant forbs: probably *A. aneura* sub-alliance (27, 28, 30); also 3
5	10			Intergroves and non-groved areas: very open mulga and other *Acacia* spp., with inedible shrubs, forbs, and short annual grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10); also 27, 28, 30
6	<10	Channels	No bed-load	As in unit 3, but forming a denser fringe

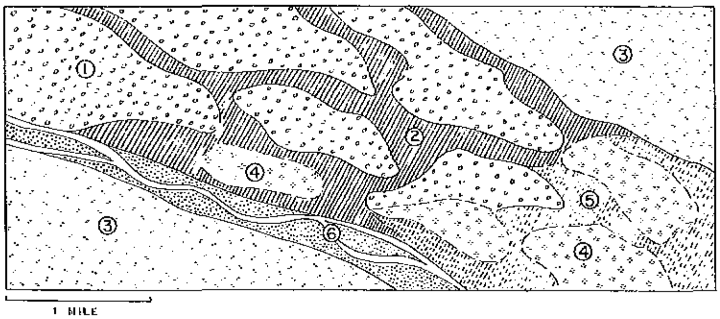
(29) CUNYU LAND SYSTEM (600 SQ. MILES)

Opaline country with mulga plains.

Geology.—Tertiary calcrete with opaline silica and fine gravel at depth, partly overlain by cemented Quaternary alluvium.

Geomorphology.—Depositional surfaces—calcreted valley fills: up to 5 miles wide, with a mosaic of calcrete platforms up to 15 ft high, and narrow intervening alluvial floors; broader alluvial plains on outer margins, locally burying the calcrete; restricted channel drainage; gradients below 1 in 1000.

Land Use.—Short grass–forb pastures with minor halophytic shrubland: units 1–4 should be stocked heavily in good seasons, and unit 5 subjected to controlled stocking; high drought resistance in unit 5, low elsewhere; degradation common in unit 5, with water and wind erosion; plentiful shallow water, particularly in unit 4, locally adequate for irrigation, but commonly saline in lower parts.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	200	**Platforms:** typically up to ½ mile wide and 1½ miles long, locally widening to 5 miles down-valley; up to 10 ft high, decreasing in height up-valley; flat-crested or saucer-shaped, with rims up to 100 yd wide and 5 ft higher than centres; rocky irregular rims; outer slopes, up to 10%, partly sand-masked; stony inner slopes, less than 1%, commonly leading to central alluvial flats	Shallow, stony calcareous earths, mainly coarse-textured, locally medium-textured; also calcareous sands, shallow red earths, and areas with little soil adjacent to calcrete outcrops. 5*d*	Very open mulga and other *Acacia* spp., with patches of eucalypts, sparse shrubs, numerous forbs and short annual grasses; most species calciphilous: *Acacia aneura* (mulga)–*A. sclerosperma* (18, 19, 20); denser fringing communities (72, 74, 75)
2	80	**Alluvial floors between platforms:** up to ¼ mile wide, gradients below 1 in 1000; heavily sealed, locally cracking surfaces, with gilgais near margins	Medium- and fine-textured red earths, and alluvial soils, including shallow soils on calcrete; deeper soils with weakly cemented fragmentary pan and/or carbonate; coarse-structured clay soils near gilgais. 6*b*, 4*c*, 4*h*	Open mulga with larger trees of beefwood and gidgee, shrubs, forbs, and short annual grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (11, 13) and locally 72
3	120	**Marginal alluvial plains:** up to 1 mile wide, transverse gradients above 1 in 1000; sealed surfaces, with shallow drainage runnels and many hard-pan exposures	Shallow, fine-textured red earths on hard-pan; locally deeper red earths and alluvial soils. 4*h*, minor 1*d*	Dense *Acacia* communities, locally with sparse shrubs and grasses: *A. aneura–A. craspedocarpa* sub-alliance (15); less commonly *A. aneura* sub-alliance (27)
4	120	**Alluvial plains above calcrete:** scalded surfaces up to 1 mile wide, some calcrete exposures	Fine-textured red earths on calcrete. 4*c*	As in unit 2, but with denser short annual grass cover and abundant herbage
5	80	**Saline alluvial plains:** severely scalded surfaces up to ¾ mile wide, with salt crusts	Various salt-affected soils of similar character to those of units 2 and 4; also texture-contrast soils. Principally 6*b*	Halophytic shrubland with or without a variable tree layer and with numerous forbs and short annual grasses: *A. aneura–Kochia pyramidata* (bluebush) sub-alliance (60, 62), fringing community (74), also 17
6	10	**Drainage channels and marginal zones:** up to 25 yd wide and incised to 5 ft into hard-pan or calcrete; marginal flood-banks or levees locally	Bed-loads range from coarse sand to pebbles	Fringing communities: 72 and 74

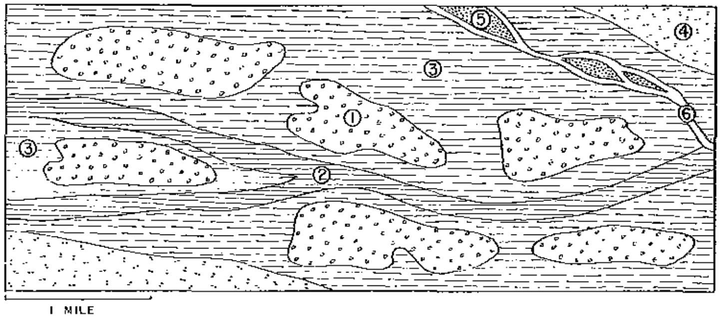
(30) Mileura Land System (240 sq. miles)

Opaline country with saltbush flats.

Geology.—Tertiary calcrete, with opaline silica and fine gravel at depth, partly overlain by Quaternary saline alluvium.

Geomorphology.—Depositional surfaces—calcreted valley fills: up to 5 miles wide, with a mosaic of calcrete platforms up to 15 ft high, and adjacent saline alluvial plains; non-saline alluvial plains on outer margins; minor channel drainage; gradients below 1 in 1000.

Land Use.—Halophytic shrubland: palatable shrubs should be preserved by controlled stocking; drought resistance high; severe degeneration under stocking, and units 2–6 subject to severe water and wind erosion; plentiful ground water, locally adequate for irrigation but commonly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	80	**Platforms:** typically up to ½ mile wide and 1½ miles long, widening to 5 miles at entrances to salt lakes; mainly up to 10 ft high, locally attaining 15 ft in lowest sectors; flat-crested or saucer-shaped, with rims up to 100 yd wide and 5 ft higher than centres; rocky irregular rims; outer slopes, up to 10%, partly sand-masked; stony inner slopes, less than 1%, commonly leading to central alluvial flats	Shallow, stony calcareous earths, mainly coarse-textured; locally medium-textured; also, calcareous sands and shallow red earths on calcrete, little soil adjacent to exposed calcrete. *5d*	Very open mulga with sparse shrubs, numerous forbs, and short annual grasses; some patches of eucalypts; most species calciphilous: *Acacia aneura* (mulga)–*A. sclerosperma* sub-alliance (18, 20), with dense fringing communities on the margins of the platforms (72, 74, 75)
2	20	**Lower saline plains:** drainage tracts up to ¼ mile wide, with many shallow runnels and small flood-banks; hummocky, sealed surfaces, liable to cracking	Texture-contrast soils and medium and fine-textured alluvial soils, with weakly-cemented, fragmentary pan and/or carbonate or gypseous horizons. *6b*	Halophytic communities of samphire (*Arthrocnemum* spp.), low shrubs, and annual forbs and grasses: samphire alliance (70)
3	100	**Higher saline plains:** up to 1½ miles wide and 4 ft above unit 2; salt crusting, minor calcrete mounds; circular, shallow depressions up to 40 yd dia. in outer sectors		Mostly halophytic shrubland with numerous forbs and short annual grasses: *A. aneura–Kochia pyramidata* (bluebush) alliance (62, 63, 67)
4	40	**Marginal alluvial plains:** up to 2 miles in extent, transverse gradients above 1 in 1000	Shallow and moderately deep red earths on hard-pan. *4h*	Dense mulga with edible shrubs and forbs: *A. aneura–K. pyramidata* (67) and *A. aneura–A. craspedocarpa* (15) sub-alliances
5	<10	**Flood-plains:** uneven, scalded tracts up to ¾ mile wide, with many shallow flood channels and low flood-banks	Shallow red earths and alluvial soils, locally eroded and salt-affected. *1d, 4h, 6b*	Open curara communities with much bare ground: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
6	<10	**Channels:** up to 25 yd wide and incised to 5 ft into hard-pan, or into calcrete locally	Bed-loads range from coarse sand to pebbles	Various dense fringing communities (71, 72, 74)

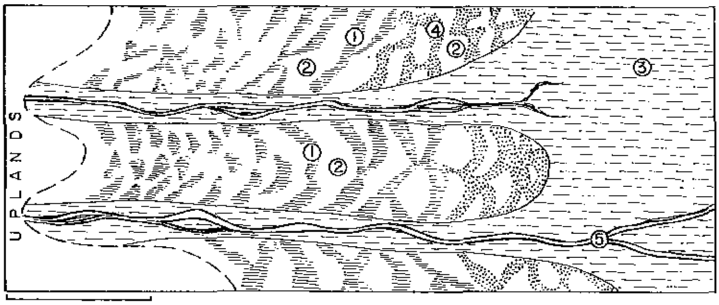
(31) Jundee Land System (550 sq. miles)

Scattered stony plains with thin mulga groves.

Geology.—Cemented Quaternary alluvium derived mainly from fine-grained lava and mudstone.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: stony upper tributary plains, extending mainly less than 5 miles downslope, gradients 1 in 200 to 1 in 500; multiple lobes up to 1½ miles wide with thin vegetation groves and transverse or elongate sand-banks in lower sectors, separated by channelled drainage tracts which open into wider flood-plains downslope.

Land Use.—Alluvial plains with short grass–mixed forb pastures: ephemeral growth after rain in units 1, 2, 3, and 5 should be stocked; possible improvement through tree removal and check banks or water-spreading in units 1 and 4; plentiful stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	100	**Surfaces subject to sheet-flow:** sealed, locally scalded, and stony surfaces	Red earths of irregular depth to hard-pan, increasingly stony upslope. 4*i*, 4*h* with 4*j*	Groves: dense mulga with mostly inedible shrub layers, palatable and unpalatable perennial grasses, clumps of spinifex, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (27); also 51
2	300			Intergroves: sparse mulga with short annual grasses: *A. aneura* sub-alliance (21)
3	100	**Central drainage plains:** winding tracts up to 1 mile wide, gradients about 1 in 500; sealed surfaces, with shallow elongate scalds up to 50 yd wide	Red earths on hard-pan. 4*h*	Open mulga with sparse edible shrubs, unpalatable perennial grasses, forbs, and short annual grasses: *A. aneura–Eremophila leucophylla* sub-alliance (4)
4	30	**Sand banks:** up to 1 ft high and 100 yd wide; transverse or elongate, extending up to ½ mile downslope; hummocky, moderately loose surfaces veneered with lateritic grit	Red clayey sands on hard-pan. 3*g*	Open mulga with edible shrubs, palatable and unpalatable perennial grasses and some clumps of spinifex, forbs, and short annual grasses: *A. aneura–E. leucophylla* sub-alliance (3)
5	20	**Channelled tracts:** up to ¼ mile wide, with multiple shallow runnels incised to 2 ft into hard-pan, and low intervening flood-banks of coarse sand to pebbles	Red earths of variable depth to hard-pan. 4*h*	Moderately dense mulga with variable shrubs, abundant herbage and annual grasses in season: *A. aneura–A. tetragonophylla* (curara) (10, 11) and *A. aneura–A. craspedocarpa* (15) sub-alliances

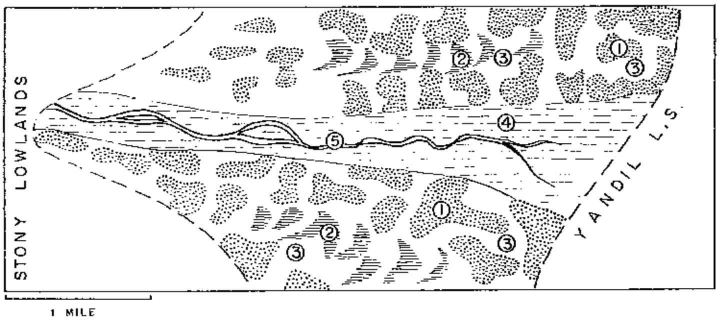
(32) Trennaman Land System (300 sq. miles)

Wanderrie plains with mulga groves, in the centre and east of the area.

Geology.—Quaternary cemented alluvium and sand derived mainly from weathered amphibolitic and feldspathic schists and fine-grained sedimentary rock.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: sandy upper tributary plains occupying lowland embayments and extending up to 5 miles downslope, gradients 1 in 250 to 1 in 500; inter-drainage sectors with wanderrie tracts, separated by zones of more active sheet-flow with vegetation groves; central drainage plains, locally with channels.

Land Use.—Open mulga with wanderrie shrubland: palatable pastures in units 1 and 2 should be preserved by controlled stocking; water-spreading possible on to unit 1; plentiful stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	100	**Sandy tracts**: ranging from surface mantles to hummocky sand banks up to 1 ft high; typically up to 200 yd wide and extending up to ¾ mile downslope, locally transverse to slope; loose grit or pebble veneers	Coarse-textured soils of moderate depth to hard-pan, mainly red clayey sands. 3*g*	Similar to wanderrie communities, with open mulga, edible shrubs, feathertop spinifex, and/or other perennial grasses: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (3, 5)
2	30	Zones up to ½ mile wide subject to minor sheet-flow	Principally shallow red earths, locally stony, and of irregular depth to hard-pan near groves. 4*h*, 4*h* with 4*j*, 4*i*	**Groves**: open mulga, with dense shrubs, forbs, and annual grasses: *A. aneura* sub-alliance (30); also 5
3	120			**Intergroves and wanderrie flats**: stunted mulga with sparse shrubs and short annual grasses: *A. aneura–Eremophila fraseri* sub-alliance (6)
4	40	**Drainage floors**: upper sectors up to ½ mile wide, gradients above 1 in 250, with many channels and small flood-banks; lower sectors up to ¾ mile wide, gradients about 1 in 500, with sealed surfaces and dispersed runnels	Red earths and locally alluvial soils of variable depth to hard-pan. 4*h*, minor 1*d*	Stunted mulga with sparse shrubs and short annual grasses: *A. aneura–Eremophila fraseri* sub-alliance (6)
5	<10	**Channels**: up to 20 ft wide and incised to 1 ft in hard-pan	No bed-load	Dense communities of mulga and other *Acacia* spp. with forbs and annual grasses in season: *A. aneura–A. craspedocarpa* sub-alliance (15)

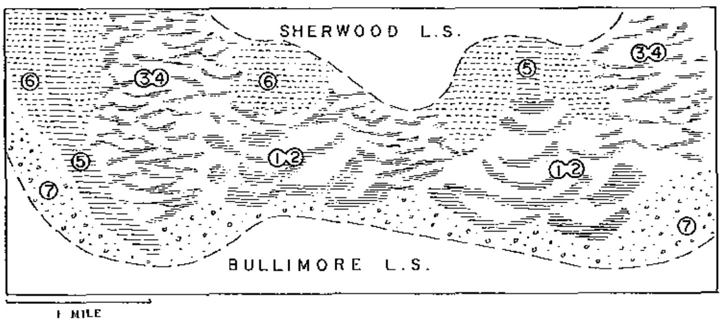
(33) Yanganoo Land System (1600 sq. miles)

Widespread plains with prominent mulga groves.

Geology.—Quaternary cemented alluvium derived mainly from gneiss, granite, and feldspathic schist; aeolian sand on margins.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: lobate upper tributary plains, extending generally less than 5 miles downslope, gradients above 1 in 500; apart from minor feeder drainage zones in upper and inter-lobe sectors, surfaces are subject to sheet-flow; margins are commonly transitional to sand plain.

Land Use.—Dense mulga with wanderrie shrubland: pastures should be preserved by controlled stocking and improved by clearing of upper storey, with introductions based on water-spreading, high drought resistance; not susceptible to erosion, but prone to pasture degeneration; widespread shallow stock waters, more plentiful in units 4 and 6; irrigation supplies locally, but some salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	250	**Zones with strong sheet-flow:** up to $1\frac{1}{2}$ miles wide and extending up to 2 miles downslope	Red earths of irregular depth to hard-pan. 4*h* with 4*j*, minor 4*i*	**Groves:** dense mulga with some edible shrubs and variable sparse grass layers: *Acacia aneura* (mulga) sub-alliance (26); also 3
2	450			**Intergroves:** mulga as in unit 1, but more open, and also *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)
3	150	**Zones with more dispersed sheet-flow:** extending up to 3 miles downslope	Red earths of irregular depth to hard-pan, as in units 1 and 2; also red clayey sands. 4*h* with 4*j*, 3*g*	**Groves:** moderately dense mulga with some edible shrubs, palatable and unpalatable perennial grasses: *A. aneura–Eremophila leucophylla* sub-alliance (3); and *A. aneura* sub-alliance (30)
4	450			**Intergroves:** very open mulga with mostly inedible shrubs and short annual grasses: *A. aneura* sub-alliance (30)
5	100	**Central drainage zones with concentrated run-on:** tracts up to $\frac{3}{4}$ mile wide, transverse slopes below 0·2%; lightly sealed surfaces with localized scouring and small flood-banks	Red earths of varying texture and depth to hard-pan or to weakly cemented pan, locally with only a nodule horizon in very deep soils. 4*d*, 4*h*	Very dense mulga with some sparse mallee, edible shrubs, palatable and unpalatable perennial grasses, small patches of spinifex, and abundant herbage: *A. aneura* sub-alliance (21, 27); also 3, 5, 16, 58
6	<50	**Central drainage zones with diffuse run-on:** tracts up to $\frac{1}{2}$ mile wide marginal to channelled zones, and alluvial plains up to 1 mile wide in lower part; multiple shallow runnels and small flood-banks; sealed surfaces, with stone patches and hard-pan exposures	Shallow, fine-textured red earths on hard-pan. 4*h*	Variable mulga communities with sparse edible shrubs, forbs, and annual grasses; much bare ground: *A. aneura* sub-alliance (27); also 10, 15
7	200	**Zones transitional to sand plain:** firmed, hummocky surfaces	Red clayey sands and sandy red earths of moderate or greater depth to hard-pan or weakly cemented pan. 3*g*, 3*h*	Dense mulga with edible shrubs, spinifex, and other perennial grasses: *A. aneura–Eremophila leucophylla* (5), and *Eucalyptus kingsmillii* (mallee)–*A. aneura* alliances (57); also 28

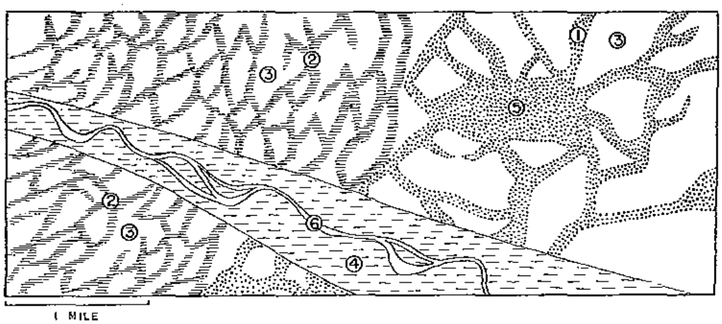
(34) Cole Land System (220 sq. miles)

Plains with mulga groves and wanderrie banks, in the east of the area.

Geology.—Quaternary cemented alluvium and aeolian sand derived mainly from weathered mudstone, shale, and feldspathic grit.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: tributary plains generally extending up to 5 miles, locally up to 10 miles, downslope, gradients 1 in 250 to 1 in 1500; widely-spaced through-going central drainage plains, and intervening sectors with vegetation groves in upper parts and wanderrie banks downslope.

Land Use.—Open mulga with wanderrie shrubland: palatable pastures in units 1 and 2 should be preserved by controlled stocking; elsewhere, ephemeral growth after rain should be heavily stocked; check banks and water-spreading possible in units 2, 4, and 5; stock water little developed, but probably plentiful.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	40	**Wanderrie banks:** up to 1 ft high, 100–300 yd wide, and continuous from $\frac{1}{2}$ to 3 miles along the contour; loose, hummocky surfaces stabilized by vegetation	Red clayey sands on hard-pan. 3*g*	Open mulga with inedible shrubs, spinifex and palatable and unpalatable perennial grasses, forbs, and short annual grasses: *Acacia aneura* (mulga) sub-alliance (30)
2	20	Slopes up to $\frac{3}{4}$ mile long and 3 miles wide, gradients 1 in 250 to 1 in 1500; sealed surfaces with stony patches, hard-pan exposures, and minor clay pans	Principally shallow red earths, locally stony, and of irregular depth to hard-pan near groves. 4*h*, 4*h* with 4*j*, 4*i*	**Groves:** mulga with edible and inedible shrubs, some palatable perennial grasses, forbs, and short annual grasses: *A. aneura* sub-alliance (28, 30, 32)
3	100			**Intergroves and wanderrie flats:** very open mulga with mainly inedible shrubs, forbs, and sparse short annual grasses; much bare ground: *A. aneura* sub-alliance (21, 30)
4	40	**Central drainage plains:** up to $\frac{1}{2}$ mile wide, gradients about 1 in 500; sealed surfaces, with shallow scouring and numerous hard-pan exposures; channelled zones up to 300 yd wide, with small flood-banks	Shallow, fine-textured red earths on hard-pan. 4*h*	Stunted mulga with sparse inedible shrubs and short annual grasses: *A. aneura–Eremophila fraseri* sub-alliance (6)
5	10	**Sand plain:** areas up to $\frac{1}{2}$ mile wide and extending up to 3 miles downslope; hummocky or lightly firmed surfaces	Coarse-textured soils, mainly deep red clayey sands. 3*h*	Spinifex with scattered trees and numerous shrubs; forbs and annuals abundant after a burn: *Eucalyptus kingsmillii* (mallee)–*A. aneura* alliance (48, 52)
6	<10	**Channels:** small channels incised to 2 ft, mainly into hard-pan	Bed-loads mainly sand and grit on hard-pan	As for unit 5, but forming a dense fringe

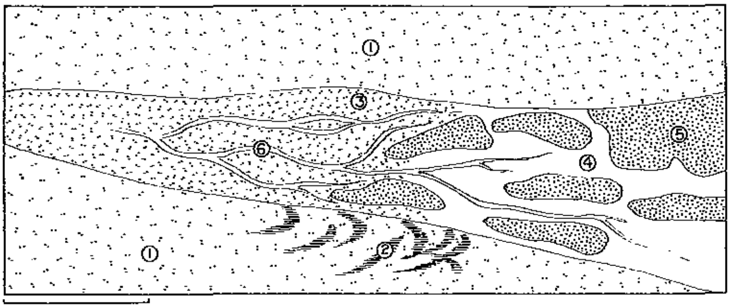
(35) Yandil Land System (1100 sq. miles)

Curara flats with shallow hard-pan, in the west of the area.

Geology.—Quaternary cemented alluvium derived mainly from gneiss and granite.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: lower tributary plains, commonly up to 5 miles wide and extending for considerable distances downslope, gradients 1 in 500 to 1 in 1000; sealed surfaces with localized, impersistent channelled tracts with adjacent scalded or gravel-strewn areas; minor zones of less active flow, with vegetation groves in upper parts and wanderrie banks in lower parts.

Land Use.—Alluvial plains with short grass–mixed forb pastures: should be heavily stocked in good seasons; low drought resistance; some improvement from check banks in areas of deeper soils or from water-spreading on to unit 5; pasture degradation common, with extensive water and wind erosion of shallow soils; fairly plentiful stock water, locally saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	550	**Alluvial plains with diffuse drainage:** gradients mainly between 1 in 500 and 1 in 1000, transverse gradients below 1 in 1000; patches of lateritic grit and pebbles	Principally shallow red earths on hard-pan, locally alluvial soils. 4*h*, minor 1*d*, 4*h* with 4*j*, 6*b*	Sparse mulga with stunted shrubs, forbs, and short annual grasses; much bare ground: *Acacia aneura* (mulga)–*A. tetragonophylla* (curara). (10) and *A. aneura–Eremophila fraseri* (6) sub-alliances
2	20			**Groves:** dense mulga: *A. aneura* sub-alliance (27)
3	200	**Alluvial surfaces receiving more run-on than unit 1:** less even surfaces with shallowly scoured tracts up to 50 yd wide; patches of pebbles		Dense mulga with various shrubs and abundant herbage and annual grasses in season: *A. aneura–A. tetragonophylla* (10, 11) and *A. aneura–A. craspedocarpa* (15) sub-alliances
4	150	**Scalded tracts:** zones up to ½ mile wide, with up to two-thirds of surface scalded to 6 in. depth, with extensive exposure on hard-pan; runnels with low flood-banks on margins of unit 6		Stunted mulga with sparse shrubs and annual grasses: *A. aneura–A. tetragonophylla* (10, 11) and *A. aneura* (21) sub-alliances
5	100	**Sand banks:** up to 6 in. high and ½ mile wide, commonly elongate downslope; loose, hummocky surfaces stabilized by vegetation	Coarse-textured soils, mainly red clayey sands. 3*g*	Commonly, open mulga with edible shrubs and palatable perennial grasses: *A. aneura–Eremophila leucophylla* (1) and *A. aneura–A. tetragonophylla* (10) sub-alliances; also 12, 22
6	80	**Channelled tracts:** up to 350 yd wide, with multiple anastomosing channels up to 20 ft wide and 2 ft deep, locally larger, mainly incised into hard-pan; separated by low flood-banks of sand and pebbles	Channel-eroded red earths and alluvial soils of varying depth to hard-pan or gravel as in the above units. 4*h*, minor 1*d*. Bed-loads range from coarse sand to pebbles	Variable fringing communities: 72 and, on minor stream lines, 15, 35

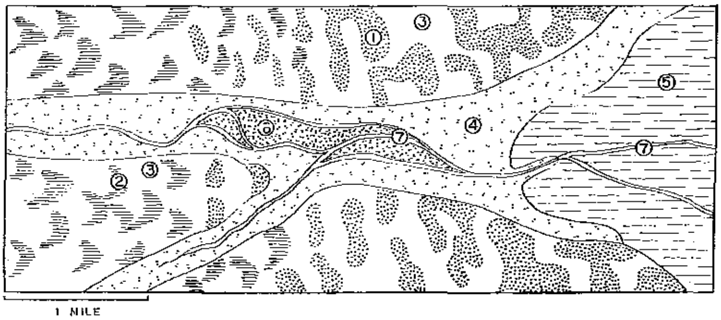
(36) Ero Land System (400 sq. miles)

Wanderrie plains with mulga groves and salt flats, in the north-west of the area.

Geology.—Quaternary cemented alluvium and minor aeolian sand derived mainly from gneiss and granite.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains; lower tributary plain up to 5 miles wide and extending up to 20 miles downslope, gradients 1 in 500 to 1 in 1000; central drainage tracts with discontinuous, anastomosing channels and flanking flood-plains, widening up to 1½ miles and becoming rather saline in lowest sectors; inter-drainage zones with vegetation groves in upper parts and wanderrie banks in lower parts.

Land Use.—Short grass-forb pastures with minor halophytic shrubland: ephemeral growth after rain should be heavily stocked; water-spreading possible onto parts of unit 1; abundant stock water, very locally saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	**Wanderrie banks:** masking small slope breaks in lower parts of land system; up to 1 ft high and 200 yd across, extending up to 2 miles laterally, partly on the contour, partly as interconnecting patterns oblique to slope; hummocky surfaces	Red clayey sands on hard-pan. 3*g*	Open mulga with shrubs and palatable grasses: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (1)
2	20	Slope up to 1 mile long; sealed surfaces with stony patches and minor clay pans	Principally shallow red earths on hard-pan, of irregular depth near groves. 4*h*, 4*h* with 4*j*	**Groves:** mulga with shrubs and palatable perennial grasses: *A. aneura*–*Eremophila leucophylla* (1) and *A. aneura* (30) sub-alliances
3	150			**Intergroves and wanderrie flats:** stunted, open mulga, few shrubs, forbs, and short annual grasses; much bare ground: *A. aneura*–*A. craspedocarpa* (15) and *A. aneura*–*A. tetragonophylla* (curara) (10) sub-alliances
4	100	**Non-saline alluvial plains:** sealed surfaces up to 1 mile wide, with shallow anastomosing runnels, small flood-banks, and scoured tracts with hard-pan exposures	Shallow red earths on hard-pan. 4*h*	Sparse mulga with stunted shrubs, annual grasses, and forbs; much bare ground: *A. aneura*–*A. tetragonophylla* (10) and *A. aneura*–*Eremophila fraseri* (6) sub-alliances
5	50	**Saline alluvial plains:** up to 1½ miles wide, gradients less than 1 in 1000; severely scalded, with sealed, locally salt-crusted cracking surfaces; prominent clay pans up to 300 yd dia., with fringing sand banks	Presumably mainly texture-contrast soils. 6*b*	Open mulga with a variable halophytic shrub layer, abundant forbs, and annual grasses: *A. aneura*–*Kochia pyramidata* alliance (67) and *A. aneura*–*A. tetragonophylla* sub-alliance (10, 14)
6	30	**Flood-plains:** uneven surfaces up to ½ mile wide, with low flood-banks and shallow flood channels	No record, probably similar to unit 5	Very open curara community with halophytic shrubs, forbs, and annual grasses: *A. aneura*–*A. tetragonophylla* (10) sub-alliance
7	<10	**Channels:** up to 25 yd wide and incised to 5 ft into layered alluvium and hard-pan	Bed-loads range from sand to coarse grit	Fringing community of eucalypts, shrubs, and various tall grasses (72)

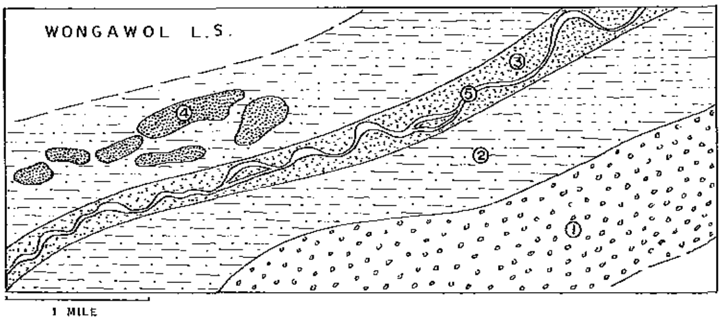
(37) WADJINYANDA LAND SYSTEM (100 SQ. MILES)

Degraded river plains with stunted mulga, near Lake Carnegie.

Geology.—Quaternary fine-textured alluvium with minor aeolian sand.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: flood-plains up to 5 miles wide, gradients 1 in 500 to 1 in 1000; stable outer plains; severely degraded plains with scalds, clay pans, and sand banks; narrow, active inner plains with winding, locally anastomosing channels.

Land Use.—Alluvial plains with short grass–mixed forb pastures: ephemeral growth after rain should be stocked; water-spreading possible on to unit 4; subject to degradation and to severe wind and water erosion; stock water little developed, but probably adequate.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	25	**Stable outer plains:** sealed alluvial surfaces up to 1 mile wide	Principally shallow red earths on hard-pan, of irregular depth near groves. 4*h*, 4*h* with 4*j*	Probably sparse mulga with stunted shrubs and forbs; much bare ground; diffuse mulga groves locally: *Acacia aneura* (mulga)–*A. tetragonophylla* (curara) (10) and *A. aneura* (27) sub-alliances
2	50	**Degraded plains:** stony, sealed surfaces up to 1 mile wide; more than 50% scalded; many clay pans up to ¼ mile in extent	Severely scalded, shallow soils, principally red earths on hard-pan. 4*h*	Stunted mulga with sparse shrubs, forbs, and short annual grasses; much bare ground: *A. aneura* sub-alliance (21)
3	<10	**Active inner flood-plains:** uneven surfaces up to ½ mile wide, with shallow flood channels and minor levees	No records, probably shallow alluvial soils and red earths on hard-pan or gravel at irregular depths. 1*d*, 4*h*	Probably similar to unit 5
4	15	**Sand banks:** up to 5 ft high, ¼ mile wide, and extending up to 1 mile down-valley; hummocky, loose crests; marginal slopes, up to 5%, stabilized by vegetation	Deep red sands. 3*i*	Open mulga with some edible shrubs and generally unpalatable perennial grasses: *A. aneura–Eremophila leucophylla* sub-alliance (4)
5	<5	**Channels:** up to 50 yd wide and 5–10 ft deep	No bed-load	Fringing communities of *Acacia* spp.: probably *A. aneura–A. craspedocarpa* (15) and *A. aneura* (35) sub-alliances

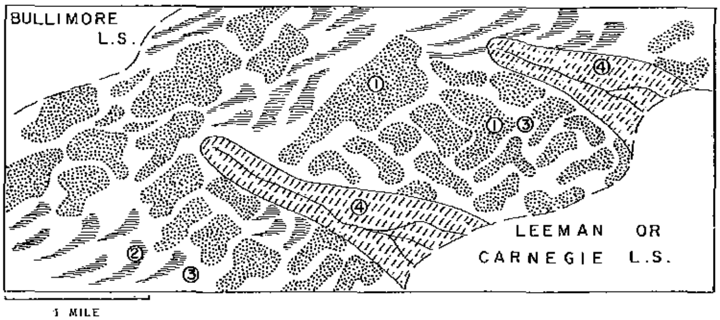
(38) Mitchell Land System (180 sq. miles)

Spinifex sand plain, wanderrie banks, and salt flats, in the east of the area.

Geology.—Quaternary alluvium and aeolian sand.

Geomorphology.—Depositional surfaces—mainly non-saline alluvial plains: sandy plains extending up to 5 miles downslope, gradients 1 in 500 to below 1 in 1000; upper parts, adjacent to Bullimore land system, contain extensive sand plain, wanderrie banks, and non-saline alluvial plains; in lower parts, these elements occupy zones between saline alluvial flats with some through-going channels.

Land Use.—Open mulga with wanderrie shrubland: should be encouraged by controlled stocking; degradation is severe, owing to isolated occurrence and small size of the land system; stock water in units 3 and 4, with some salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	Wanderrie banks and sand plain: banks up to 200 yd across and extending up to ¾ mile along the contour, locally widening into sand plain "islands" up to 1 mile in extent; loose or lightly firmed, hummocky surfaces	Coarse-textured soils, mainly red clayey sands. 3*g*	Open mulga with mallee, edible shrubs, and palatable and unpalatable perennial grasses: *Eucalyptus kingsmillii* (mallee)–*Acacia aneura* (mulga) alliance (58)
2	10	Slopes subject to sheet-flow; sealed surfaces with minor salt crusts and locally scalded	Principally shallow red earths on hard-pan of irregular depth near groves, and some salt-affected soils. 4*h*, 4*h* with 4*j*, minor 6*b*	Groves: diffusely groved mulga with shrubs, much herbage, and some palatable perennial grasses: *A. aneura* sub-alliance (28)
3	90			Intergroves and wanderrie flats: low, sparse halophytic shrubs with chenopods and short annual grasses; much bare ground: *A. aneura–Kochia pyramidata* (bluebush) alliance (64)
4	30	Saline alluvial plains: extending up to 2 miles downslope, gradients less than 1 in 1000; sealed surfaces, extensively scalded and rilled, with prominent pan depressions and salt crusts, and with minor channels	Presumably salt-affected soils. 6*b*	Tall halophytic shrubland with sparse trees, shrubs, chenopods, forbs, and perennial grasses: *A. aneura–K. pyramidata* alliance (63, 68); fringing community along channels (74)

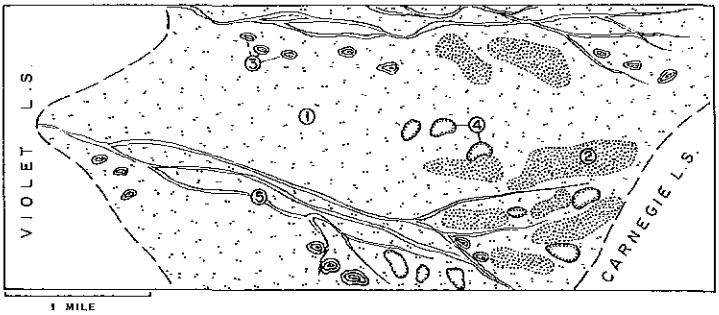
(39) Barwidgee Land System (260 sq. miles)

Stony bluebush flats in the east of the area.

Geology.—Quaternary fine-textured saline alluvium derived mainly from weathered basic schist; minor aeolian sand.

Geomorphology.—Depositional surfaces—partly saline alluvial plains: tributary plains extending up to 5 miles downslope, gradients 1 in 250 to 1 in 500; stonier upper parts with aligned, small clay-pan depressions and a distributary pattern of channelled zones; lower parts have sand banks in inter-drainage sectors.

Land Use.—Halophytic shrubland: valuable shrubs should be preserved by management; high drought resistance, but subject to pasture degeneration and to severe erosion by wind and water, aggravated by flooding; stock water limited by salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	180	**Alluvial plains:** extending up to 4 miles downslope, and several miles wide, gradients 1 in 250 to 1 in 500; scalded, stony surfaces with numerous shallow gullies, sand hummocks, and clay pans	Texture-contrast soils. *6d*, *6b*	Tall halophytic shrubland with sparse trees, chenopods, herbage, and short annual grasses: *Acacia aneura* (mulga)–*Kochia pyramidata* (bluebush) alliance (60, 63, 65, 68) and 21
2	20	**Sand banks and dunes:** up to ¼ mile wide, normally parallel with local drainage; hummocky, flattish crests up to 10 ft high, marginal slopes up to 5%; stabilized by vegetation	Red clayey sands and red sands. *3i*, *3g*	Open mulga with edible shrubs and palatable and unpalatable perennial grasses: *A. aneura–Eremophila leucophylla* sub-alliance (5) and 37
3	10	**Circular depressions:** up to 50 yd dia. and lowered to 3 ft in unit 1; stony rims up to 10 yd wide, and heavily sealed, cracking floors with gilgais	Probably both saline and non-saline soils, including coarse-structured clay soils around gilgais	Fringing communities of *Acacia* spp. and chenopods: *Acacia aneura–Kochia pyramidata* alliance (66), with perennial grasses in the floors
4	<10	**Pans:** sealed, locally salt-crusted sandy floors up to ¼ sq. mile in extent and lowered to 1 ft in unit 1	Scalded, fine-textured soils. Saline sediments and gypsiferous sands	Bare
5	40	**Channels:** multiple channels in zones up to 200 yd wide; individual channels up to 50 yd wide and incised to 3 ft, commonly into hard-pan	Bed-loads range from coarse sand to small cobbles	Eucalypt and mulga fringing communities with chenopods and herbage: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10); also 72

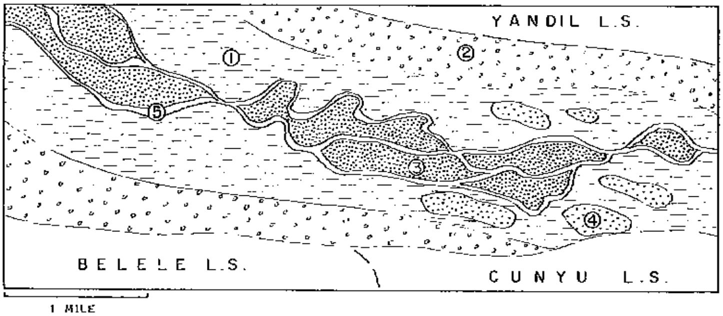
(40) Beringarra Land System (120 sq. miles)

Degraded river plains with curara and salt flats, in the north-west of the area.

Geology.—Quaternary fine-textured, saline, cemented alluvium with minor aeolian sand.

Geomorphology.—Depositional surfaces—partly saline alluvial plains: flood-plains up to 5 miles wide, gradients below 1 in 1000; scalded surfaces with many small clay pans and fringing sand banks; more stable, non-saline outer margins; active inner plains flanking anastomosing channels.

Land Use.—Halophytic shrubland: should be preserved by controlled stocking; subject to degradation and to severe wind and water erosion aggravated by flooding; cultural treatment may be necessary for rehabilitation where the land system is severely degraded; abundant stock water, but partly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	60	**Degraded flood-plains:** extending up to 3 miles from drainage channels; sealed, locally salt-crusted or cracking surfaces, severely scalded and scoured by runnels to 1 ft depth; many clay pans up to ¼ mile in extent	Salt-affected soils, including texture-contrast soils. 6*b*	Open mulga with halophytic shrubs, abundant forbs, and annual grasses: *Acacia aneura* (mulga)–*Kochia pyramidata* alliance (67) and *A. aneura–A. tetragonophylla* sub-alliance (10, 14)
2	40	**More stable outer plains:** sealed, moderately scalded surfaces up to 1 mile wide, with minor runnels, low flood-banks, and aligned circular depressions up to 200 yd dia.	Non-saline soils; presumably, red earths and alluvial soils on hard-pan. 4*h*, minor 1*d*	Very open curara community with sparse shrubs and short annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (10)
3	10	**Active inner flood-plains and inter-channel zones:** up to ½ mile wide, with levees up to 1 ft high, slopes 0·5%; uneven, sealed surfaces with moderate scalding, traversed by shallow flood channels and low flood-banks	As for unit 1, but including some less saline soils, e.g. alluvial soils with a fragmentary pan. 6*b*	Moderately dense community of mixed *Acacia* spp. with halophytic shrubs, forbs, and annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (14), also 60
4	<10	**Sand banks:** up to 2 ft high, 400 yd wide, and extending up to 1 mile down-valley; also forming rims up to 50 yd wide about depressions in unit 2; loose, hummocky crests	Sands apparently derived from erosion of topsoils of unit 1, and probably masking texture-contrast soils. 6*b*	Very open curara community with halophytic shrubs, forbs, and annual grasses: *A. aneura–A. tetragonophylla* sub-alliance (14)
5	<10	**Channels:** up to 25 yd wide and incised to 5 ft into layered alluvium and hard-pan	No bed-load	Fringing community of eucalypts and *Acacia* spp. with shrubs, and various tall grasses (72)

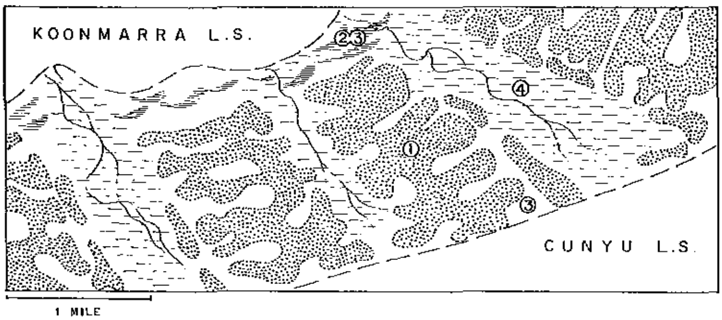
(41) Belele Land System (2000 sq. miles)

Wanderrie plains in the west of the area.

Geology.—Quaternary cemented alluvium and aeolian sand derived mainly from gneiss and granite.

Geomorphology.—Depositional surfaces—alluvial plains with wind modification: tributary plains, gradients 1 in 250 to 1 in 1000; inter-drainage sectors up to 3 miles wide, with wanderrie banks and flats, mainly transverse, but also oblique and elongate downslope, and forming connected patterns locally; through-going central drainage plains.

Land Use.—Open mulga with wanderrie shrubland: palatable species should be encouraged by controlled stocking; high drought resistance; very commonly degraded, with shallow erosion in units 3 and 4; water-spreading feasible on to large banks in lower parts; fairly plentiful stock water in unit 4, but some salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	700	**Wanderrie banks:** up to ½ mile wide, 2 miles long, and 3 ft high; hummocky crests with moderately loose surfaces stabilized by vegetation	Red clayey sands on hard-pan. 3*g*	Open mulga with edible shrubs and palatable perennial grasses: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (1, 2)
2	50	Slopes subject to sheet-flow; sealed, locally scalded surfaces with hard-pan exposures and minor clay pans; gradients about 1 in 500	Principally shallow red earths on hard-pan, of irregular depth near groves. 4*h*, minor 4*h* with 4*j*	**Groves:** mulga with some edible shrubs, sparse perennial grasses, forbs, and short annual grasses: *A. aneura* sub-alliance (22, 28)
3	650			**Wanderrie flats and intergroves:** sparse, low mulga with stunted shrubs and annual grasses; much bare ground; dominantly *Acacia aneura*–*Eremophila fraseri* sub-alliance (6); also 22
4	600	**Drainage floors:** alluvial plains up to ½ mile wide, gradients 1 in 500 to 1 in 1000; sealed surfaces with some hard-pan exposures; commonly traversed by drainage zones with multiple shallow runnels and small flood-banks		Variable mulga and other *Acacia* spp. with sparse shrubs, forbs, and annual grasses: *A. aneura*–*A. tetragonophylla* (curara) (10) and *A. aneura*–*A. craspedocarpa* (15) sub-alliances

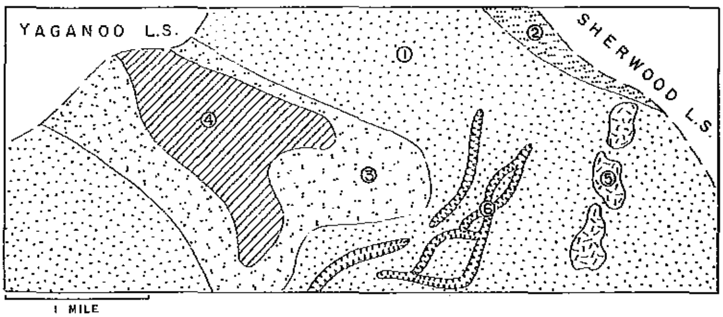
(42) Bullimore Land System (5400 sq. miles)

Spinifex sand plain in the centre and east of the area.

Geology.—Quaternary aeolian sand derived mainly from gneiss and granite.

Geomorphology.—Depositional surfaces—sand plain and dunes: extensive undulating interfluves with little local drainage, consisting mainly of sand plain, with scattered NW.-trending linear dunes in lower areas; smaller areas with run-on from adjacent areas; minor sand-masked incipient breakaway tracts, with steeper slopes and rock outcrops; small areas downslope from breakaway crests with weathered rock at shallow depths.

Land Use.—Spinifex sand plain: short-term improvement by burning to encourage palatable volunteer species, with local introduction of palatable perennial grasses in units 3 and 4; minor wind erosion following burning; widespread adequate stock waters, but with some salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	2800	Open sand plain: tracts up to 3 miles in extent, with a thick sand cover; broadly undulating, with slopes generally less than 1%; looser sand hummocks about vegetation tussocks and firmed surfaces in depressions	Deep, coarse-grained red clayey sands, at least partly on hard-pan, weakly cemented soil, or the weathering crust; locally, coarse-textured red earths. 3*h*, minor 3*c*	Spinifex with scattered trees and various shrub layers; forbs and annuals numerous after a burn: *Eucalyptus kingsmillii* (mallee) – *Acacia aneura* (mulga) alliance (45, 50, 52, 53)
2	<100	Zones behind breakaways: up to ½ mile wide, normally sloping up to 1% from the breakaway crests; surfaces as in unit 1, with a patchy gravel veneer		Spinifex with low mallee, and as unit 1: *E. kingsmillii–A. aneura* alliance (52, 56)
3	1000	Tracts receiving minor run-on: up to 1½ miles wide; locally with bedrock or calcrete at shallow depth; slopes 0·5–1%; surfaces as in unit 1, but less even, with loose sand locally	Mainly red clayey sands, locally on a carbonate horizon. 3*h*	Spinifex with clumps of tall mallee, mulga, some edible shrubs and perennial grasses, numerous forbs and annuals: *E. kingsmillii–A. aneura* alliance (45, 48, 49, 50, 51, 55)
4	1200	Tracts receiving significant run-on: extending up to 1 mile laterally and 3 miles downslope, commonly as lobes; slopes less than 0·5%; surfaces rather firmer than in unit 1	Red clayey sands and red earths on variable hard-pan. 3*g*, 4*h*	Spinifex with mulga, edible shrubs, palatable and unpalatable perennial grasses, forbs, and annuals: *E. kingsmillii–A. aneura* alliance (46, 47, 54); also 59
5	<100	Dissected tracts: incipient breakaway zones up to ½ mile wide, slopes up to 5%; minor outcrops of weathered rock	Mainly red clayey sands. 3*c*, 3*h*	Mulga communities with some mallee, edible shrubs, palatable and unpalatable perennial grasses, clumps of spinifex, forbs, and short annual grasses: *E. kingsmillii–A. aneura* alliance (51, 54); also 5
6	300	Sand dunes and swales: dunes up to 30 ft high and 3 miles long; slopes up to 10% on the west and up to 15% on the east, with sand slopes up to 35%; uneven crests with small blow-outs; swales up to 400 yd wide, slopes 1–5%; softer surfaces than in unit 1, but mainly stable	Red sands in dunes, and coarse-textured soils in swales. 3*i*	Spinifex with rich shrub layers, abundant forbs, and various grasses, and with a sparse tree layer of native pine or eucalypts locally: *E. kingsmillii–A. aneura* alliance (48, 51). Swales commonly as for unit 1 (52)

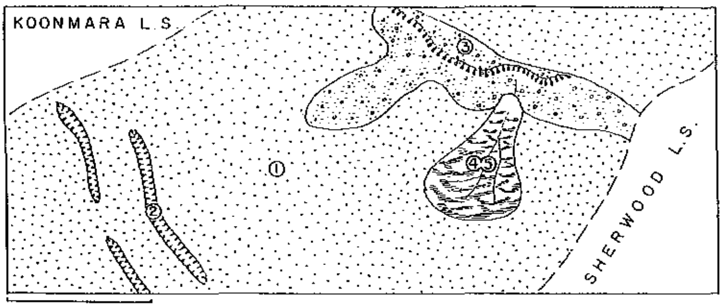
(43) Kalli Land System (250 sq. miles)

Sand plain with soft spinifex, in the west of the area.

Geology.—Quaternary aeolian sand derived mainly from gneiss and granite.

Geomorphology.—Depositional surfaces—sand plain and dunes: gently sloping sand plain with minor linear dunes, irregular or with E.–W. orientation; surface drainage restricted to small, lightly stripped surfaces on weathered rock; small alluvial fans occur locally, downslope from stripped areas; relief less than 30 ft.

Land Use.—Dense mulga with wanderrie shrubland: should be preserved by controlled stocking; pasture improvement possible through tree removal in units 1 and 2; abundant stock water.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	200	Sand plain: several miles in extent, with regional slopes up to 2%; loose or lightly firmed, slightly hummocky surfaces with lateritic gravel	Deep, coarse-textured soils, mainly red clayey sands. 3*h*	Tall, dense mulga with edible shrubs, palatable and unpalatable perennial grasses, and patches of feathertop spinifex: *Acacia aneura* (mulga)–*Eremophila leucophylla* sub-alliance (3, 4, 5)
2	<10	Sand dunes: up to 2 miles long and 30 ft high; rounded crests, flanking slopes up to 15%; soft surfaces stabilized by vegetation	Deep red sands. 3*i*	Open mulga with a dense shrub layer, perennial grasses, and patches of soft spinifex: *A. aneura–E. leucophylla* sub-alliance (5)
3	20	Stripped rocky surfaces: uneven tracts up to ¼ mile wide, locally with low breakaways	Outcrop with little adjacent soil. Rock outcrop and 2	Stunted mulga with some native pines, low scattered shrubs, sparse short annual grasses; much bare rock: *A. aneura–Callitris hugelii* (native pine) sub-alliance (43, 44)
4	10	Alluvial fans: generally less than ½ mile wide and extending up to 1 mile downslope, gradients about 1 in 250	Red earths of irregular depth to hard-pan. 4*h* with 4*j*	Groves: open mulga with some edible shrubs and palatable and unpalatable perennial grasses: *A. aneura–E. leucophylla* (3) and *A. aneura* (30) sub-alliances
5	10			Intergroves: more open mulga without perennial grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10)

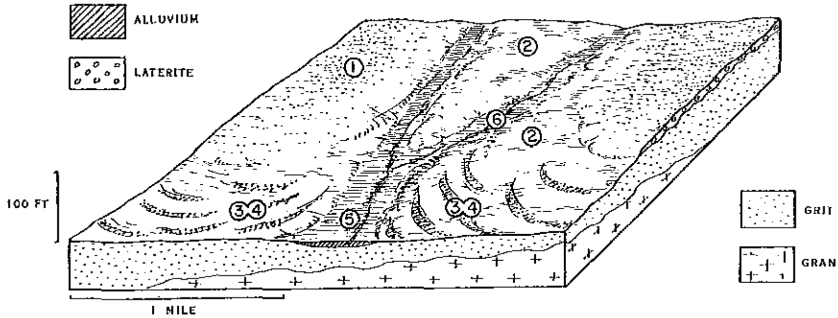
(44) Yelma Land System (100 sq. miles)

Mainly sandy plains with spinifex, in the east of the area.

Geology.—Weathered, flat-lying (?)Permian feldspathic grit, extensively overlain by Quaternary aeolian sand and alluvium.

Geomorphology.—Depositional surfaces—sand plain and dunes: extensive sand plain; stony plains with small breakaways and with extensive gentle slopes subject to sheet-flow; restricted linear drainage, locally feeding alluvial lobes in lowest parts; relief generally less than 10 ft.

Land Use.—Spinifex sand plain: valuable volunteer pastures in unit 1 after burning; elsewhere, ephemeral growth after rain should be heavily stocked; check banks possibly effective in unit 3; stock water undeveloped, but probably adequate, with local salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	50	**Sand plain:** flat or gently sloping tracts up to 1 mile in extent; slightly hummocky surfaces	Deep, coarse-textured soils, mainly red clayey sands. 3*h*	Spinifex with scattered trees and a rich shrub layer; forbs and annuals abundant after a burn: *Eucalyptus kingsmillii* (mallee)–*Acacia aneura* (mulga) alliance (50, 52)
2	10	**Stripped plains:** flattish-crested, gently sloping interfluves up to 2½ miles in extent and 10 ft high; lightly dissected margins up to ½ mile long, slopes up to 2%, with outcrops of weathered rock and low breakaways locally	Presumably very shallow, stony soils. 2	Open mulga with inedible shrubs, unpalatable perennial grasses, clumps of spinifex, and forbs: *A. aneura* sub-alliance (30, 32); also 3
3	5	**Lowermost slopes:** about 0·5% and up to 4 miles long, forming low interfluves up to 1½ miles wide; surfaces subject to sheet-flow and masked with colluvium	Red earths of irregular depth to hard-pan. 4*h* with 4*j*	**Groves:** dense mulga with some edible shrubs and variable grass layers: *A. aneura* sub-alliance (27, 28)
4	20			**Intergroves:** similar to unit 3, but with more open mulga, sparse shrubs, and short annual grasses
5	10	**Drainage floors and alluvial plains:** sealed alluvial surfaces up to ½ mile wide, gradients 1 in 50 to 1 in 500; channelled central tracts in upper sectors	Principally shallow soils, including red earths and texture-contrast soils on hard-pan; locally, red earths of irregular depth to hard-pan near groves. 4*h*, 4*h* with 4*j*, 6*d*	Stunted, open mulga with sparse shrubs and short annual grasses, denser along drainage lines: *A. aneura*–*A. tetragonophylla* (curara) sub-alliance (10, 11); mulga groves: *A. aneura* sub-alliance (21, 27)
6	<5	**Channels:** small channels shallowly incised into hard-pan	No bed-load	Fringing community of mulga and other *Acacia* spp. with dense shrubs and various grasses: probably 35

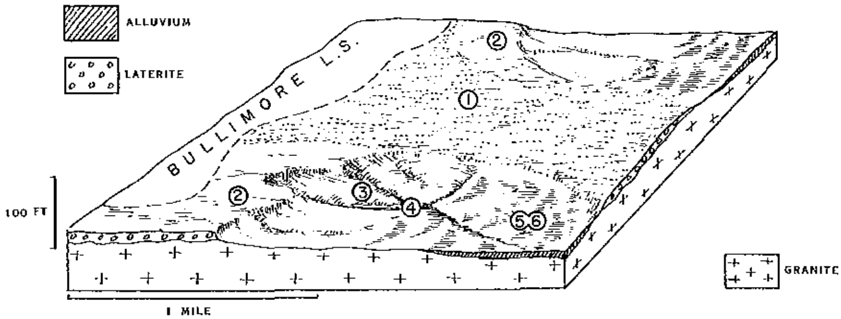
(45) Waguin Land System (200 sq. miles)

Sand plain with spinifex and some stony tracts, in the east of the area.

Geology.—Weathered and unweathered Archaean gneiss and granite; Quaternary aeolian sand and alluvium.

Geomorphology.—Depositional surfaces—sand plain and dunes: stripped plains with minor breakaways formed in the mottled zone; minor plains eroded in little-weathered rock; extensive sand plain remnants; ill-defined surface drainage, locally with definite alluvial floors, more commonly diffuse and ending in small alluvial lobes; relief less than 20 ft.

Land Use.—Spinifex sand plain: palatable pastures in units 5 and 6 should be preserved by controlled stocking; elsewhere, ephemeral growth after rain should be stocked; check banks possible in unit 5; stock water undeveloped, but probably adequate in units 4–6.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	80	**Sand plain:** tracts up to ½ mile wide, with slopes up to 5% locally; slightly hummocky surfaces	Coarse-textured soils, mainly red clayey sands. 3*h*	Spinifex with scattered trees and various shrub layers; forbs and annuals very numerous after a burn: *Eucalyptus kingsmillii* (mallee) – *Acacia aneura* (mulga) alliance (51, 52, 50); also 5
2	50	**Lightly-stripped surfaces and breakaways:** gently sloping tracts up to ¼ mile wide, with extensive rock outcrops with pitted, stony surfaces; marginal breakaways up to 20 ft high	Outcrop with little adjacent soil. Rock outcrop and 2	Stunted mulga with scattered native pines, shrubs, and forbs; much bare rock: *A. aneura–Callitris hugelii* (native pine) sub-alliance (43, 44)
3	10	**Erosional plains:** slopes less than 1% and up to 1 mile long, dissected into slightly rounded interfluves up to ¾ mile wide and 5 ft high; stony surfaces, with many outcrops of weathered rock	Very shallow stony soils. 2	Stunted mulga with sparse shrubs and short annual grasses: probably *A. aneura* sub-alliance (21)
4	<10	**Drainage floors:** mainly up to 100 yd wide; flat central floors with numerous shallow runnels; gently sloping, concave margins	Red earths and, locally, alluvial soils. 4*h*, minor 1*d*	Sparse mulga with some inedible shrubs and variable grasses: *A. aneura–A. tetragonophylla* (curara) sub-alliance (10); also 14, 72
5	10	**Alluvial fans and plains:** up to 2 miles long, gradients 1 in 50 to 1 in 500	Red earths of irregular depth to hard-pan. 4*h* with 4*j*	**Groves:** dense mulga with some edible shrubs and variable sparse grass layers: *A. aneura* sub-alliance (26, 33); also 3, 5, 16, 58
6	40			**Intergroves:** similar to unit 4, but more open; also *A. aneura–A. tetragonophylla* sub-alliance (10)

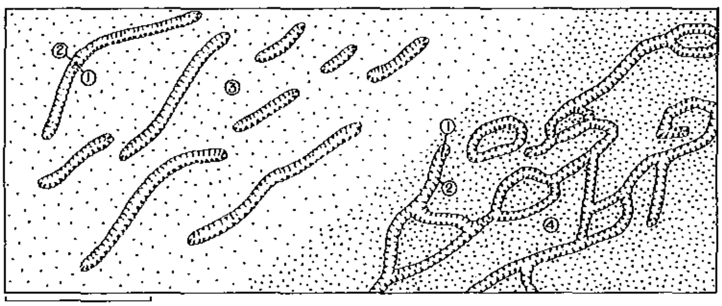
(46) Heppingstone Land System (80 sq. miles)

Spinifex-covered sand dunes in the south-east of the area.

Geology.—Quaternary aeolian sand derived mainly from feldspathic grit.

Geomorphology.—Depositional surfaces—sand plain and dunes: dune fields with NE.-trending linear and locally braiding or reticulate sand dunes; uneven, slightly eroding dune crests, and more stable flanks which are steeper on the eastern sides; the wider swales open out into sand plain; disorganized systems of branching drainage floors occupy the narrower swales; relief up to 40 ft.

Land Use.—Spinifex sand plain: inaccessible; valuable volunteer species may appear after rain following burning; some danger of wind erosion following burning; introduction possible in unit 4; stock water undeveloped.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	10	Dune crests: up to 40 ft high; uneven tracts up to 50 yd wide and continuous up to 2 miles; blow-outs up to 5 ft deep with bare sand	Red sands. 3*i*	Spinifex with rich shrub layers, abundant forbs, and assorted grasses. Locally native pines or eucalypts form a sparse irregular tree layer: *Eucalyptus kingsmillii* (mallee) – *Acacia aneura* (mulga) alliance (48, 52)
2	20	Dune flanks: up to 300 yd long and attaining 15% on the west sides; shorter, and attaining 20% on the east sides, with small slip faces up to 50%; slightly hummocky, concave slopes with loose stable surfaces		As for unit 1, but slightly denser
3	20	Wider swales and sand plain: dune swales more than ½ mile wide, locally opening into sand plain up to 1½ miles in extent; hummocky, loose or lightly firmed, stable sand surfaces	Coarse-textured soils, mainly red clayey sands and red sands. 3*h*, 3*i*	Spinifex with scattered trees, various shrub layers, minor palatable perennial grasses; forbs and annuals numerous following a burn: *E. kingsmillii*–*A. aneura* alliance (50, 52)
4	30	Narrower swales: swales less than ½ mile wide, with flat floors and concave marginal slopes up to 2%; commonly forming disorganized drainage lines; locally with small pans		Spinifex with clumps of tall mallee, mulga, edible shrubs and perennial grasses, and numerous forbs and annuals: *E. kingsmillii*–*A. aneura* alliance (47, 54). Locally with groves of denser mulga and shrub layers, with more open spinifex

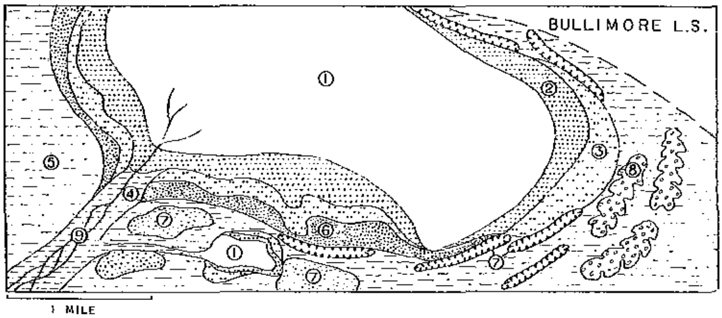
(47) Carnegie Land System (1400 sq. miles)

Salt lakes with fringing salt flats and dunes.

Geology.—Quaternary lacustrine saline clay and sand, saline alluvium, and aeolian sand.

Geomorphology.—Depositional surfaces—salt lakes and dunes: large lakes in major valleys, and smaller pans on their fringes and in areas of impeded drainage; bare floors, alluvial margins, low islands, and tributary plains and channels; sandy margins and islands, consisting of fronting dunes and smaller dunes and banks enclosing satellite pans; kopi banks south and east of lakes.

Land Use.—Salt lakes and halophytic shrubland: partly inaccessible; valuable shrubs should be preserved by controlled stocking; high drought resistance; units 4, 5, and 7 subject to pasture degeneration and wind and water erosion; stock water limited by salinity.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	450	**Inner lake floors:** mud, sand, or clay flats with water close to surface	Fine and coarse-textured saline sediments, gypsiferous in part. Saline sediments	Mainly bare
2	150	**Lower margins:** sandy slopes up to ¼ mile long, less than 1%, and attaining 4 ft above unit 1	As for unit 1, and sands and clayey sands, generally gypsiferous, locally with a gypseous pan at shallow depth. Saline sediments	Samphire (*Arthrocnemum* spp.) community with forbs and short annual grasses: samphire alliance (70)
3	80	**Higher margins:** up to 50 yd wide, slopes less than 2% towards low step to unit 2; and 10 ft above unit 1		Very open mulga with saltbush, bluebush, and forbs: *Acacia aneura* (mulga) –*Kochia pyramidata* (bluebush) alliance (60)
4	20	**Lower tributary plains:** hummocky slopes less than ¼ mile long, gradients about 1 in 500	Texture-contrast soils and saline and calcareous alluvial soils. 6*b*	Low halophytic shrubland with succulents, forbs, and short annual grasses: *A. aneura–K. pyramidata* alliance (64)
5	280	**Higher tributary plains:** more than 4 ft above unit 1, and normally separated by a low step from unit 4; slopes up to 1 mile long, gradients 1 in 250 to 1 in 500	Texture-contrast soils. 6*d*, 6*b*	Tall halophytic shrubland with forbs and short annual grasses: *A. aneura–K. pyramidata* alliance (68)
6	20	**Sandy slopes above lake margins:** up to 50 yd long with a height range of 10 ft	Gypsiferous or clayey sands, and texture-contrast soils. 6*b*	Paper-bark (*Melaleuca* spp.) fringing community with halophytic undershrubs and forbs: fringing communities (71)
7	350	**Dunes and sand banks:** dunes up to 50 ft high and 200 yd wide; stable slopes, 10–30%, and uneven crests; hummocky banks up to 10 ft high and 1 mile in extent	Red sands, and red clayey sands on hard-pan. 3*i*, 3*g*	Open silver-leafed mulga with halophytic shrubs, forbs, and perennial grasses: *A. aneura* sub-alliance (37, 38); also 4
8	20	**Kopi dunes:** banks up to 35 ft high and ½ mile wide; pitted surfaces with slopes up to 15%, commonly cliffed or dissected by branching depressions	Mainly encrusted kopi, with shallow red soil cover in hollows	Very open eucalypts with sparse shrubs, forbs, and annual grasses; most species calciphilous: *A. aneura–A. sclerosperma* sub-alliance (20)
9	40	**Channels:** up to 10 ft wide and 1 ft deep, gradients 1 in 250 to 1 in 500	No bed-load	Mulga fringing community: *A. aneura–A. craspedocarpa* sub-alliance (15)

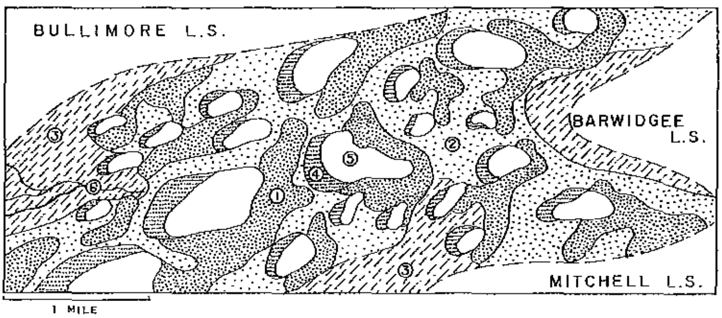
(48) Leeman Land System (200 sq. miles)

Spinifex-covered dunes and small salt pans in the east of the area.

Geology.—Quaternary lacustrine saline clay and sand, saline alluvium, and aeolian sand.

Geomorphology.—Depositional surfaces—salt lakes and dunes: valley tracts up to 5 miles wide with numerous small salt lakes; higher sand banks and lower saline sand banks on east sides of lakes; saline tributary alluvial plains mainly on west sides of lakes; relief up to 10 ft.

Land Use.—Salt lakes and halophytic shrubland: units 1–3 should be conserved through controlled stocking, since degradation is commonly due to their isolated occurrence; units 4–6 are of little value; stock water at little depth, commonly saline.



Unit	Approx. Area (sq. miles)	Land Form	Soil and Soil Association	Vegetation
1	80	**Higher sand banks:** flattish crests up to 300 yd wide and 6–10 ft above lakes, marginal slopes less than 5%; hummocky, loose, but stable surfaces	Red sands with thin hard-pan bands. 3*i*	Spinifex and palatable perennial grasses and forbs, with sparse mulga and shrubs: *Acacia aneura* (mulga)–*Kochia pyramidata* (bluebush) alliance (61)
2	80	**Lower sand banks:** uneven crests up to 200 yd wide and 3–6 ft above lakes; mainly loose surfaces, minor blow-outs with sealed salt-crusted floors		As for unit 1, but with mulga very sparse or absent
3	20	**Saline alluvial plains and higher lake margins:** up to ¼ mile wide and extending up to ½ mile down-slope, gradients less than 1 in 500; 3–6 ft above lakes; uneven, sealed surfaces with minor salt crusts	Texture-contrast soils, in part severely wind-eroded and modified to form scalds with adjacent sandy hummocks. 6*b*	Shrubland of halophytic species, with forbs and annual grasses: *A. aneura*–*K. pyramidata* alliance (65)
4	10	**Lower lake margins:** generally less than 50 yd wide, slopes less than 3%, extending to 3 ft above lakes; sealed, locally cracking surfaces with salt crusts		Samphire (*Arthrocnemum* spp.) community with forbs and annual grasses; samphire alliance (70)
5	10	**Lakes:** sand or clay flats up to ½ mile in extent; locally cracking floors with minor salt crusts, water-table near surface	Presumably fine-textured or layered fine- and coarse-textured saline sediments, partly gypsiferous	Bare, or with samphire communities as in unit 4
6	<10	**Channels:** up to 10 ft wide and 3 ft deep	No bed-load	Fringing communities of sparse *Acacia* spp. with chenopods

PART III. CLIMATE OF THE WILUNA–MEEKATHARRA AREA

By Jennifer M. Arnold*

I. Introduction

The area lies in an arid region according to the classification of Meigs (1953), namely one which does not receive adequate rain to permit the regular production of crops without supplementary water sources.

Because use of the area depends primarily on the grazing of the native vegetation, the effects of the various climatic factors must be considered in relation to native plant growth and distribution. The most important of these factors is rainfall, and the frequency of occurrence of rain and its effectiveness in initiating and maintaining plant growth are of particular significance. Rainfall effectiveness is limited by other climatic factors, since high temperatures and low humidity greatly increase water requirements by increasing rates of evapotranspiration, whilst low temperatures depress growth even when water is available.

It is possible that small areas of crops irrigated with underground water will be of some importance in the future. In the case of irrigated crops, rainfall is significant mainly from the point of view of recharge of underground water supplies, whilst other factors such as temperature and humidity, which determine the amount of water used by crops, assume greater importance. Temperature is also important in that extremes such as frosts or heat waves can cause serious damage to crops at critical growth periods.

II. Major Weather Controls

(*a*) *Summer* (*December to February*)

One of the commonest synoptic situations is that in which an anticyclone is centred off the south coast, often with a slight ridge towards the Wiluna–Meekatharra area. Under these circumstances weather in the area is fine and warm to hot, there is little or no cloud, and easterly winds predominate.

As the anticyclonic centre moves eastwards a low-pressure trough often develops southwards along the west coast from the Onslow–Marble Bar area. If it moves eastwards through the Wiluna–Meekatharra area without any marked development, winds in that area back from north-east to south-east as the trough passes, and the temperature change is not marked. If, on the other hand, the trough deepens or a low-pressure centre forms in it, winds back through north-east to north-west and later to south-west as the trough or depression passes, before returning to the south-easterly circulation.

When the west side of a depression covers the area, surface winds may be easterly in the morning and north-westerly in the afternoon. The reversal of direction

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appears to be brought about by the convective mixing of the surface layers and the north-westerly winds of higher altitudes. As temperatures fall, the north-westerly wind dies away, and by morning the winds again blow along the pressure gradient, from the south-east.

High and middle-level cloud accompanies the development of these troughs, with occasional cumulonimbus and thunderstorms.

The district is occasionally visited by tropical cyclones which usually move in a southerly or south-easterly direction from the north-west coast between Carnarvon and Port Hedland. These bring widespread cloud and rain and, although sporadic, are of considerable importance to land use. On the credit side, they provide the most marked and widespread vegetation response; on the debit side, they cause widespread floods, accentuate erosion, and disrupt communications.

(*b*) *Autumn* (*March to May*)

Similar synoptic situations occur in early autumn, but as the season progresses the surface winds become lighter and more variable. Average rainfall is heaviest in March, the first month of this season, and the heaviest daily falls for most stations are recorded during this month. After March, the probability of rains coming from depressions of tropical origin decreases, and by May the northward movement of the anticyclonic belt has become very noticeable.

As individual anticyclones move eastwards, the Wiluna–Meekatharra area experiences north to north-west winds which may persist for some days. At times, middle-level cloud brings rain to the area under these circumstances, and frontal action associated with a following depression of southern origin may bring low cloud and further showers. These usually clear rapidly as the following anticyclone extends across the area from the west.

There is a marked fall in temperature during this season, the average values of both maximum and minimum temperature falling by about 20°. In May, when anticyclones following southern depressions bring a strong flow of southerly air to the area, with clear night skies and little or no wind in the early mornings, minimum temperatures occasionally approach freezing point.

(*c*) *Winter* (*June to August*)

Conditions in winter are characterized by a continuous sequence of anticyclones, since during this season the anticyclonic system reaches its northern limit. As an anticyclone is moving away, north to north-west winds sometimes occur, usually followed by southern depressions which move across Western Australia. These occasionally bring rain and sometimes gales to the area. However, in many cases the influence of the depression does not extend far enough north to bring good rains, and average rainfall during these months is lower than during the preceding season, though there are about the same number of wet days. Although westerly gales occasionally extend to this area, winds are frequently light and variable when anticyclonic systems are centred over it. Under these conditions minimum temperatures occasionally fall below freezing point on several successive days.

(*d*) *Spring* (*September to November*)

In this season the high-pressure systems become weaker and gradually move further southwards, and in November the anticyclonic belt is centred off the south coast and extends to the tropics. Over the tropics, rising temperatures establish a more or less permanent low-pressure system which is occasionally displaced by the southern anticyclonic system, particularly in the early part of the season when the anticyclones are further north and more intense than they are later. As the season develops, the southern depressions influence the region less and less, whilst the development of low-pressure troughs extending southwards from the tropics along the west coast becomes more evident.

At this time of the year, very little rain from the southern depressions reaches the Wiluna–Meekatharra area, whilst at the same time it is too early for the northern systems to produce any worth-while rain. Because of this, the spring months are the driest of the year.

The absence of the anticyclone which is often centred over the continent, and which roughly conforms to it in shape during the winter months, leads to the disappearance of the prevailing northerly component of the surface winds and easterlies are again more frequent than any other wind in spring.

III. General Climatic Characteristics

To provide a clearer picture of climatic conditions in the area, data are included for several stations which lie outside the area covered by the regional survey. These are Cue to the south-west and Peak Hill to the north of Meekatharra, and Earaheedy, which lies north-east of Wiluna. Of the stations in the survey area, greatest attention has been paid to Meekatharra and Wiluna.

(*a*) *Rainfall*

Average annual rainfall ranges from just over 7 in. in the west of the area to 10 in. in the east. This increase in rainfall towards the east is due to the heavier rainfall from summer storms in this part of the area, which more than compensates for the decrease in winter rainfall from the west.

March has the highest average rainfall and there are minor peaks in January and May. The driest months are September, October, and November, the first two of these months only recording rain in approximately two years out of three. General features of the average rainfall regime are shown in Table 1 and Figure 2.

Winter rainfall decreases towards the east and north, and a corresponding increase in summer rainfall can be observed in this direction. Variability, expressed as 100 standard deviation/mean, is high, ranging from 43% at Cue to 63% at Lorna Glen. Since summer rain is more variable than winter, the annual variability increases sympathetically with the proportion of summer rainfall in the annual totals.

The high variability of summer rainfall compared with that of winter rainfall is due to its origin. It can be seen from the remarks on major weather controls that whereas winter rainfall usually comes from widespread disturbances, a large part of the summer rainfall comes from convectional storms which may be extremely sporadic in occurrence and localized in effect.

TABLE 1

MEAN MONTHLY AND SEASONAL RAINFALL (IN.) AT SELECTED STATIONS*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Oct.–Mar.	Apr.–Sept.
Cue	1·06	0·72	1·29	0·57	0·99	0·97	0·81	0·65	0·22	0·22	0·36	0·60	8·46±3·70†	4·25±2·41	4·21±1·58
Meekatharra	1·34	0·85	1·70	0·87	1·10	0·90	0·61	0·57	0·16	0·18	0·32	0·57	9·17±3·50	4·96±2·64	4·21±1·66
Wiluna	1·47	1·11	1·53	1·33	1·09	0·86	0·46	0·37	0·17	0·26	0·31	0·84	9·80±4·89	5·52±3·25	4·28±1·55
Peak Hill	1·30	1·14	1·65	0·88	1·03	1·11	0·54	0·38	0·16	0·14	0·33	0·67	9·33±4·53	5·23±3·21	4·10±1·62
Earaheedy	1·31	1·12	1·72	0·65	0·98	1·08	0·78	0·36	0·13	0·16	0·52	0·76	9·57±5·71	5·59±3·77	3·98±1·75
Lorna Glen	1·38	1·34	1·86	0·76	1·11	0·93	0·65	0·38	0·14	0·23	0·44	0·79	10·01±6·30	6·04±4·60	3·97±1·40

* Sources of data: (1) Commonwealth Bureau of Meteorology—Climatic Averages, Australia; (2) daily rainfall records.

† Standard deviation (in.).

In general, the west of the area experiences a greater number of wet days* than the east, though more of the falls are of less than 0·50 in. in the west. Intensity of rainfall expressed as average rain per wet day is significantly higher in the east: 0·32 in. at Lorna Glen compared with 0·25 in. at Meekatharra. This increase in intensity is due to the heavier falls which may occur during January, February, and March in the east of the area.

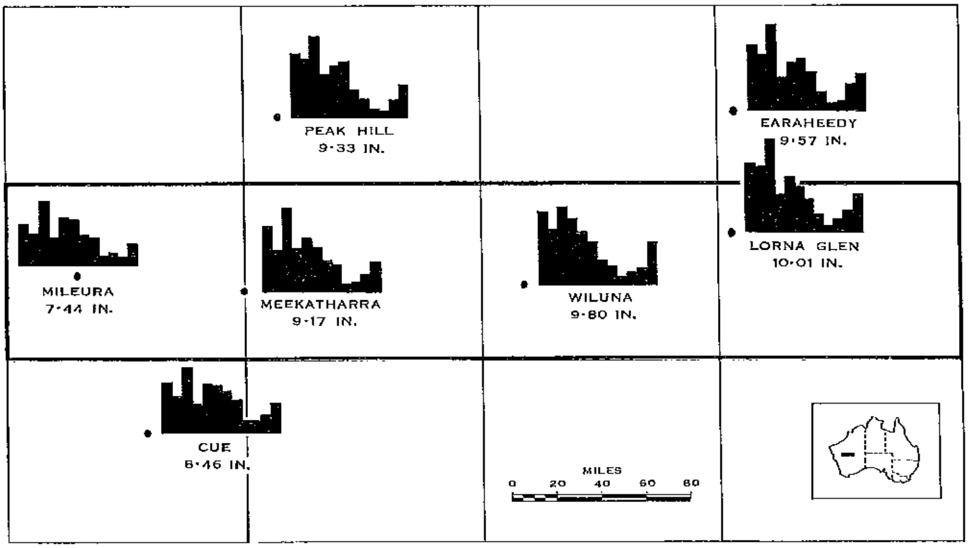

Fig. 2.—Histograms of annual rainfall distribution (January to December) at recording stations in and near the survey area.

If a wet period is defined as a period of rainy weather which is terminated by more than 2 dry days, about half the wet periods last 1 day only; they do not often persist for longer than 5 days, and approximately one such occurrence can be expected per year. Table 2 shows the number of wet periods of specified duration expected to occur at Cue, Meekatharra, Wiluna, Peak Hill, and Lorna Glen. The number of wet periods lasting more than 2 days increases towards the east in the summer and decreases in this direction in the winter.

The expected number of wet periods per month varies from about 2·5 in mid winter to about 1·1 in spring. In winter, slightly less than one-half of the wet periods persist for longer than 2 days, whilst in early summer wet days almost always occur singly. In late summer and autumn about one-third of the falls last for 2 days or longer.

Table 3 shows the amount of rain that can be expected per wet period. At Cue and Meekatharra slightly more wet periods receiving 0·5 in. or more can be expected in the 6 months April to September than in the 6 months October to March, but at Wiluna, Peak Hill, and Lorna Glen the reverse applies. However, though the total number of wet periods decreases towards the east, there is an eastwards increase in the proportion of falls greater than 1·0 in.

* A wet day is any day on which at least 0·01 in. of rain is recorded.

TABLE 2

EXPECTED NUMBER OF WET PERIODS OF DURATION EXCEEDING THAT INDICATED*

Duration (days)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Oct.–Mar.	Apr.–Sept.
							Cue							
0	1·74	1·63	1·72	1·47	2·20	2·43	2·61	2·29	1·45	1·16	1·08	1·49	8·82	12·45
2	0·59	0·51	0·49	0·49	0·92	1·00	0·86	0·72	0·22	0·16	0·18	0·24	2·17	4·23
5	0·12	0·10	0·10	0·06	0·22	0·31	0·27	0·20	0·00	0·02	0·00	0·06	0·40	1·06
							Meekatharra							
0	1·82	1·53	1·76	1·28	2·02	2·18	2·43	1·84	1·04	0·81	0·90	1·23	8·05	10·79
2	0·65	0·49	0·67	0·46	0·70	0·88	0·69	0·49	0·18	0·08	0·23	0·33	2·45	3·40
5	0·18	0·12	0·33	0·08	0·24	0·28	0·28	0·10	0·02	0·00	0·06	0·06	0·75	1·00
							Wiluna							
0	1·90	1·38	1·78	1·26	2·05	1·76	1·90	1·64	0·71	0·83	1·07	1·50	8·46	9·32
2	0·64	0·48	0·64	0·43	0·67	0·64	0·48	0·38	0·19	0·07	0·36	0·48	2·67	2·79
5	0·21	0·12	0·24	0·07	0·17	0·24	0·10	0·05	0·00	0·00	0·12	0·10	0·79	0·63
							Peak Hill							
0	1·38	1·14	1·21	0·90	1·36	1·57	1·36	1·02	0·46	0·51	0·76	1·10	6·10	6·67
2	0·58	0·43	0·48	0·21	0·50	0·48	0·28	0·19	0·00	0·02	0·19	0·22	1·92	1·66
5	0·18	0·12	0·26	0·07	0·05	0·12	0·24	0·05	0·00	0·00	0·02	0·02	0·60	0·53
							Lorna Glen							
0	1·78	1·33	1·33	1·22	1·61	1·67	1·33	0·89	0·50	0·78	1·17	1·61	8·00	7·22
2	0·67	0·50	0·28	0·22	0·44	0·44	0·39	0·33	0·06	0·11	0·61	0·44	2·61	1·88
5	0·22	0·39	0·11	0·11	0·17	0·06	0·00	0·00	0·00	0·06	0·00	0·06	0·84	0·34

* Source of data: daily rainfall records.

TABLE 3

EXPECTED NUMBER OF WET PERIODS IN WHICH RAINFALL OCCURRED IN AMOUNTS EXCEEDING THOSE INDICATED*

Amount (in.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Oct.–Mar.	Apr.–Sept.
							Cue							
0·5	0·57	0·53	0·49	0·33	0·65	0·65	0·47	0·33	0·08	0·14	0·14	0·27	2·14	2·51
1·0	0·43	0·37	0·29	0·10	0·24	0·29	0·14	0·16	0·02	0·02	0·06	0·12	1·29	0·95
2·0	0·16	0·16	0·16	0·04	0·04	0·06	0·02	0·02	0·00	0·00	0·00	0·06	0·54	0·18
							Meekatharra							
0·5	0·65	0·45	0·76	0·38	0·68	0·56	0·36	0·45	0·06	0·08	0·16	0·27	2·37	2·49
1·0	0·31	0·26	0·49	0·20	0·28	0·30	0·04	0·18	0·02	0·00	0·08	0·10	1·24	1·02
2·0	0·16	0·16	0·20	0·04	0·10	0·06	0·00	0·02	0·00	0·00	0·02	0·04	0·58	0·22
							Wiluna							
0·5	0·67	0·48	0·57	0·48	0·57	0·40	0·19	0·24	0·10	0·10	0·19	0·31	2·32	1·98
1·0	0·40	0·36	0·48	0·24	0·33	0·24	0·05	0·07	0·02	0·02	0·10	0·17	1·53	0·95
2·0	0·12	0·17	0·21	0·12	0·12	0·12	0·00	0·00	0·00	0·02	0·00	0·07	0·59	0·36
							Peak Hill							
0·5	0·52	0·48	0·60	0·33	0·50	0·40	0·21	0·12	0·05	0·05	0·19	0·29	2·13	1·61
1·0	0·30	0·28	0·40	0·24	0·31	0·33	0·05	0·02	0·02	0·00	0·12	0·17	1·27	0·97
2·0	0·05	0·14	0·28	0·00	0·07	0·14	0·00	0·00	0·00	0·00	0·00	0·07	0·54	0·17
							Lorna Glen							
0·5	0·67	0·33	0·56	0·44	0·56	0·44	0·39	0·22	0·11	0·17	0·06	0·61	2·40	2·16
1·0	0·39	0·22	0·44	0·11	0·33	0·44	0·28	0·11	0·05	0·06	0·06	0·17	1·34	1·33
2·0	0·17	0·17	0·28	0·06	0·17	0·11	0·00	0·00	0·00	0·00	0·00	0·11	0·73	0·34

* Source of data: daily rainfall records.

TABLE 4

EXPECTED NUMBER OF OCCURRENCES OF MINIMUM TEMPERATURES IN SPECIFIED RANGES AT THREE STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Meekatharra													
25–29 °F	—	—	—	—	—	0·3	—	—	—	—	—	—	0·3
30–34 °F	—	—	—	—	—	0·4	0·9	0·1	—	—	—	—	1·4
35–39 °F	—	—	—	—	0·4	2·0	4·7	0·7	0·4	—	—	—	8·2
40–44 °F	—	—	—	—	3·3	8·1	9·9	10·1	3·0	—	0·3	—	34·7
Total no. of occurrences of temperatures below 45 °F	—	—	—	—	3·7	10·8	15·5	10·9	3·4	—	0·3	—	44·6
Wiluna													
25–29 °F	—	—	—	—	—	0·1	0·6	0·1	—	—	—	—	0·8
30–34 °F	—	—	—	—	0·2	1·8	4·4	2·4	0·1	—	—	—	8·9
35–39 °F	—	—	—	—	3·1	6·6	9·1	6·6	1·9	0·1	—	—	27·4
40–44 °F	—	—	—	0·3	5·6	8·7	6·7	7·8	5·2	1·3	—	—	35·6
Total no. of occurrences of temperatures below 45 °F	—	—	—	0·3	8·9	17·2	20·8	16·9	7·2	1·4	—	—	72·7
Peak Hill													
25–29 °F	—	—	—	—	—	—	—	—	—	—	—	—	—
30–34 °F	—	—	—	—	—	0·1	0·8	0·1	—	—	—	—	1·0
35–39 °F	—	—	—	—	—	1·2	2·6	1·0	—	—	—	—	4·8
40–44 °F	—	—	—	—	1·3	7·6	10·2	9·6	2·1	0·2	—	—	31·0
Total no. of occurrences of temperatures below 45 °F	—	—	—	—	1·3	8·9	13·6	10·7	2·1	0·2	—	—	36·8

* Source of data: daily temperature records.

(b) Dew

Dews are of little importance in the area. In the summer, mean minimum temperatures are at least 20°F above mean dew point, so that dews cannot be expected except during and immediately following rainy weather. During the three coldest months, June to August, dew point is 40–45°F at Cue and Meekatharra and 37–40°F at Wiluna and Peak Hill, only 3 or 4 degrees below mean minimum temperature, so that dews can be expected fairly frequently. From Table 4, which shows the expected number of occurrences of minimum temperatures in various ranges, it is seen that Meekatharra can expect 10 days per year with minima below 40°F and 45 days with minima below 45°F. Wiluna can expect 10 days per year with minima below 35°F and 37 days with minima below 40°F. However, on many of the days on which minimum temperatures fall below dew point, temperatures are low enough for frosts to occur, and this minimizes the effect of the dew-fall.

Dews are most likely to occur in the area during winter when an anticyclone moves over the west of the continent after a southern depression, bringing an influx of cold southern air. Frosts usually occur for the first 2 or 3 days, followed by a gradual return to milder weather during which dews may occur on several successive mornings and be of some significance to plant growth.

(c) Temperature

The annual temperature regime is characterized by marked diurnal and seasonal fluctuations. Diurnal fluctuations in temperature are a result of the extreme radiation conditions which generally prevail, as humidity is low and normally there is little cloud to hinder incoming or outgoing radiation.

There is little difference in mean monthly maximum temperature between stations (Table 5 and Fig. 3). Each station has 5 months with mean maxima above 90°F, and 3 of these months have averages above 95°F.

Table 6 shows the expected number of occurrences of maximum temperatures in specified ranges at Meekatharra, Wiluna, and Peak Hill. It can be seen from this that there are no marked differences in maximum temperature between these three stations.

There are greater differences in mean minimum temperature between stations, particularly in the winter months, mean minimum temperature at Wiluna being 3 or 4 degrees lower than at stations further west.

Table 4 shows the expected number of occurrences of minimum temperatures in specified ranges at three stations. The more extreme winter temperatures to be experienced towards the east of the area are clearly shown here. Whilst Wiluna can expect about 73 days per year with minima below 45°F, 45 such days can be expected at Meekatharra and only 37 at Peak Hill. Wiluna can expect 10 days with minima below 35°F, while Meekatharra can expect less than 2 days and Peak Hill only 1 day.

The area experiences a short frost season which is more severe towards the east. However, frost days usually occur in groups of two or three, when an anticyclone follows a southern depression bringing with it a strong flow of cold air. Wiluna may occasionally record minimum temperatures of 36°F as early as May and as late as

TABLE 5.
MEAN TEMPERATURES AT FOUR STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Cue													
Mean max. temp. (°F)	99·3	98·8	92·7	84·4	74·0	66·8	65·4	68·7	76·7	82·8	91·1	97·1	83·1
Mean min. temp. (°F)	72·5	72·5	68·4	60·2	51·7	46·7	44·3	45·9	50·4	55·3	63·4	69·2	58·4
Meekatharra													
Mean max. temp. (°F)	100·4	99·7	93·9	85·7	76·0	68·6	67·5	71·2	78·6	84·8	92·9	98·2	84·8
Mean min. temp. (°F)	73·1	73·1	69·4	61·0	52·5	46·3	44·0	46·5	51·0	56·9	64·7	70·0	59·0
Wiluna													
Mean max. temp. (°F)	99·0	98·4	93·1	84·4	74·3	66·9	66·0	70·4	78·8	85·6	93·3	98·3	84·0
Mean min. temp. (°F)	72·4	71·8	67·3	58·1	49·5	43·3	40·8	43·8	49·3	56·1	64·4	70·0	57·2
Peak Hill													
Mean max. temp. (°F)	99·5	98·0	94·2	85·3	74·5	67·3	66·0	70·2	78·2	85·1	93·6	99·2	84·3
Mean min. temp. (°F)	74·4	73·9	70·2	62·5	53·6	47·6	45·5	47·6	52·9	58·5	66·5	72·7	60·5

* Source of data: Commonwealth Bureau of Meteorology—Climatic Averages, Australia.

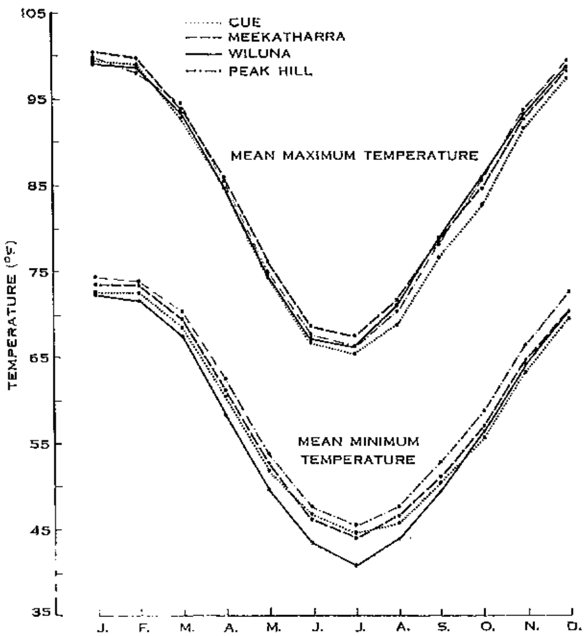

Fig. 3.—Mean monthly maximum and minimum temperatures for Cue, Meekatharra, Wiluna, and Peak Hill.

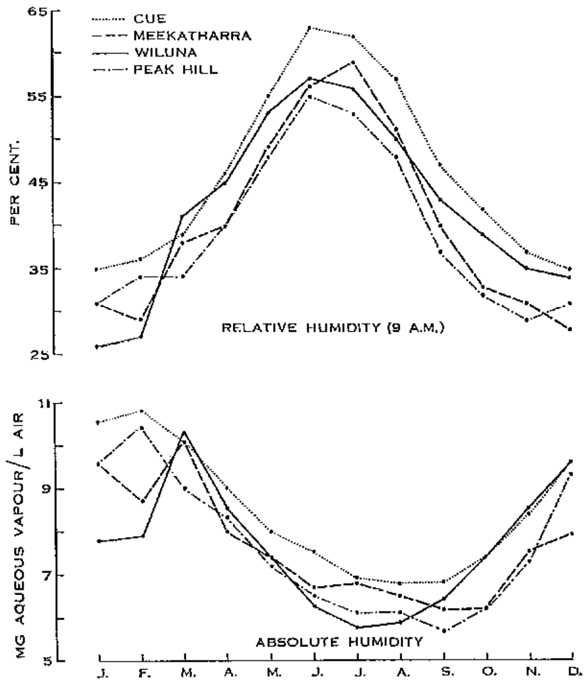

Fig. 4.—Relative humidity (9 a.m.) and absolute relative humidity for Cue, Meekatharra, Wiluna, and Peak Hill.

TABLE 6

EXPECTED NUMBER OF OCCURRENCES OF MAXIMUM TEMPERATURES IN SPECIFIED RANGES AT THREE STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						Meekatharra							
90–94°F	3·4	4·0	7·6	8·0	0·4	—	—	0·1	2·0	7·4	5·1	5·1	43·1
95–99°F	6·1	7·0	8·0	1·6	—	—	—	—	0·2	3·4	8·4	8·4	43·1
100–104°F	12·5	7·4	5·0	0·6	—	—	—	—	—	0·6	3·7	8·2	38·0
105°F and over	8·2	4·4	—	—	—	—	—	—	—	—	0·8	4·9	18·3
Total no. of occurrences of 90°F and over	30·2	22·8	20·6	10·2	0·4	—	—	0·1	2·2	11·4	18·0	26·6	142·5
						Wiluna							
90–94°F	3·5	4·4	6·8	6·3	0·4	—	—	—	2·2	6·1	5·7	4·1	39·5
95–99°F	5·3	6·8	8·3	1·9	0·1	—	—	—	0·5	3·7	8·4	8·1	43·1
100–104°F	11·0	6·7	5·0	0·2	—	—	—	—	—	0·8	4·1	8·6	36·4
105°F and over	9·1	4·8	0·6	—	—	—	—	—	—	—	1·2	5·4	21·1
Total no. of occurrences of 90°F and over	28·9	22·7	20·7	8·4	0·5	—	—	—	2·7	10·6	19·4	26·2	140·1
						Peak Hill							
90–94°F	3·1	5·2	10·4	5·1	0·2	—	—	—	1·7	4·9	9·7	4·3	44·6
95–99°F	9·0	6·2	9·7	1·3	—	—	—	—	0·2	1·1	7·2	9·6	44·3
100–104°F	12·4	10·0	4·4	—	—	—	—	—	—	0·7	4·9	10·9	43·3
105°F and over	5·7	3·9	0·3	—	—	—	—	—	—	—	0·5	3·3	13·7
Total no. of occurrences of 90°F and over	30·2	25·3	24·8	6·4	0·2	—	—	—	1·9	6·7	22·3	28·1	145·9

* Source of data: daily temperature records.

September, whilst Meekatharra and Cue usually record such temperatures only in June, July, and August, and at Peak Hill they occur only in some years in July. Temperatures of 32°F or less occur rarely at Meekatharra and Cue, but they can be expected at Wiluna in July (Foley 1945).

The average length of the frost-free period decreases eastwards and southwards and ranges from 350 days at Peak Hill and 341 days at Meekatharra to 288 days at Wiluna.

(*d*) *Humidity*

Humidity is low throughout the area except during and immediately following wet weather. Table 7 and Figure 4 show mean monthly and annual values.

Mean relative humidity at 9 a.m. ranges from about 30% in January to about 60% in June. Mean 3 p.m. values are generally 10–15% lower than 9 a.m. values in summer and 15–20% lower in winter.

The trend shown by dew point and absolute humidity is the reverse of that shown by relative humidity, the highest values occurring in summer and early autumn and the lowest in winter and spring.

Dew point in the months December to March is 50–55°F, dropping to 40°F or less in mid winter. Absolute humidity is equal to about 10 milligrams of water vapour per litre of air in mid summer or early autumn and about 6 mg/l in mid winter.

(*e*) *Evaporation*

Rates of evaporation from a free water surface are extremely high. Yearly figures from a standard Australian 3-ft-diameter tank evaporimeter are between 90 and 110 in. per year. Rates as high as 14 in. per month may be recorded during the summer, but in winter they fall to 2–3 in.

IV. Climate and Vegetation

The perennial components of the vegetation are able to make some growth after rains but remain virtually dormant during periods of water shortage. The high variability of the rainfall is important in that it permits the existence in the area of only those perennial species that can withstand periods of several years during which there is insufficient rain to permit a significant period of growth. A number of small, shallow-rooting ephemerals, mainly grasses and composites, are able to grow and mature rapidly following rain.

(*a*) *Rainfall Effectiveness*

Grazing of natural pastures is the primary form of land use. In determining the usefulness of rain to these pastures it is necessary to assess firstly the frequency of rains which are sufficient to initiate germination of ephemerals and regrowth of perennials, and secondly the length of time following this initial rain during which sufficient moisture is available to allow growth to continue.

(i) *Technique*.—The procedure used to assess rainfall effectiveness is essentially similar to that employed by Slatyer (1962) for the Alice Springs area. However, because growth periods appeared to be more seasonal as a result of the greater importance of winter rainfall in this area, the method has been modified to some extent.

TABLE 7
HUMIDITIES AT FOUR STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Cue													
Relative humidity 9 a.m. (%)	35	36	39	46	55	63	62	57	47	42	37	35	44
Relative humidity 3 p.m. (%)	25	26	29	34	42	49	48	42	33	29	25	24	34
Dew point (°F)	56	56	54	50	47	45	42	42	42	46	50	52	48
Absolute humidity (mg water vapour/l air)	10·5	10·8	10·1	9·0	8·0	7·5	6·9	6·8	6·8	7·4	8·4	9·6	8·5
Meekatharra													
Relative humidity 9 a.m. (%)	31	29	38	40	49	56	59	51	40	33	31	28	38
Relative humidity 3 p.m. (%)	21	26	30	27	36	40	44	36	24	19	19	16	28
Dew point (°F)	51	49	52	46	43	40	41	40	38	39	44	48	44
Absolute humidity (mg water vapour/l air)	9·6	8·7	10·1	8·0	7·4	6·7	6·8	6·5	6·2	6·2	7·5	7·9	7·6
Wiluna													
Relative humidity 9 a.m. (%)	26	27	41	45	53	57	56	50	43	39	35	34	42
Relative humidity 3 p.m. (%)	25	27	30	33	39	42	39	35	31	28	25	24	31
Dew point (°F)	47	45	54	47	43	38	37	39	39	43	47	51	44
Absolute humidity (mg water vapour/l air)	7·8	7·9	10·3	8·5	7·4	6·3	5·8	5·9	6·4	7·4	8·5	9·6	7·6
Peak Hill													
Relative humidity 9 a.m. (%)	31	34	34	40	48	55	53	48	37	32	29	31	37
Dew point (°F)	51	54	50	47	42	40	37	37	35	38	42	52	44
Absolute humidity (mg water vapour/l air)	9·6	10·2	9·0	8·3	7·2	6·5	6·1	6·1	5·7	6·2	7·3	9·3	7·6

* Source of data: Commonwealth Bureau of Meteorology—Climatic Averages, Australia.

If sufficient rain fell in any one week to leave some stored soil water at the end of that week, requirements for the initiation of growth were assumed to have been satisfied. It was assumed that if the rainfall over a period of 1 wk exceeded $0 \cdot 4E_w$* this provision would be met. This value of E_w was selected as a suitable average figure for the 7-day period because evaporation would be high (approximately $1 \cdot 0E_w$) for the first day or so after rain but would drop markedly as soon as the soil surface became dry. Transpiration would be low throughout the period, since emergence of annuals and regrowth of perennials would not occur for several days. Rainfall fulfilling the requirements of $0 \cdot 4E_w$ was termed initial effective rainfall, using the terminology of White (1955), and the estimates thus obtained agree quite closely with growth responses observed at Wiluna by D. G. Wilcox (personal communication).

The water requirement was assumed to drop to $0 \cdot 2E_w$ in the week following initial effective rainfall, because transpiration would still be at a low but increasing level, and there would be little evaporation from the soil. However, if rain occurred during this week the water requirement was taken to remain at a level of $0 \cdot 4E_w$.

TABLE 8

INITIAL EFFECTIVE RAINFALL REQUIREMENTS (IN.) FOR FOUR STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cue	1·17	1·28	0·94	0·63	0·38	0·27	0·24	0·30	0·46	0·61	0·88	1·07
Meekatharra	1·01	0·92	0·80	0·58	0·41	0·34	0·32	0·47	0·67	0·87	0·99	1·14
Wiluna	1·15	1·01	0·87	0·64	0·50	0·36	0·37	0·52	0·76	0·98	1·10	1·18
Peak Hill	1·11	1·00	0·94	0·70	0·50	0·34	0·42	0·52	0·79	0·98	1·13	1·15

If water was still available at the end of the first 2 weeks, either from soil storage or from further rain, the water requirement was assumed to rise with the increase in transpiring leaf area to $0 \cdot 4E_w$ and to remain at this level until the water supply was exhausted.

Daily rainfall was grouped into weekly totals and a budget was drawn up with estimated evapotranspiration† depleting the soil storage as set out above, allowing for supplementation of soil water by rainfall. It was assumed that growth continued as long as there was soil moisture left.

(ii) *Initial Effective Rainfall*.—Table 8 shows initial effective rainfall requirements for Cue, Meekatharra, Wiluna, and Peak Hill, and Table 9 shows the number of occurrences of initial effective rainfall at these stations in the 30-yr period 1929–58.

* E_w = evaporation from a free water surface (Penman 1956).

† Evaporation (E_w) for Meekatharra, Wiluna, and Peak Hill was computed using the Penman formula. That for Cue was estimated using a ratio of monthly saturation deficit to evaporation of 16 (Farmer, Everist, and Moule 1947). As evaporation estimated in this way for Meekatharra, Wiluna, and Peak Hill approximated the Penman estimates for those stations, it was considered valid to use the estimated 16 S.D. values for Cue.

These tables show the northwards decrease in number of occurrences from Cue to Peak Hill and also the increase in the proportion of these which occur in the first 3 months of the year compared with the second 3 months.

This emphasizes the decrease in importance of winter rainfall towards the east already evident from average rainfall data. Cue in the south-west does not receive such heavy falls from tropical disturbances as do the other stations, but it receives a heavier rainfall from southern depressions in the late autumn and winter.

Falls of sufficient amount to fulfil the requirements of initial effective rainfall are infrequent in spring and early summer. They occur more often in August in the south-west than in the north and east, but in September, October, and November they are rarely recorded at any of the stations.

TABLE 9

NUMBER OF OCCURRENCES OF INITIAL EFFECTIVE RAINFALL IN THE 30-YR PERIOD 1929–58 AT FOUR STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Cue	7	6	6	7	19	13	12	10	2	3	0	3	88
Meekatharra	11	8	12	9	15	11	12	8	1	1	0	1	89
Wiluna	12	8	9	8	11	9	6	5	0	1	1	6	76
Peak Hill (29 yr)	6	11	6	3	13	8	4	1	0	1	0	1	54

* Source of data: daily rainfall records.

(iii) *Length of the Subsequent Growth Period*.—Table 10 shows the number of weeks following initial effective rainfall when water is available for plant growth, either from soil storage or from further rain. It can be seen that most of these periods last 4 wk or less. At Cue, growth periods commencing in May and June are most likely to last for longer than 1 month, and in about half of the 30-yr period examined, growth periods lasting 2 or more months commenced at this time. At Meekatharra, a greater number of growth periods commenced in February and March and two of these lasted for 4 months or more. At Wiluna and Peak Hill (i.e. in the east and north) there is a successive reduction in the number of growth periods.

It must be noted that the length of the growth period indicated by this method will apply only to vegetation on areas which have no gain or loss of water from run-off and which have reasonably deep (2–3 ft) soils. Vegetation on areas with shallow soils or on steep slopes would probably have a comparatively shorter growth period, while that on deeper soils or on areas which receive run-on would be expected to have a rather longer growth period.

(*b*) *Droughts and their Effects*

The vegetation of the area is well adapted to survive the rigorous climatic conditions under light grazing, but with the development of a pastoral industry and more concentrated grazing, the duration and frequency of prolonged dry periods have become important. Most of the rain falls during the 6 months January to June, so that even in favourable years there is likely to be a period of 6 to 9 months when rainfall is inadequate to allow significant plant growth. In a year of low rainfall this dry period may be unbroken by significant growth periods during the summer or winter, and in this event will continue unbroken at least until the summer of the following year.

TABLE 10

NUMBER OF OCCURRENCES OF GROWTH PERIODS, COMMENCING IN THE MONTHS SPECIFIED, OF VARIOUS LENGTHS DURING THE 30 YR 1929–58 AT FOUR STATIONS*

Growth Period (wk)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
						Cue							
<4	6	4	5	6	10	5	7	10	2	3	–	3	61
4–7	1	2	–	1	2	2	5	–	–	–	–	–	13
8–11	–	–	1	–	3	3	–	–	–	–	–	–	7
12–15	–	–	–	–	–	3	-	–	–	–	–	–	3
16–19	–	–	–	–	4	–	–	–	–	–	–	–	4
						Meekatharra							
<4	9	6	7	7	10	3	12	7	1	–	–	1	63
4–7	2	–	2	2	4	5	–	1	–	1	–	..	17
8–11	–	2	–	–	–	1	–	–	–	–	–	–	3
12–15	–	–	1	–	1	2	–	–	–	–	–	–	4
16–19	–	–	–	–	–	–	–	–	–	–	–	–	–
20–23	–	–	2	–	–	–	–	–	–	–	–	–	2
						Wiluna							
<4	9	5	5	4	8	3	6	4	–	1	1	4	50
4–7	3	2	1	3	3	3	–	1	–	–	–	2	18
8–11	–	1	1	–	–	3	–	–	–	–	–	–	5
12–15	–	–	–	–	–	–	–	–	–	–	–	–	–
16–19	–	–	–	1	-	–	–	–	–	–	–	–	1
20–23	–	–	2	–	–	–	–	–	–	–	–	–	2
						Peak Hill							
<4	5	7	4	2	9	2	4	1	–	1	–	1	36
4–7	1	3	1	–	2	4	–	–	–	–	–	–	11
8–11	–	1	1	–	2	2	–	–	–	–	–	–	6
12–15	–	–	–	1	–	–	–	–	–	–	–	–	1

* Source of data: daily rainfall records.

D. G. Wilcox (personal communication) has made the following observations on pasture response in the area. He considers that drought conditions for sheep will exist if winter rains fail to break a dry spell which commenced following satisfactory rains in the previous year. Light falls of rain, though they may freshen up the perennial elements of the pasture, can be harmful to annual pastures because they tend to destroy available feed, and a dry spell will only be broken by rains of sufficient quantity to initiate germination of annuals and to maintain their growth for at least 4 wk. A 4-wk growth period should provide enough fodder to enable stock to survive for about 6 months, but following prolonged drought, of more than 2 yr duration for example, an appreciably longer growth period is necessary for pasture recovery. Pastures dominated by summer-active perennials and gramineous annuals will respond more rapidly to summer rains than to falls in winter, when temperatures are lower. However, the amount of rain required to initiate growth is much lower in winter and the response of non-gramineous annuals, particularly of composites, is much greater.

According to Foley (1957) the worst droughts to have occurred in the Murchison District since records commenced were those of 1896–1900, 1902–4, 1911–14, 1935–41, and 1943–45. The most severe drought was that of 1935–41, when stock numbers were greatly depleted. If daily rainfall records are examined from this point of view it is evident that the most prolonged droughts coincide approximately with those

TABLE 11

YEARS IN WHICH NO DRAUGHT-BREAKING RAINS OCCURRED (1929-58 INCLUSIVE)

Station	Years
Cue	1930, 1935, 1936, 1937, 1939, 1944, 1946, 1949, 1954
Meekatharra	1930, 1935, 1936, 1937, 1940, 1943, 1944, 1946, 1950, 1953
Wiluna	1929, 1932, 1935, 1936, 1939, 1940, 1943, 1944, 1950, 1956, 1957
Peak Hill	1930, 1932, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1943, 1944, 1946, 1947, 1950, 1952, 1953, 1956

defined by Foley. In addition, there have been a number of other years when no drought-breaking rains were recorded, these being progressively more frequent in a north-easterly direction from Cue towards Peak Hill. Table 11 shows the years in which there was no continuous period of 4 wk when water was available for plant growth during the 30 yr 1929–58. The longest drought to occur in this time was 1935–40 inclusive, when the dry period was broken for only brief intervals during 6 yr. Slightly less than 1 yr in 3 could be classified as drought at Cue, while the frequency increases north-eastwards to 1 yr in 2 at Peak Hill.

(c) *Influence of Temperature*

Although rainfall is the most important climatic factor affecting the distribution and growth of vegetation, temperature plays an important part by limiting the effectiveness of rainfall during the hot summer months and by depressing growth rates during the colder months.

In December, January, and February, it is estimated that a fall of at least 1·00 in. is required to initiate growth, and further falls of this magnitude are required

TABLE 12

EVAPOTRANSPIRATION ESTIMATES FOR IRRIGATION AT THREE STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						Meekatharra							
Evaporation* (in.)	11·5	9·3	9·1	6·3	4·7	3·9	3·8	5·3	7·4	9·8	10·8	12·8	94·7
Average rainfall (in.)	1·34	0·85	1·70	0·87	1·10	0·90	0·61	0·57	0·16	0·18	0·32	0·57	9·17
Irrigation need (in.)	10·16	8·45	7·40	5·43	3·60	3·00	3·19	4·70	7·24	9·62	10·48	12·23	85·53
						Wiluna							
Evaporation* (in.)	12·7	10·1	9·6	6·8	5·5	3·8	4·1	5·8	8·4	10·9	11·8	13·0	102·5
Average rainfall (in.)	1·47	1·11	1·53	1·33	1·09	0·86	0·46	0·37	0·17	0·26	0·31	0·84	9·80
Irrigation need (in.)	11·23	8·99	8·07	5·47	4·41	2·94	3·64	5·43	8·23	10·64	11·49	12·16	92·70
						Peak Hill							
Evaporation* (in.)	12·3	10·0	10·4	7·5	5·6	3·6	4·7	5·7	8·5	10·9	12·1	12·7	104·0
Average rainfall (in.)	1·30	1·14	1·65	0·88	1·03	1·11	0·54	0·38	0·16	0·14	0·33	0·67	9·33
Irrigation need (in.)	11·00	8·86	8·75	6·62	4·57	2·49	4·16	5·32	8·34	10·76	11·77	12·03	94·67

* Estimates of evaporation from a free water surface (Penman 1949, 1956).

within a week or so if growth is to be maintained for any significant period. In the cooler months, 0·5 in. or less is required to initiate growth. It follows from this that parts of the area which receive a higher proportion of their rain in the winter months could expect a more effective growth period than those which receive the bulk of their rain during the summer.

Growth rates, particularly of perennial plants, may be considerably suppressed by low temperatures during the frost season. However, soil water reserves are maintained, to be utilized following a return of warm weather. Particularly at Wiluna, this factor may cause the growing season to extend further into the spring months than is shown in Table 10.

V. Evapotranspiration and Irrigation

Depending on adequate supplies of ground water, irrigation may be practised on small areas. Rates of evapotranspiration of actively growing lucerne in small (10 ac) plots measured at Alice Springs (Jackson 1960) indicate that it approximates to $1 \cdot 0E_w$, and similar rates of evapotranspiration on small plots could be expected in this area where the regional energy balance and local advective effects are similar. Table 12 shows evapotranspiration at Meekatharra, Wiluna, and Peak Hill on this basis (Chapman 1962). However, the water requirements for irrigation include both evapotranspiration and losses in delivery and are influenced by frequency of application, size of irrigated area, and whether water is required merely to ensure survival of the crop or to maintain active growth.

VI. Acknowledgments

The account of general synoptic conditions in the area is closely based on a statement prepared by the Commonwealth Bureau of Meteorology.

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PART IV. GEOLOGY OF THE WILUNA–MEEKATHARRA AREA

By J. Sofoulis* and J. A. Mabbutt†

I. Introduction

The Wiluna–Meekatharra area forms part of the Western Australian Pre-Cambrian shield and includes portions of the Murchison, East Murchison, and Mt. Margaret gold-fields.

Most of the area is underlain by Archaean gneiss and granite traversed by remnant belts of metamorphic rock. The metamorphic rock is generally referred to as greenstone (predominantly metavolcanic) or whitestone (predominantly metasedimentary). A small tract of younger metasedimentary rock, regarded as equivalent to the Mosquito Creek series, occurs along the central northern fringe of the area.

Proterozoic volcanic and sedimentary rocks, correlated with the Nullagine "system", are developed in the central and north-eastern parts. The eastern part of the area also contains grit and tillite which are tentatively regarded as Permian in age.

Little-consolidated Tertiary and Quaternary deposits mask these older rocks in broad drainage tracts and cover approximately 50% of the area.

The various rock types are briefly described below in order of age, with some reference to their significance to the nature and distribution of land systems. Some mention is made of the economic geology of the area.

A geological map, scale 1:1,000,000, accompanies this report.

II. The Archaean Basement

The basement rocks may be divided on the basis of lithology into two groups. The older group consists of belts of folded and metamorphosed rocks (greenstone, whitestone, and Mosquito Creek series); the younger group includes gneiss, granite, and other igneous derivatives. By analogy with adjacent Pre-Cambrian areas these two groups appear to belong to the older Pre-Cambrian, and they constitute the Archaean basement of the area.

(a) *The Metamorphic Belts*

These are subparallel elongate belts, mainly in the south of the area. Two trends may be recognized — an east-north-east trend in the west of the area and a north to north-north-west trend elsewhere. The belts attain a width of approximately 15 miles in the south, generally tapering and becoming discontinuous northwards. They form the whitestone ranges and the hill belts referred to in Part V.

The metamorphic belts consist of two phases, the greenstone phase and the whitestone phase, which correspond respectively to metavolcanic and metasedimentary phases in the formation of the belts. The greenstone appears to be lower in

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the stratigraphic succession and is hence regarded as the older phase. Separation of the two phases is not everywhere complete, as thin greenstone bands may be included in the whitestone and vice versa.

(i) *The Greenstone Phase.*—The greenstone assemblages are metamorphic derivatives of typical volcanic piles, and consist predominantly of basic amphibolitic lava, tuff, and agglomerate, with minor intercalations of metasedimentary lenses, ultrabasic schist, and acid volcanic rock.

The basic volcanic rock is principally fine- to medium-grained, with characteristic blocky fracture, and is locally agglomeratic, pillowed, amygdaloidal, or tuffaceous. It is metamorphosed to varying degrees, the recrystallized forms now appearing as fine- or medium-grained amphibolite. Where stress conditions have prevailed, the rock develops a mineral orientation frequently masking original characteristics and grades into amphibolitic, talcose, hornblendic, chloritic, actinolitic, or tremolitic schist.

Several rock masses were observed infolded with the greenstone or whitestone, or as isolated folded bands, consisting of medium- to coarse-grained amphibolites, some of which had textures indicative that they were recrystallized doleritic or gabbroic lava (e.g. Barloweerie Peak, 32 miles west-south-west of Meekatharra). These tend to form higher ground, as in Yagahong land system, whilst the more schistose greenstone forms gentler slopes, as in Wiluna and Violet land systems.

The greenstone in the west of the area has been described by Johnson (1950) as the Igneous series. Greenstone belts further east have been mapped and described by Clarke (1916) and by Talbot (1920).

Clarke, in the Meekatharra district, distinguishes between unmetamorphosed basic igneous rock and a number of more or less metamorphosed rocks of basic igneous origin. The former includes basaltic dolerite, the Barloweerie norite, and basaltic and andesitic flows; the latter, which are more widespread, include massive and schistose rock, mainly of doleritic origin and partially of peridotitic origin.

In the Wiluna district, Talbot has distinguished four greenstone belts. His Comedy King and Wiluna belts together form the Wiluna hill belt; the Barwidgee hill belt is termed Barlow's belt by Talbot, and the Mount Eureka hill belt is also distinguished further east. All these belts are described as consisting of massive, foliated or schistose greenstone of doleritic origin, with minor whitestone bands.

Kaolinization and ferruginization of the greenstone was widespread during the Tertiary phase of deep weathering.

The weathered cappings take the form of pisolitic gravel overlying kaolinized schist and of more resistant limonitic and hematitic cappings to higher ground on more massive rock. Secondary limestone weathering crusts and carbonate coatings are extensive on the more basic rocks. These weathering crusts have been subsequently dissected and are now restricted to higher parts. Strike and schistosity foliation and transverse joints have exercised an important control on the patterns of this dissection.

(ii) *The Whitestone Phase.*—The largest element among the metasediments is a wide variety of schist, including mica-schist, quartz-mica-schist, quartz-feldspar-schist, and graphitic schist. Higher grades of metamorphism within these belts are indicated by local development of the metamorphic minerals andalusite, garnet, kyanite, and sillimanite. The schist is diversified by interbedded jaspilite and quartzite, which are considerably more resistant than the adjacent bands and which tend to form outstanding strike ridges. Accordingly, the whitestone gives rise to more prominent relief.

As with the greenstone, the rocks of this phase are everywhere highly folded, with dips greater than 70°.

In the west of the area, two prominent whitestone belts trend west or west-south-west, where they form the whitestone ranges constituting Weld land system. Both belts have been previously described by Johnson (1950), by whom they are referred to as the Sedimentary series. Johnson gives a minimum thickness of 5000 ft for this series in the Jack Hills.

Talbot (1920) has grouped the whitestone with the greenstone in the east of the area, whilst Clarke (1916) gives no separate account of the whitestone element of the metamorphic belts in the Meekatharra district, the metasedimentary jaspilite being interpreted by him as marking shear zones. Further east, the whitestone forms smaller parts of the metamorphic belts.

Because of their acid nature, weathering on these rocks has been less general than on the greenstone, but silicified hematitic crusts are particularly prominent on jaspilite bars. In the western hill belts, these weathering crusts have been extensively dissected and removed in Gabanintha land system, but they survive extensively further east in Fisher land system.

(iii) *Mosquito Creek Series*.—These are a very small but separate group of metasedimentary schists outside the main metamorphic belts in the north-central fringe of the area, but which share the westerly trend of the whitestone ranges. They have been referred to as the Mosquito Creek series by Clarke (1916) and by Talbot (1920), and they consist of quartz-feldspar-schist, slate, conglomerate, and minor amphibolite-schist.

(*b*) *Granite and Gneiss*

These are the most extensive of the Archaean basement rocks and cover broad areas between the metamorphic belts. The granite is mainly medium- to coarse-grained, usually porphyritic (with microcline), and pinkish in colour, and it has a low ferromagnesian content. The gneiss is usually fine- to medium-grained, greyish in colour, exhibiting mineral orientation, and showing a higher ferromagnesian content.

Two major granitic masses have been distinguished — one in the Murchison plains and the other between the Meekatharra and Wiluna hill belts. The gneiss occurs in broad zones peripheral to these granite masses, with foliation parallel to the outer perimeter of the granite or to the adjoining metamorphic belts. Local mobilization has yielded small granite bodies within the gneiss. Granitic rocks of the Murchison plains have been described by Johnson (1950), who distinguished between granite and gneiss. Two types of granite are recognized, although they are of a common magmatic origin. Three-quarters of the granite consists of a coarse-grained, usually porphyritic microcline granite with subordinate biotite and few accessory minerals. It forms the central mass of the batholith and builds the granite hills of Norie and Mindura land systems.

Near the periphery, the granite is mainly a medium-grained orthoclase granite containing some plagioclase feldspar and plentiful biotite and accessory minerals.

Under gneiss, Johnson grouped numerous banded and foliated rocks which he classed as granitization-gneiss, paragneiss, orthogneiss, and mylonitic gneiss.

In his account of the Meekatharra district Clarke (1916) did not distinguish between granite and gneiss, but recognized two main types which he regarded merely as phases of the same magma. He described as the Southern Cross type a biotite-microcline-granite which is only occasionally sheared, has a prevailing yellow-brown colour, contains pegmatitic dykes, and is locally associated with mineralization. It has a restricted occurrence on the west side of the Meekatharra metamorphic belt. The more widespread Meekatharra type is a foliated microcline-biotite-granite, described in this report as gneiss. Talbot (1920) regarded the granitic rocks further east as essentially of one type; he noted that the granite is much jointed and occasionally sheared, and that it is traversed by quartz reefs near the contacts with the metamorphic belts.

The uniformity of the granite and gneiss is reflected in the broad, undulating land surfaces with uniform lateritic weathering crusts which underlie much of the sand plain in the area. This lateritic crust is undergoing dissection in Sherwood land system, and in the Murchison plains has been extensively stripped to form Koonmarra and Mindura land systems.

In granitic areas, kernels of unweathered rock have given rise to rounded granite domes, as in Mindura and Norie land systems. On the gneiss, dissection has left linear rocky belts which form low watersheds.

The granite and gneiss are intruded by a network of thin pegmatitic veins and by younger intrusives. The latter include quartz bars, which form narrow rocky ridges corresponding to jointing and locally to fault planes, and rare quartz-dolerite dykes following similar jointing directions.

(c) *Archaean Tectonics*

The metamorphic belts are regarded as synclinorial remnants of Archaean orogenic structures with mainly northerly trends. The whitestone ranges show an exceptional west-south-west trend and are somewhat arcuate, suggestive of a regional southerly pitch with minor crossfolding on east–west axes.

It is significant that the metamorphic belts end approximately on an east-south-east line extending from latitude 26°15′ to 26°30′, a line followed by several major drainage elements, e.g. Yalgar River and Leemans valley, and also by the axis of the central basin of Nullagine rocks (see below).

The granitic rocks accordingly occupy broad anticlinal tracts, possibly of dome-like form although elongated along north–south axes. Granite occurs towards the centres of these tracts, whilst gneiss forms peripheral granitized zones with circumferential foliation trends which are also conformable with the strike of adjacent metamorphic belts. Conformity of structure between metamorphic and crystalline rocks suggests that the granitization occurred simultaneously with the folding.

Widespread faulting of a minor character is evident in all the metamorphic belts. Clarke (1916) mentioned two directions of faulting and shearing, one slightly east of north, which has imposed a schistose structure on most of the metamorphic belts, and another more or less at right angles to the first. The transverse fissuring is stated by Clarke never to exceed 200 ft, but a transverse displacement of half a mile is seen on the western margin of the Meekatharra metamorphic belt approximately 3 miles north of the rabbit-proof fence.

Two major jointing directions are recognized within both granite and gneiss, one trending west of north, the other running east–west. These directions are followed by minor valleys dissecting the granitic rocks and also by some major topographic features, such as the Hope River and its larger tributaries. Many joint and fault planes are followed by or are occupied by quartz bars. Younger quartz-dolerite dykes believed to be pre-Nullagine in age are similarly controlled by Archaean fracturing.

Mineralization is widespread along the margins of granitic bodies, extending in zones up to 1 mile wide. Mineralization is particularly associated with transverse fissuring, but in the Meekatharra mining area it is also associated with axial faulting.

III. Proterozoic Rocks

(*a*) *The Proterozoic Succession*

These consist of gently folded, unfossiliferous sedimentary and volcanic rocks unconformably overlying the Archaean basement. They are the southernmost extension of rocks which are widely developed further north as far as the Pilbara goldfield and which have been termed the Nullagine "system".

These Nullagine rocks accumulated in a shallow arm of the sea extending from the north-west of the continent. They are dated as Proterozoic by analogy with the Kimberley area, where lithologically similar rocks bearing a like relationship to the Archaean basement are unconformably overlain by fossiliferous Cambrian sediments.

There are three principal occurrences of these rocks, with differing successions and structures and different land system patterns.

(i) *Mt. Yagahong Area.*—A line of small but prominent plateaux occurs near Gabanintha 25 miles south-east of Meekatharra. The succession is revealed at Mt. Yagahong, which rises some 600 ft above the adjacent granitic plains. A thin basal conglomerate is overlain by 20 ft of basalt, followed by 500 ft of flat-lying slate and by 100 ft of an upper basalt.

(ii) *Central Basin.*—A second area of Nullagine rocks occurs in the northern half of the area between Meekatharra and Wiluna. The Nullagine succession here is known to exceed 250 ft and consists of basal lava overlain by argillaceous sediments, locally with thin dolomite beds, which give place increasingly to sandstone in the upper part of the succession. There is no evidence here of an upper volcanic phase.

This succession is well exemplified in sections at Mt. Alice (approximately 16 miles north of Wiluna) and 5 miles further north. A minimum of 75 ft of flat-lying basalt is exposed in low hilly country to the north, whilst at Mt. Alice this is presumably overlain by up to 150 ft of flaggy mudstone, phyllite, and shale in layers up to 50 ft thick, with interbedded thinner sandstone-quartzite which becomes more prominent in the upper part of the succession, where it forms structural benches. Thin dolomite bands occur near the base of the succession at the north foot of the Glengarry Ranges.

Exposed surfaces in these arenaceous rocks have commonly undergone secondary silicification into grey-white "billy" which characteristically gives rise to sub-rounded blocky surfaces. The argillaceous rocks are commonly deeply weathered, with porcellanitic cherty bands, ochreous horizons, and limonitic box-works.

The shallow-water origin of the quartzite is indicated locally by ripple marks, which are well developed on hill summits on the south side of the Wiluna road approximately 27 miles east of Meekatharra. Conglomerates locally exceeding 15 ft in thickness also occur in the Glengarry Ranges and in low hills approximately 5 miles south-east of Yandil homestead.

Regionally, this succession is disposed along east–west lines and forms a shallow basin, the axis of which is followed by West Creek. The sediments frequently overlap the basal volcanics in the south of this basin, and extensively transgress onto the granitic basement. In this area they are seen to have gentle depositional dips off the granite floor.

The dissected plateau rim of Glengarry land system is formed by the sandstone-quartzite horizons, whilst the underlying rocks exposed in the centre of the basin form the fairly stable lateritized surfaces of Diamond and Dural land systems. Dissected weathered basalts form Killara land system.

(iii) *North-eastern Basin.*—The third occurence of Nullagine rocks is in the north-east sector, where Nullagine sediments dip gently north-east towards Lake Carnegie and give rise to a series of parallel north-west-trending uplands. The base of the Nullagine rocks is exposed on Windidda station approximately 5 miles south of Paddy well. Conglomeratic and feldspathic grit up to 15 ft thick here rests unconformably on gneiss and is in turn overlain by 5 ft of silicified sandstone capping a strike belt of low plateaux (Glengarry land system).

These basal beds appear to be at least 75 ft thick where traversed by the Granite Peak road 4 miles south-west of Camel bore, and here they are seen to alternate with fine-grained and locally cross-bedded sandstone.

To the north-east, the succession consists of mudstone and shale, with a capping of ferruginous grit and sandstone giving rise to a second upland belt. The ferruginous sandstone is overlain by up to 60 ft of flaggy mudstone and shale, which is exposed on the road 10 miles north-east of Camel bore and also on the lower slopes of the Christmas Range south of Windidda homestead. Elsewhere, these form the low uplands of Doman land system.

The mudstone and shale are followed by thin-bedded dolomite and shale which generally form lowlands, as in Windidda and Kalyaltcha land systems, although more massive dolomite up to 40 ft thick may build ridges, as in Boondin land system north of the Christmas Range.

The dolomite-shale belt is overlain by massive, gently dipping sandstone and quartzite in the Princess Range (Princess land system). Together with interbedded mudstone they form a succession up to 400 ft thick.

North-east again, the quartzite of the Princess Range is overlain by thinly interbedded dolomite and shale which form the lowlands of Wongawol land system and are at least 200 ft thick. In the higher part of this sequence, these rocks are interbedded with sandstone, locally ripple marked, and are intruded by dolerite as thin dykes and sills.

(*b*) *Proterozoic Tectonics*

The Proterozoic Nullagine sediments were laid down in fairly shallow basins in the Archaean basement, the initial form and the subsequent deformation of the basins owing something to Archaean structures. The Nullagine succession nowhere appears to be of great thickness, ranging from 600 ft in the west to possibly 1000 ft in the north-east.

The survey area shows no parallel with the strong block faulting of the Pilbara and Balfour Downs areas further north, but the prominent diagonal joint patterns of the northern areas are also widespread here.

In common with the Nullagine rocks further north, the Proterozoic rocks in this area have undergone only gentle folding, with dips seldom exceeding 5°. A further similarity with the northern area is in the lithology of the sediments and in the occurrence of basalt at the bottom and top of the succession.

So far as is known, the Nullagine rocks of this area have not been intruded by granite and show no evidence of hydrothermal mineralization.

IV. Permian Beds

In the Christmas Range, south of Windidda homestead, the Nullagine rocks are unconformably overlain by flat-lying boulder tillite and feldspathic grit with a prominent silcrete (grey billy) duricrust.

These beds have been described as Cretaceous by Talbot (1920, 1926), but by analogy with the known Permian glacial beds in the Pilbara and Irwin River districts north and west of the survey area they are here tentatively regarded as Permian.

The Christmas Range section shows approximately 10 ft of silcrete capping (gritty in the lower section) above 25 ft of porcellanized siltstone, below which is 20 ft of glacial tillite made up of fresh and kaolinized glacial boulders embedded in a siltstone matrix. These rest unconformably on gently dipping Nullagine shale and slate.

The erratics consist mainly of granite and gneiss of various types, with scattered boulders of porphyry, quartzite, and greenstone, all indicating a southern derivation, as well as Nullagine quartzite and conglomeratic boulders of local origin. They range in size from cobbles to massive boulders up to 5 ft in diameter. They are commonly subrounded, but sometimes angular and faceted, and some bear striae.

Further east, at Boondin Bluff, the siltstone above the tillite is in turn overlain by passage beds up to 10 ft thick consisting of kaolinized and ochreous grit with silt cakes, and these in turn are overlain by up to 25 ft of medium- to coarse-grained feldspathic grit with a thin silcrete duricrust.

In the area south of Lake Carnegie, remnants of these Permian beds form flat-crested summits in Tooloo and Boondin land systems, whilst in the less dissected areas further south they are extensive in Yelma land system.

To the north-west, the Permian beds were laid down in broad valleys eroded in Nullagine rocks, and here the duricrusted sediments form valley-side benches, as in Sodary land system.

A former greater extent of these beds is indicated by the widespread occurrence of erratic boulders on the plains south of Lake Carnegie, particularly in Kalyaltcha land system. In some areas the Permian beds survive only as a boulder veneer on hill slopes of Nullagine rocks.

V. Tertiary and Quaternary

Since Palaeozoic times the Wiluna–Meekatharra area has remained dry land and has undergone no significant deformation. The formations which follow are merely superficial and their development is related to the present landscape evolution, in particular to the general tendency towards deposition on lower ground associated with deterioration of climate and the development of interior drainage from Tertiary times onwards.

(*a*) *Lateritic Weathering Profiles*

These weathering crusts form part of the pan-Australian duricrust (Woolnough 1927) and were probably developed under a humid climate in early Tertiary times. The differing forms taken by the weathering crust have been described in relation to the rock types, and the erosional land systems of the area have been broadly classified according to whether this lateritic profile remains intact, or has been partially dissected, or completely removed.

The crusts include pisolitic ironstone gravel, as on greenstone schist, Nullagine basalt, and some sediments; case-hardened, locally silicified mottled zones with some pisolitic gravel, as on granite and gneiss; and resistant silcrete cappings on arkosic Permian grit. These form duricrusts above kaolinized and porcellanized pallid zones of variable depth.

Weathering crusts on more resistant rocks include limonitic and hematitic enrichments on iron-rich rock or jaspilite (as in the Weld Range at Wilgiemia), or zones of secondary silicification on Nullagine sandstone, as in Glengarry land system.

Weathering to depths of 50 ft or more is common, and fresh rock outcrops are generally restricted to the more resistant rocks in dissected uplands. The presence of a zone of soft, weathered rock has facilitated shallow mining activity in the past, few shafts being carried beyond the zone of alteration. The water-table is commonly related to the junction of weathered and fresh rock, particularly in the granitic areas.

(*b*) *Calcreted Valley Fills*

These occupy tracts up to a few miles wide with low limestone platforms, and occur mainly in the trunk valleys, commonly tributary to the main lake basins. They form Cunyu and Mileura land systems, and their origin is discussed in Part V.

Typically, they consist of unconsolidated fine gravel up to 20 ft or more thick, overlying a surface eroded in weathered rock. The gravels are overlain by calcrete or surface limestone, which may be rubbly, earthy, or massively laminar, and which may contain detrital horizons. Bands of vesicular opaline silica up to a few feet thick are characteristically developed between gravels and limestone, marking the present water-table, whilst other opaline bands also occur within the limestone locally, possibly in finer-textured horizons.

These valley fills form the most important shallow aquifers in the area, and their importance in water supply is discussed in Part IX. This source of supply has been reported on in the Wiluna area (Ellis 1951).

Somewhat similar terrestrial or freshwater limestone unconformably overlying the lateritic zone is extremely widespread in west and north-west Australia, and in the Pilbara area has been referred to as the Oakover beds (Maitland 1904).

(*c*) *Alluvium and Hard-pan*

Throughout the area, the lower valleys have been filled with alluvium, locally to depths exceeding 100 ft. These alluvial deposits cover 30% of the survey area. The bulk of them have been cemented into a siliceous hard-pan, known locally as cement, which commonly extends to within a foot of the surface. Cemented alluvium characterizes all non-saline alluvial land systems.

The hard-pan is usually red-brown in colour, typically vesicular, and massive or coarsely laminar, locally with gravel seams. Cemented alluvium may be tributary to or may overlie the calcreted valley fills, but is distinctly younger than the lateritic profile. It is sufficiently hard to be a serious obstacle to well-sinking, erection of fences, etc., and may provide a check to ground-water infiltration. Its development in very young deposits indicates that it is still being formed.

(*d*) *Saline Alluvium and Lacustrine Beds*

The lower valley tracts and lake basins consist characteristically of fine-textured saline alluvium. Thin layers of lime, gypsum, or salt occur interbedded in the lacustrine mud of the larger lakes. The amount of fill reaches its maximum in the lake basins, thicknesses exceeding 150 ft having been recorded in Lake Way.

(*e*) *Aeolian Sand*

The most extensive feature in the area is the sand plain of Kalli and Bullimore land systems. This originated as a sandy lateritic soil over weathered granite and gneiss, or as derived alluvium, and has since undergone varying amounts of aeolian re-sorting.

Linear or reticulate sand dunes are scattered through the sand plain and also form small dune fields in the Heppingstone land system in the south-east of the area. Dunes fringe most of the larger lakes, particularly on the south and east sides, and wind-formed sand banks are also numerous in lake areas and in degraded saline alluvial plains. The low wanderrie sand banks of Belele land system have surfaces closely resembling that of the sand plain.

These sands are generally reddish quartz sands with a notable veneer of quartz or lateritic grit, and are largely stabilized by vegetation.

(*f*) *Kopi Dunes*

Encrusted linear dunes of fine gypseous flour occur mainly on the south or east lake borders in Carnegie land system. They are now stable features and appear to have originated at a period when gypseous crusts on the lakes were more general than at present.

VI. Economic Geology

In a survey of this nature the geological examination of the area was of necessity hurried, and other than their delineation, no detailed mapping of the individual metamorphic belts and their contained mining centres was undertaken. Such information, with individual descriptions of mines, together with plans and sections, is given in the publications referred to elsewhere in this Part and in numerous Annual Progress Reports of the Geological Survey of Western Australia.

The present survey has contributed to the geological knowledge of the area and has been responsible for the clearer delineation of the Pre-Cambrian rocks. In addition, a large tract of volcanic rocks previously regarded as mineral-bearing greenstone has now been dated as Proterozoic, so that the accompanying geological map would provide an up-to-date and accurate distribution of the potentially auriferous and mineral-bearing belts and should facilitate future exploration in the area.

Gold has been the principal economic mineral mined in the area, and mining activity has occurred at numerous localities within the metamorphic belts of the Meekatharra and Wiluna districts.

Miscellaneous rocks and minerals other than gold which have been produced or which may have an economic potential are discussed below.

Ground water, if classified as a mineral, would be economically the most important mineral of the area, as it forms the basis of the pastoral industry. Water is dealt with in Part IX.

(*a*) *Gold-mining*

All the metamorphic belts can be regarded as possible containers of gold. From the distribution of old workings it is evident that the principal areas of gold mineralization were those in which the Meekatharra and Wiluna townships were established and that the ore bodies were mainly localized in favourable structures in the metamorphosed rocks lying at or within 1 mile of the granite margin.

Except for some of the larger producers, the deepest workings seldom exceeded 500 ft, and much of the mining activity was confined to depths of less than 200 ft and was terminated once the water-table or the bottom of the zone of oxidation was reached.

Concentrations of gold were mainly associated with quartz in the form of quartz reefs, veins, or lodes, the gold itself being associated with quartz in the free state or with the metallic sulphides such as arsenopyrite, pyrite, and pyrrhotite.

A great number of the ore bodies were of a small lenticular nature or became uneconomic with depth, and most of the metamorphic belts now show many abandoned workings.

Current activity is practically at a standstill, the small production which has been recorded in recent years being mainly derived from the scavenging of old "shows".

Crushing facilities are still available at the State Batteries at Meekatharra, Wiluna, and Cue (south of the survey area), and a cartage subsidy for the transportation of low-grade ores to these public batteries is operative at the present time.

Gold was first discovered in the area at Nannine in 1891 and subsequent discoveries were made during the middle and late 1890s in other centres of the Meekatharra and Wiluna districts. The total recorded production for the Meekatharra and Wiluna districts to the end of 1959 is given in Table 13.

TABLE 13

TOTAL RECORDED GOLD PRODUCTION TO END OF 1959 IN MEEKATHARRA AND WILUNA MINING DISTRICTS

	Alluvial Gold (fine oz)	Dollied Specimen (fine oz)	Ore Produced ('000 long tons)	Gold from Ore ('000 fine oz)
Meekatharra district	14,627	18,244	2300	1307
Wiluna district	233	1254	8874	1872
Total for area	14,860	19,498	11,174	3179

Annual production for both the Meekatharra and Wiluna districts is represented in graphical form in Figure 5. The vicissitudes of the gold-mining industry in both districts will be appreciated from the graphs.

In the Meekatharra district the periods of greatest activity were the years 1913 to 1915, the highest annual production being in 1914, when 79,550 fine ounces of gold were recovered from 140,360 long tons of ores treated.

In the Wiluna district, the period of greatest activity was the years 1931 to 1946, the highest annual production being recorded in 1938, when 148,180 fine ounces of gold were recovered from 744,260 long tons of ores treated.

World War II saw the decline of gold-mining in both districts, the total production for the past 3 years (1957–59) being only 2800 fine ounces, of which 2560 fine ounces came from a few small mining ventures still surviving in the Meekatharra district.

For the whole of the recorded production period, the average grade of all ores produced from the Meekatharra district was 13·63 dwt per ton, whilst that of the Wiluna district was much lower, at 5·06 dwt per ton. In both districts the production of higher-grade ores corresponded to more selective mining during slump periods, whilst lower-grade ores were produced during periods of greatest activity.

Production statistics and periods of production from the abandoned leases located in the various mining centres of these two districts are available from the Statistician, Western Australian Mines Department. Positions for each lease are shown on the appropriate lithographs of the Meekatharra and Wiluna districts.

Most of the statistical information is contained in the "List of Cancelled Gold Mining Leases Which Have Produced Gold" published in 1954 by the Western Australian Department of Mines.

Many of the abandoned "shows" were in operation during the early days of mining, but with present-day mining methods, facilities, and knowledge, such areas may be worthy of more intensive and systematic exploration. To stimulate further interest in gold-mining in these and other gold-fields of the State, the Western Australian Department of Mines is drilling at many of the former large mines, and in addition is offering a subsidy for exploratory diamond drilling programmes.

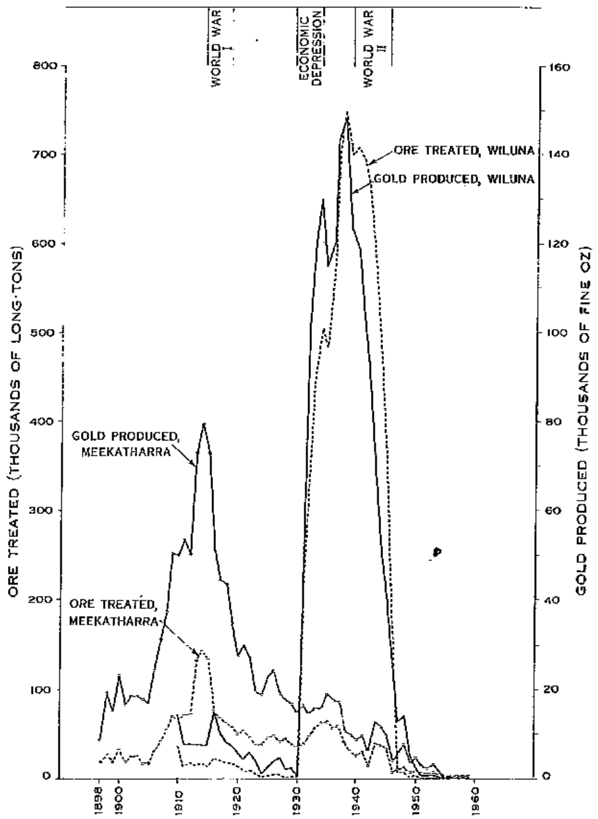

Fig. 5.—Annual gold production for Meekatharra district, 1897–1959, and Wiluna district, 1910–59. Average grade of total ores produced = 13·63 dwt/ton at Meekatharra and 5·06 dwt/ton at Wiluna.

(*b*) *Minerals other than Gold*

A varied assortment of minerals other than gold are known in the survey area. Some of these have been sporadically or are currently mined, whilst others are of insufficient quality or quantity or too remote to be of present commercial significance. The recorded productions and some brief comments on other deposits of economic interest are given below.

(i) *Copper and Cupreous Ores.*—Copper ores yielding 136 tons of copper valued at £11,600 have been recorded from 998 tons of copper ore and concentrates produced from a few small copper deposits in the Meekatharra district. Recent production from this district has been recorded as 1800 tons of cupreous ore containing 12,600 copper units of assay value 7% and valued at £17,600, these ores having been used in the manufacture of trace mineral fertilizers.

Only a small production, amounting to 3·37 tons of copper ore valued at £136, has been recorded from the Wiluna district.

(ii) *Arsenic.*—To 1949, a total production of 38,673 tons of arsenic valued at £747,180 was recovered as a by-product in the metallurgical treatment of gold ores at Wiluna.

(iii) *Silver.*—Silver, representing the chief accessory to gold in the bullion produced from all ores treated in the Meekatharra and Wiluna districts, amounted to 5130 fine ounces and 10,300 fine ounces respectively.

(iv) *Barytes.*—A total production of 547 tons of barytes valued at £2695 was produced during the periods 1952 and 1954–56 from leases north of Meekatharra.

(v) *Yellow Ochre.*—A total of 220 tons of yellow ochre valued at £1647 was recently produced from Mindoolah in the Meekatharra district.

(vi) *Red Ochre.*—Over the period 1945–59, a total production of 4479 tons of red ochre valued at £44,500 was recorded as coming from the Wilgiemia locality in the Weld Range.

(vii) *Iron.*—No production has been recorded, but the known hematitic ore bodies in the Weld Range are estimated by Johnson (1950) to contain some 18 million tons of high-grade iron ore. A drilling programme to test these deposits has been planned by the Western Australian Mines Department.

(viii) *Tin, Tantalum, and Associated Minerals of Pegmatitic Origin.*—No production of minerals of this group has been recorded from the area, but Johnson (1950) has reported the occurrence of cassiterite in the Weld Range. The granitic areas are traversed by numerous pegmatite veins, and although those noted were of simple mineralization, the more complex forms could well be present.

Production of beryl, emeralds, and mica has been recorded from an area adjacent to the survey area in the west.

(ix) *Manganese.*—No deposits of manganese have been reported from the area, but from the known occurrence in the adjacent Peak Hill area it is possible that similar deposits could exist. As in the Pilbara occurrences, the Tertiary manganese concentrations could also occur about the headwaters of the major drainage in areas of Nullagine rocks.

(x) *Dolomite.*—Areas of Nullagine rocks contain numerous horizons of dolomitic limestone. Dependent on quantity, grade, and remoteness, some of these deposits could have an economic potential. Dolomite production has been recorded from the Mt. Magnet district, south of the area.

(xi) *Road Materials.*—Should the major roads of this area require metalling, the abundant fresh basaltic and doleritic rock could supply a suitable source of materials. Lateritic gravel, which is widely distributed through the area, is at present the main material utilized for road surfacing.

(xii) *Other Deposits.*—Deposits of clay, shale, slate, sandstone, quartzite, kopi, gypsum, salt, etc. are too remote from the populated areas to have any commercial use. Some of the natural stones and flaggy rocks have been used locally for building and paving purposes.

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PART V. GEOMORPHOLOGY OF THE WILUNA–MEEKATHARRA AREA

By J. A. Mabbutt*

I. Introduction

This Part begins with the description of the physical regions of the area, followed by a short account of the history of the physical landscape, on which the genetic classification of the land systems is based. The geomorphology of each group of land systems is then briefly discussed, and the distinguishing characteristics of each land system are stated.

II. Physical Provinces and Regions

The Wiluna–Meekatharra area is delimited by latitude and longitude and has no natural boundaries. It lies between 200 and 600 miles inland, on the highest part of the interior plateau of Western Australia and on a broad watershed. Its western part is drained to the Indian Ocean by the Murchison River; the eastern part of the area, which descends gently southwards and eastwards, has an interior drainage with large salt lakes.

In the survey area, the plateau is a broadly undulating surface underlain mainly by gneiss and granite, diversified by hill belts formed by metamorphic rock and by uplands of younger sedimentary rock. It was formerly deeply weathered, but the weathering crust has been extensively stripped, leaving a younger surface on relatively fresh rock. These two surface elements have been termed the old and new plateaux (Jutson 1934). The lower parts of the area consist of alluvial plains which become saline in their lower parts and which commonly lead to salt lakes. Most of the old plateau and part of the new plateau are covered by aeolian sands, now stabilized by vegetation.

Four physical provinces can be distinguished, with differences due partly to structure and partly to their history (see map of land forms and physical provinces and regions).

(*a*) *Murchison Plains*

This province is drained by the Murchison River and forms part of the Murchisonia division of Jutson (1934). The new plateau is relatively extensive here. The province forms the lowest part of the survey area, and it descends northwards and westwards from about 1450 ft at Lake Annean in the south-east to between 1000 and 1200 ft above sea-level along the Murchison River.

It contains five main types of country.

The main interfluves consist of stony erosional plains, generally with less than 30 ft of relief, and with clusters of low hills in the higher parts. Small tracts of the old plateau survive in the south, as sand plain bounded by breakaways. Shallow alluvial drainage floors radiate from these remnants and from the hilly zones.

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Tributary alluvial plains extend down-slope from the erosional plains and form wide tracts bordering the main flood-plains. They consist of featureless drainage floors and broader intervening tracts with alternating low sandy banks and alluvial flats to which the native term *wanderrie* is applied.

Flood-plains occupy the floors of the larger valleys of the Murchison River, Pindabarn Creek, Hope River–Ord Creek, and Lake Annean.

Calcreted valley fills occur in most of the valleys, as a mosaic of low calcrete platforms with intervening alluvial floors which become increasingly saline down-valley. Saline alluvial plains occur along the Murchison River and in the lower tributary valleys. Lake Annean is a fairly large salt lake near the head of the Hope River.

The fifth type of country consists of whitestone ranges which are narrow strike belts with parallel rocky ridges generally between 250 and 500 ft high. Their east-north-easterly trend is unusual for the area. They comprise Jack Hills in the north-west and Weld Range in the south.

(*b*) *Salinaland Plains*

This province comprises the plateau surface east of the Murchison catchment. It has an interior drainage and it forms part of the Salinaland division of Jutson (1934). The plateau attains its greatest elevation in this province, locally exceeding 2000 ft above sea-level between Meekatharra and Wiluna and rising again east of Lake Way in a broad tract between 1800 and 1900 ft above sea-level. The smaller western area delimits the drainage southwards to Lake Austin; the eastern tract forms a broad divide against the Lake Nabberu–Lake Carnegie drainage on the north and east. In this region, the old plateau survives extensively on the watersheds and the new plateau is restricted to the lowlands.

The most extensive of the three types of country in this province are the old plateau and its marginal plains consisting mainly of sand plain, which is continuous on the old plateau and which increasingly extends onto the younger surface eastwards from Lake Way, forming an almost unbroken sand cover in the south-east of the area. In the west of the province, the old plateau is bounded by breakaways in weathered rock, but these become lower and discontinuous in the east, where drainage dissection was originally less vigorous and where its patterns have subsequently been masked by sand. The stony erosional surfaces typical of the Murchison plains are here very restricted. In the west they are replaced by the alluvial plains which flank the main drainage lines; further east they are replaced by sand plain and by small alluvial fans.

There are two trunk valleys in the province. Lake Way consists largely of the salt lake with a minor area of tributary calcreted valley fill. The Leemans valley is a long west–east valley tributary to Lake Carnegie, occupied mainly by small pans and sandy plains.

Hill belts formed on the metamorphic belts occur in north–south tracts in the south half of the province. Greenstone occupies the larger part and gives rise to lines of rounded hills up to 100 ft high; whitestone builds somewhat higher, rocky ridges.

The hill belts form secondary watersheds with closely spaced, incised valleys.

The five main hill belts, from west to east, are Meekatharra, German well, Wiluna, Barwidgee, and Mount Eureka.

(*c*) *Central Uplands*

This province is conterminous with the central basin of gently dipping Nullagine rocks and has a corresponding relief pattern, consisting of a dissected higher rim and of inner lowlands which are drained mainly eastwards to Lake Way and partly westwards to the Murchison River. It consists of the following regions.

(i) *Outer Plateaux.*—Sandstone plateaux up to 200 ft high form a southern and eastern rim between 5 and 10 miles wide. They have prominent escarpments and bevelled summits which descend gently inwards, and they are generally drained in this direction by a vigorously incised drainage. The summits exceed 2100 ft above sea-level in the west, but decline in altitude eastwards to about 1850 ft above sea-level.

(ii) *Inner Lowland.*—This occupies a central tract up to 30 miles wide, descending eastwards from 1900 to 1700 ft above sea-level. In the west is a lowland consisting of undulating terrain formed on weathered shale and basalt in an undissected zone between 10 and 20 miles wide, mainly between the east-going drainage and the catchment of the Murchison River. The central part consists of calcreted valley fills in the axis of the lowland, whilst in the north-east is an alluvial plain tributary to the calcreted valley fills on the north-east.

(iii) *Basalt Hills.*—These form a dissected zone between 5 and 15 miles wide on the north side of the inner lowland. They have been eroded by the head tributaries of the Murchison River, by drainage to Lake Way, and to a lesser extent by the upper part of drainage north-eastwards to Lake Nabberu.

(iv) *Northern Plains.*—This region comprises the undissected watershed in the north of the province, and it includes gently undulating terrain and sand plain.

(*d*) *North-eastern Uplands*

This province is developed on gently dipping Nullagine rock in the north-eastern basin. Four parallel regions can be distinguished following the north-westerly strike, and they are here described as they occur from south-west to north-east.

(i) *South-western Plateaux.*—This is a belt about 5 miles wide consisting of two or three lines of discontinuous sandstone plateaux with between 50 and 150 ft of relief, separated by sandy strike vales. Relief is greatest in the north and central parts of the belt, where it is traversed by drainage to Lake Carnegie, but it decreases south-eastwards and the uplands pass into sand plain.

(ii) *Inner Lowland.*—This occupies a belt between 20 and 30 miles wide eroded on softer shale, dolomitic limestone, and minor sandstone.

In the north-west it is undulating sandy terrain with little surface drainage. Further south, it has been dissected into sandstone hills and stony plains by the upper tributaries of Wongawol Creek. The hills give place southwards to broader plains with extensive saline alluvial tracts up-valley from the drainage gaps through to Lake Carnegie. The southern limit of the lowland is the Treuer tableland, a broad cuesta with a prominent south-facing escarpment.

(iii) *Princess Ranges.*—In the north-west these consist of parallel rocky quartzite cuestas with up to 400 ft of relief, but further south-eastwards they are lower and more plateau-like and are increasingly broken by drainage to Lake Carnegie.

(iv) *Lake Carnegie Lowland.*—Most of this region is occupied by Lake Carnegie, but at the head of the lake and along its north-east shore are lowlands formed on dolomitic limestone and shale, with minor sandstone uplands. The region also includes the plains drained to Lake Wells via Bonython Creek in the extreme south-east.

III. History of the Physical Landscape

(*a*) *The Old Plateau*

A convenient starting-point is the land surface which survives as the old plateau. It was a surface of little relief, with extensive plains on gneiss and granite, undulating surfaces on Nullagine mudstone and lava, belts of low greenstone hills, and subdued sandstone plateaux. Strong relief was restricted to ranges of whitestone and Nullagine quartzite.

This land surface had been lateritized, presumably under a humid climate. Weathering to depths of 50 ft was general on the gneiss and granite, on basic lava, and on Permian grit in the south-east. Elsewhere, weathering had been more selective, but only arenaceous Nullagine rock escaped significant alteration. This "lateritic duricrust" was recognized by Woolnough (1927) as being of continental extent and as having developed on a plain which was later uplifted to form the interior plateau of Western Australia.

The form of the weathering crust shows that the major elements of the present relief and drainage already existed on the old plateau. Apart from the main valleys, where there has been later dissection, relief was as great as at present, with only two important differences. Firstly, the weathered surface passed more smoothly over the divides and bevelled uplands, with escarpments either absent or less steep than in the present landscape; secondly, there was a continuous mantle of soil and weathered rock, even on fairly steep slopes.

The Wiluna–Meekatharra area already formed part of a watershed. A minor part was drained westwards to the Indian Ocean, but the larger part was drained southwards and eastwards.

Two important components of the drainage pattern were geologically controlled. An east–west component followed a common structural trend on the granite and gneiss, and south-east-trending valleys followed the main structural grain of crystalline rock and the trend of the metamorphic belts.

The south-easterly drainage was directed towards a marine gulf on the south coast. The littoral limestone of Lake Cowan, at 900 ft above sea-level near Norseman (Clarke, Teichert, and McWhae 1948), may mark a shoreline and drainage outlet of the old peneplain, and would indicate that the old plateau already existed during the Eocene but that it then stood between 500 and 1000 ft lower relative to sea-level.

(*b*) *Dissection of the Old Plateau*

Subsequent dissection of the old plateau was probably caused by the uplift of the area to its present altitude, possibly in the late Tertiary (Jutson 1934). Erosion worked back along the major valleys and spread laterally across the interfluves, eroding the weathering mantle and forming the new plateau. Vertical incision has been limited by the thickness of weathered rock and has remained small, even in the trunk valleys. In Lake Way, for instance, the rock bed is less than 200 ft below remnants of the weathered surface on the west shore. Elsewhere, the old and new plateaux are generally separated by less than 50 ft.

The land forms produced by the advancing younger cycle varied with geology and with the initial form of the old plateau. On the gneiss and granite plains there was a broad frontal attack on the partially silicified weathering crust, and stripped plains were formed by breakaway retreat. On metamorphic rock in the hill belts, stripping was complicated by the incision of a closely-spaced, strike-controlled headwater drainage, which formed lines of rounded, laterite-capped hills. Plateaux of flat-lying Nullagine sandstone were etched out by renewed erosion of the softer rock on their margins to form stronger relief, with rejuvenated escarpments. The few mountainous tracts on the old plateau underwent intensified marginal dissection and stripping.

The new plateau cycle was extended more effectively by the Murchison River than by the longer rivers trending south-eastwards, giving rise to the most important regional contrast within the area. In the Murchison plains, the new cycle has extended up to 25 miles laterally from the main valleys and the old plateau has been almost destroyed; in Salinaland the cycle has generally progressed less than 10 miles from the main valleys, with the result that the old plateau survives extensively on the interfluves.

(*c*) *The Establishment of Interior Drainage*

During the period in which the new plateau was being formed, the climate gradually changed from humid to semi-arid, causing a decline in the competence of the streams and resulting in extensive alluviation in the lower parts of the area.

Eventually, the trunk valleys were choked by alluvium and lakes were formed which have since acted as drainage foci. These "river-lakes" occur over much of interior Western Australia. Their narrow, winding shapes, their alignment in series in dissected valley floors on the old plateau, and the absence of reverse gradients in the underlying rock beds indicate that they are remnants of dismembered river systems.

There are three large lakes in the Wiluna–Meekatharra area, namely Lakes Carnegie, Way, and Annean, and they share features which denote a common history. All are situated in trunk valleys on upland margins where drainage incision had occurred in the new plateau cycle, and at the confluence of head tributaries with extensive upland catchments and good run-off. All taper down-valley, partly as a result of the impingement of the alluvial deposits which originally ponded the lakes and partly owing to the subsequent encroachment of aeolian sand.

The alluvial deposits in the main valleys consisted of fine gravel overlain by sand. These fills led into the larger lakes, generally widening into delta flats at the lake entrances. The water-table was higher than at present, and the valleys were occupied by small pans subject to periodic flooding and drying. With increasing desiccation and lowering of the water-table, the upper layers of the alluvial fills were calcreted. Bands of opaline silica have since formed above the gravel, approximately at the present water-table.

Most of the alluvial deposits in the area must be attributed to this period of declining drainage activity, for there has been little subsequent erosion to provide a sediment source. Young alluvia are in fact very restricted.

Much of the alluvium in the area has been cemented to form a siliceous hard-pan. Cementation is keeping pace with deposition and the hard-pan is clearly forming at present. However, it is unlikely that cementation has been confined to the latest stage of landscape formation, which has accounted for only a small part of the alluvium. The hard-pan commonly has a coarse laminar structure with erosional partings, indicating that deposition and silicification have been almost contemporaneous and that cementation of the alluvium has probably occurred throughout its deposition.

(*d*) *The Arid Period of Sand Movement*

The climate eventually became more arid than at present, and widespread wind-sorting of surface deposits took place. Sand movement was general on the old plateau and was widespread on younger alluvial surfaces.

The aeolian sand formed sand plain, with scattered dunes in lower areas with thicker sand cover. The sand was moved eastwards and southwards, as shown by its accumulation on the east and south sides of pans and drainage lines, where it has commonly buried older alluvium and has obliterated surface drainage. The dune forms also indicate extension south-eastwards.

On the alluvial plains formed on the new plateau, the effect of increasing aridity was to cause the lower margin of significant run-on to retreat upslope. As a result, the lower parts were increasingly subject to wind action. Sand plain has rarely extended into the upper drainage sectors, however, and it is likely that surface drainage was never wholly obliterated.

The small extent of sand plain on the Murchison plains is partly due to the restricted occurrence there of the old plateau, and also to the fact that sand plain does not occur on younger depositional surfaces in this region. It is possible that the wanderrie banks may have formed by alternating wind and water action at this same period. Surface drainage may have persisted to a greater degree on the Murchison plains because of the more efficient catchments offered by the erosional surfaces of the new plateau.

The floors of the salt lakes were lowered by deflation, commonly to as much as 10 ft below the tributary calcreted valley fills. Fine-textured gypseous alluvia were redeposited on the lake margins as kopi dunes.

(*e*) *Renewal of Drainage*

A subsequent increase in rainfall led to the stabilization of sand by vegetation and to an extension of surface drainage, and has caused renewed erosion in the higher parts of the area. The erosion achieved in this latest phase has been very small, for sand plain commonly extends close to the foot of the breakaways separating the two cyclic surfaces. There has been some redistribution of aeolian sand by sheet floods in this latest phase, particularly on the higher parts of the sand plain.

The lower sectors of the calcreted valley fills have been slightly dissected as a result of rejuvenation caused by wind-lowering of the lake floors. At the same time, the upper sectors have been buried by younger alluvium.

(*f*) *Current Land-forming Processes*

The processes now at work in the area reflect the semi-arid climate, the low relief, and the low energy of an ephemeral, mainly interior drainage.

Hills and uplands comprise 15% of the area. They form the local watersheds, where their close valley patterns indicate that run-off is fairly high. Hill slopes steeper than 5% are mainly rocky and bare of soils. The slopes commonly bear remnants of the former weathering mantle, so that erosion must now be quite slow.

The drainage channels of the higher ground give place down-valley to alluvial fans or drainage floors. These surfaces and the adjacent lower hill slopes are subject to sheet-flow. Such slopes, with gradients between 1 in 100 and 1 in 500, commonly have a contour pattern of vegetation groves. Many of the groves are typically situated on very slight convex slope breaks separated by longer, concave intergrove sectors. The groves appear to result from an adjustment of vegetation cover to surge patterns of sheet-flow on smooth, gentle slopes. The patterns are perpetuated since the run-off from the sparsely vegetated intergroves is intercepted by the grove downslope. There is an associated trapping of alluvium which locally gives rise to the slightly uneven profiles described above.

The extensive stone mantles on these and higher slopes consist mainly of resistant rock-weathering products transported by sheet-flow and slightly concentrated at the surface by deflation.

The tributary alluvial plains, with gradients between 1 in 500 and 1 in 1000, are subject to widespread shallow inundation following heavy rains. Flooding has produced smooth surfaces, with runnels which serve to carry off minor flow. The restricted occurrence of young alluvia on these plains indicates that erosion is now proceeding slowly in higher areas.

At lower levels in the landscape, with gradients below 1 in 1000, the alluvium is commonly saline and the fine-textured deposits are liable to severe surface degradation. Widespread wind erosion and flood-scouring have led to the formation of clay pans and sand banks, and to severe gullying along drainage lines.

The salt lakes are the drainage termini and are subject to episodic flooding after heavy rains. Despite evaporation losses, their floors show little salt-crusting. This may be partly due to deflation, since the bare floors are the areas of strongest wind erosion. It may also reflect a continuation of subsurface drainage along the former river valleys, and it may be partly due to the geological youthfulness of the salt lakes.

The sand plain is the most stable environment in the area, with sufficient vegetation to restrict wind movement of sand and with sufficiently permeable soils to keep run-off to a minimum.

IV. Geomorphology of the Land Systems

The Wiluna–Meekatharra area contains land surfaces inherited from all stages of its history. Since the land systems forming part of these surfaces cannot be fully understood apart from the environments in which they formed, they have been classified by their origins as set out below.

(*a*) *Undulating Terrain Forming Part of the Old Plateau*

These land systems occur on a wide range of weathered rocks, including feldspathic schist, basalt, and unresistant mudstone, shale, and thin sandstone. They have survived only in situations naturally protected from dissection, such as the inner lowlands in the central uplands and in the north-eastern uplands, and also the inner parts of the hill belts, headwards of dissecting drainage.

These land systems are mainly broadly undulating with between 10 and 40 ft of relief, and they consist of rounded crests and a diffuse pattern of shallow valleys. In their lower parts they comprise stripped surfaces with a more defined pattern of alluvial drainage floors, but there is typically no channel drainage.

(1) *Dural land system* is more strongly undulating, with minor steeper slopes and rocky crests formed by sandstone. It occurs chiefly in the inner lowland and northern plains of the central uplands.

(2) *Fisher land system* is moderately undulating terrain formed on feldspathic schist in the Barwidgee and Mt. Eureka hill belts.

(3) *Lorna land system* is sandy, gently undulating country formed on mudstone and shale in the north-eastern uplands, where the south-western plateaux region merges into sand plain.

(4) *Diamond land system* is very gently undulating and is underlain by basalt, mudstone, and shale. It occupies the most stable parts of the inner lowland in the central uplands, particularly the low watersheds. It lacks the alluvial drainage floors of the lower parts of other land systems in this group.

(*b*) *Surfaces Formed by Dissection of the Old Plateau*

These land systems are situated where the old plateau is being destroyed by encroachment of the new plateau surface, and they comprise the areas of greatest relief and most active erosion.

(i) *Mountain and Hill Ranges*.—These land systems have been formed by the dissection of strong relief on the old plateau. They are underlain by resistant rocks which have been selectively rather than deeply weathered, and they contain the strongest relief in the area. There is marked structural control of relief, with narrow ranges on steeply dipping metamorphic rock and with cuestas on flatter-lying quartzite. These land systems are characterized by steep, rocky slopes, and have only minor lowlands. They generally form secondary watersheds and are undergoing active headwater dissection, the incised drainage normally following strike or joint lines. Relief is characteristically between 150 and 500 ft.

(5) *Weld land system* consists of whitestone mountain ranges in the Murchison plains. It occurs as narrow strike belts of continuous rocky ridges, commonly formed by jaspilite. Relief is generally less than 500 ft, but on more massive rock it may take on stronger outlines, culminating in higher summits.

(6) *Princess land system* is mainly formed of gently dipping quartzite, and is part of the Princess Ranges in the north-eastern uplands. The high ground consists mainly of rocky cuestas with steep escarpments and closely dissected dip slopes, locally broadening into high plateaux. The uplands are separated by narrow strike valleys eroded on softer strata.

(7) *Yagahong land system* consists mainly of greenstone hill ranges forming a narrow, higher core in the north of the Meekatharra hill belt. It also comprises small plateaux of flat-bedded Nullagine slate capped by basalt, which rise steeply from the plains to the east, in the Mt. Yagahong area.

(8) *Gabanintha land system* is made up of whitestone hill ranges, and it forms higher tracts in most of the hill belts. It is mainly comprised of parallel ridges, with rocky crests formed by hematitic jaspilite and with stony slopes eroded on schist.

(ii) *Sandstone Plateaux*.—The land systems in this group consist of plateaux and their bounding slopes, with relief mainly between 50 and 150 ft, formed by moderate dissection of surfaces of moderate relief on flat-lying sandstone. The plateau summits form between 25 and 50% of the land systems. Although they owe their basic forms to structure, the summits were part of the old plateau surface and have commonly undergone secondary silicification. In areas of strong relief the summits are bounded by steep escarpments; elsewhere, stripped hill slopes of moderate steepness form a large part of the land systems. Rocky, stony surfaces are general.

These land systems are confined to the central and north-eastern uplands, where they generally occur as small plateaux, each with its radial pattern of incised drainage. They are here arranged in order of decreasing relief.

(9) *Glengarry land system* consists of plateaux capped by fairly massive sandstone, which gives rise to prominent escarpments and to gently undulating summits. In part, it forms broad watershed tracts with numerous incised strike valleys; elsewhere, it consists of narrow upland belts. It is the most extensive land system in this group, and its chief occurrence is in the outer plateaux of the central uplands.

(10) *Lynne land system* consists of smaller plateaux formed on more weathered quartzite, sandstone, and feldspathic grit. It occurs in the south-western plateaux region in the north-eastern uplands, as discontinuous plateaux separated by somewhat saline alluvial plains.

(11) *Doman land system* consists of subdued plateaux or rounded low uplands formed on thinly bedded shale and sandstone in the north-eastern uplands. It is distinguished by the very gentle hill slopes formed on these less resistant rocks.

(12) *Wongawol land system* is more complex and consists of low plateaux formed by sandstone, dolomite, and intrusive dolerite, and of relatively extensive lowlands with alternating low dolerite ridges, degraded shale belts, and alluvial tracts. It occurs in the Lake Carnegie lowland.

(iii) *Low Hills.*—These land systems have been formed by close dissection to moderate depth of surfaces of moderate relief on weathered greenstone and basalt, with minor areas of unresistant sedimentary rock. They commonly form or adjoin watersheds in the hill belts and in the central and north-eastern structural basins of Nullagine rocks. Narrow valleys incised into the old plateau surface have picked out structural patterns in the less weathered underlying rock, forming lines of rounded hills and short ridges with between 25 and 100 ft of relief.

Locally the old plateau survives intact as an undulating surface on the divides. More commonly it has been lightly stripped and forms lateritic hill cappings or bevelled stony summits. These remnants are much less extensive than the stony slopes eroded below the weathered surface. Incised valleys give place to alluvial drainage floors in the lower parts of the land systems, and the alluvium may be saline where it is derived from weathered rock.

(13) *Wiluna land system* consists of low hilly terrain formed mainly on weathered greenstone. Rounded hills with laterite cappings are particularly extensive in this land system, and there are minor rocky ridges formed by jaspilite. Wiluna land system is a major constituent of the hill belts.

(14) *Killara land system* is low hilly terrain formed on weathered basalt and it constitutes the basalt hills region in the central uplands. The undulating, undissected old plateau surface is moderately extensive in the higher parts, but elsewhere it has been very closely dissected, and this land system contains more broken terrain than any other in this group. The numerous tributary valleys unite in long, narrow alluvial drainage floors, which form a prominent unit of Killara land system.

(15) *Sodary land system* consists of low uplands and plains, less closely dissected and with a less regular relief pattern than other land systems in this group. The uplands are mainly rounded ridges of lightly weathered Nullagine mudstone and shale, with local cappings and benches of lateritized Permian grit. The lowlands are stony plains with broad tracts of saline alluvium derived from weathered rock. Sodary land system occurs in the inner lowland of the north-eastern uplands.

(iv) *Duricrusted Plateaux and Benches.*—The two land systems in this group have been formed by strong dissection, up to 150 ft, of old plateau surfaces of little relief on weathered Permian grit and tillite with silcrete duricrust, and of relatively soft underlying Nullagine rock. They form a selvage to the old plateau where it is being attacked by drainage to Lake Carnegie and to Lake Wells via Bonython Creek. The silcrete forms flat, stony summits with prominent breakaways. Steep hill slopes have been formed in the weathered Permian beds, and the Nullagine rock gives rise to benches, foothills, and stony plains, with saline alluvial tracts derived from the weathering profiles.

(16) *Tooloo land system* consists of duricrusted plateaux and adjacent slopes.

(17) *Boondin land system* consists of uplands, benches, and spurs, with minor silcrete summit cappings, and of fringing stony plains and saline alluvial drainage floors.

(v) *Breakaways and Plains.*—The land systems in this group have formed by moderate or shallow dissection of surfaces of little relief on the old plateau. They are most extensive on granitic rock on the Salinaland plains, particularly on the edges of the broad, featureless watersheds, but they have also formed by the shallow stripping of weathered greenstone and basalt. Relief is generally less than 30 ft.

The removal of uniform lateritic weathering crusts of moderate depth on granitic rock has formed extensive stony plains with less than 30 ft of relief, traversed by shallow alluvial drainage floors. At the heads of these land systems are escarpments up to 50 ft high, with narrow, stripped crest zones. The upper escarpment slopes and crests are formed in the mottled zones, commonly rendered more resistant by silicification. The pallid zone of the weathering profile forms lower escarpment slopes subject to cavernous weathering which aids breakaway retreat. Low hills of unweathered rock commonly occur below the escarpments and there are also small fans of saline alluvium derived from the pallid zone.

In areas of more shallow dissection, as in the eastern part of the Salinaland plains, the escarpments are poorly developed, whilst the lower plains are extensively masked by alluvium and wanderrie banks, with sand plain islands of moderate extent.

(18) *Sherwood land system* consists of breakaways and extensive stony plains formed by moderate dissection of weathered granitic rock, and is particularly widespread in the west of the Salinaland plains.

(19) *Violet land system* consists of shallowly dissected, gently undulating plains on greenstone and basalt, and it occurs on the outer margins of hill belts. Stable lateritic crests are of moderate extent in the higher parts of the land system but the extensive lower slopes have been stripped, whilst the lowermost parts, with thicker detrital mantles, have well-developed vegetation groves.

(20) *Millrose land system* consists of very shallowly stripped plains on weathered granite and gneiss.

(*c*) *Surfaces Eroded below the Old Plateau*

These land systems constitute the erosional part of the new plateau and they comprise various types of terrain, some of which also form elements in the previous class of land systems. They include uplands, but plains are much more extensive. This is partly due to the fact that complete destruction of the old plateau is naturally associated with an advanced stage of erosion. A more important reason, however, is that these are mainly stripped surfaces, underlain by rocks such as granite and gneiss which already formed plains on the old plateau and which had uniform weathering mantles that were readily removed by breakaway retreat. The rocks are typically slightly weathered rather than fresh.

These land systems occur in the Murchison plains, on the lower margins of the hill belts, and in the inner lowland of the north-eastern uplands.

(i) *Uplands.*—These two land systems have been formed where erosion below the weathering profile has met with varying resistance. They form restricted secondary watersheds with up to 100 ft of relief. They also include the adjacent slopes, which are slightly more extensive than the uplands.

(21) *Norie land system* consists of clusters of low hills and fringing pediments, mainly of massive granite, which remained as unaltered, resistant kernels in the weathering profile and which were exhumed in the new plateau cycle. It occurs on the higher parts of interfluves on the Murchison plains.

(22) *Treuer land system* is essentially the Treuer tableland, a broad cuesta of Nullagine mudstone and shale capped by Permian grit north of Bonython Creek. It has a prominent escarpment and gentle dip slopes broken by minor ridges. Surfaces are stony except in the lowest parts, where plains with vegetation groves occur.

(ii) *Low Hills and Plains*.—The two land systems in this group have been formed by the stripping of the weathering mantle from fairly uniform rocks, mainly gneiss and granite. They consist mainly of undulating plains with up to 25 ft of relief, with scattered low hills up to 50 ft high formed by more massive rock. They are fairly extensive in the Murchison plains, where they generally fringe the uplands.

(23) *Mindura land system* is the more extensive and consists of undulating stony plains and scattered hills formed on granite and gneiss. The hills have the same origin as those of Norie land system. Mindura land system forms broad interfluves in the northern half of the Murchison plains.

(24) *Edenhope land system* consists of undulating slopes formed on whitestone in a narrow tract on the south margin of the Meekatharra hill belt. Strike lines of low rounded hills are formed by more massive basic schist.

(iii) *Plains*.—These land systems consist mainly of plains formed on little-weathered rock of uniform resistance to erosion. They are most extensive on the Murchison plains, where they are formed on crystalline rock, but they also form part of the inner lowland of the north-eastern uplands, where they have been eroded on soft sedimentary rock. They consist of stony interfluves and shallow alluvial drainage floors, generally with less than 25 ft of relief. The flatter lower parts may have detrital mantles and vegetation groves where they receive sheet-flow.

(25) *Koonmarra land system* consists of plains formed on gneiss and granite. It is the most extensive land system in this group and occurs mainly in the north of the Murchison plains.

(26) *Yarrameedie land system* consists of plains formed on gneiss at the foot of the whitestone ranges and on the flanks of the Meekatharra hill belt. Because of its situation it has stronger relief than the other land systems in this group, and the higher parts have a slightly incised, transverse drainage which opens out down-slope into alluvial fans.

(27) *Windidda land system* consists of almost flat plains underlain by thinly interbedded Nullagine shale and dolomitic limestone in the inner lowland of the north-eastern uplands. The limestone forms stony bands separated by flatter areas with vegetation groves or by strike lowlands with clay soils.

(28) *Kalyaltcha land system* consists of plains formed on Nullagine mudstone and shale in the inner lowland of the north-eastern uplands. The plains are traversed by broad alluvial flats which are somewhat saline, partly owing to the influence of weathered Permian grit up-slope, partly because of their low-lying situation next to the saline plains bordering Lake Carnegie.

(d) *Depositional Surfaces*

These land systems include alluvial plains and sand plain with dunes. The alluvial plains have formed since an early stage in the new plateau cycle; they comprise approximately 30% of the area and occupy most of the lower parts. They range from tributary alluvial plains and alluvial fans of cemented, non-saline alluvium, to calcreted valley fills, saline alluvium, and salt pans down-valley. Most of the drainage is of the sheet-flood type, producing smooth surfaces with minor drainage runnels, but there is a tendency for a resumption of channel drainage on the lowest, saline plains. The alluvial land systems are naturally most extensive in the internal drainage systems of Salinaland.

The aeolian sand surfaces are most extensive on the interfluves, but they also occur in the lowlands, particularly near salt lakes. They are also mainly situated in the Salinaland plains.

(i) *Calcreted Valley Fills.*—These consist of fine gravel overlain by opaline silica and calcrete, and they occupy tracts up to 5 miles wide in trunk valleys throughout the area. They form important aquifers. They commonly lead into the salt lakes, where they widen into limestone delta flats. Longitudinal gradients are less than 1 in 1000.

They consist of a mosaic of low, saucer-shaped calcrete tables, which may be up to 15 ft high in lower sectors but which generally decrease in height up-valley, where the calcrete may pass beneath cemented alluvium. The calcrete tables are separated and flanked by alluvial drainage flats which become saline in the lower sectors.

(29) *Cunyu land system* consists of calcreted valley fills with non-saline alluvial plains, and it occurs mainly in the upper sectors of trunk valleys.

(30) *Mileura land system* consists of calcreted valley fills with mainly saline alluvial plains, and it occurs in the lower sectors of trunk valleys.

(ii) *Mainly Non-saline Alluvial Plains.*—These constitute the tributary drainage plains, with gradients mainly above 1 in 1000, and they consist largely of cemented alluvium. They comprise two subgroups, which form upper and lower tributary drainage elements respectively. The upper elements, with gradients above 1 in 500, are contiguous to uplands or erosional plains and are fed by narrow drainage floors which open out into alluvial lobes separated by narrow central drainage plains. They vary with the nature of the source rocks, but all are characterized by vegetation groves. In areas of less evolved drainage, they may form isolated alluvial fans or lobes; elsewhere they are tributary to lower drainage elements which form a second subgroup of non-saline alluvial land systems. The latter have gradients mainly between 1 in 500 and 1 in 1000. They may consist entirely of featureless plains, or such plains may form central drainage tracts separating zones with wanderrie banks. Their lowermost elements include degraded plains with some channel drainage.

(31) *Jundee land system* consists of stony upper tributary plains with thin vegetation groves, mainly flanking the hill belts.

(32) *Trennaman land system* consists of sandy upper tributary plains, mainly adjacent to uplands and plains of schist and fine-grained sedimentary rock. The

sectors between the central drainage tracts consist of zones with vegetation groves separated by lines of low wanderrie banks. Trennaman land system is scattered throughout the Salinaland plains.

(33) *Yanganoo land system* consists of lobate upper tributary plains derived from crystalline rock, and has prominent vegetation groves. It occurs throughout the survey area.

(34) *Cole land system* consists of tributary plains derived from fine-grained sedimentary rock in the north-eastern uplands. It is the only land system in this group to combine upper and lower tributary drainage elements. The upper sectors have vegetation groves and the lower sectors have wanderrie banks.

(35) *Yandil land system* consists of even-surfaced, lower tributary plains with shallow hard-pan. It is derived mainly from crystalline rock and is very extensive in the Murchison plains.

(36) *Ero land system* forms lower tributary plains derived mainly from crystalline rock in the north of the Murchison plains. It is characterized by broad central drainage plains which become slightly saline in the lower sectors, and by intervening tracts with vegetation groves in the upper parts and with wanderrie banks down-slope. Ero land system commonly has a central drainage channel with an adjoining narrow flood-plain.

(37) *Wadjinyanda land system* consists of severely degraded flood-plains of fine-textured alluvium derived in part from shale and dolomitic limestone. It occurs in the Lake Carnegie lowland and has well-developed drainage channels tributary to the salt lake.

(38) *Mitchell land system* is formed where alluvium with sand-plain cover extends into saline areas, as in Leemans valley and near Bonython Creek. The upper parts consist largely of sand plain and wanderrie banks, which give place down-slope to saline alluvial flats.

(iii) *Partly Saline Alluvial Plains.*—These land systems are mainly situated in ill-drained lowlands, commonly adjacent to salt lakes. They are formed of fine-textured alluvium which is subject to wind erosion, and they are traversed by scoured zones with multiple drainage channels. Consequently they have very degraded surfaces with scalds, pans, and sand banks.

(39) *Barwidgee land system* consists of stony plains adjacent to weathered greenstone at the head of Leemans valley. The gradients are above 1 in 500, which is unusually high for a land system in this group.

(40) *Beringarra land system* is the saline flood-plain of the Murchison River and its extensions into the lower sectors of its main tributaries. It includes less saline areas, both on the outer margins and also flanking the river channels.

(iv) *Alluvial Plains with Wind Modification.*—There is only one land system in this group.

(41) *Belele land system* consists of wanderrie banks and flats traversed by drainage floors. It forms tributary drainage plains down-slope from surfaces eroded on crystalline rock, mainly on the Murchison plains. Gradients range from 1 in 250

to 1 in 1000. The drainage floors and wanderrie flats have uniform, sealed surfaces subject to shallow scalding. The wanderrie banks have hummocky, sandy surfaces which have been wind-piled above apparent flood levels.

(v) *Sand Plain and Dunes*.—This group of land systems consists mainly of sand plain with scattered dunes, and it is generally situated on plains underlain by crystalline rock. It covers about 20% of the area. In the Murchison plains the sand plain has mainly formed by wind redistribution of sandy lateritic soils on old plateau remnants. In Salinaland, the sand cover extends across the erosional breaks separating old and new plateaux, so that the land systems here include minor dissected tracts and stony plains. In the lower parts of Salinaland, alluvial plains may also attain moderate extent. In general, these land systems are characterized by a lack of surface drainage, but differing amounts of run-on from adjacent areas and differences in subsurface geology and relief together account for most of the environmental contrasts within them.

The prevalence of sand plain is probably due to the wide grading of sands derived from crystalline rock. Sand dunes normally occur in lower areas of thicker, better-sorted sands, particularly those derived from sandstone uplands. The dunes are short, linear or braiding dunes, and trend mainly north–south, with north-easterly or north-westerly variants in the south of the area. The steeper dune flank is generally on the east. There is only one small dune field in the survey area, and it has closely spaced reticulate and linear dunes.

The sand cover increases from west to east in conformity with the distribution of the old plateau surface and of younger alluvial plains. Almost all sand surfaces are now stabilized by vegetation and sand movement is restricted to minor dune crests, pan margins, and some degraded alluvial plains.

(42) *Bullimore land system* consists of sand plain with scattered dunes in the Salinaland plains.

(43) *Kalli land system* consists of sand plain with scattered dunes in the Murchison plains.

(44) *Yelma land system* consists of sand plain with stony plains in the south-east of the Salinaland plains.

(45) *Waguin land system* consists of sand plain with low breakaways, stony plains, and lobate alluvial plains, mainly in the western half of the Salinaland plains.

(46) *Heppingstone land system* is a dune field in the south-east corner of the survey area.

(vi) *Salt Lakes and Dunes*.—This group of land systems comprises large and small salt lakes and their marginal features. The salt lakes are the foci of drainage in the east of the area and they occupy its lowest parts. They are flooded only after heavy rains, but at other times the water-table is close to the surface. The bare floors consist of gypseous and saline clays and sands and have sloping, sandier margins. They are subject to strong wind erosion. In general, wind transport has been eastwards and southwards, so that the eastern lake shores are sandier, with more massive fronting dunes. In the larger lakes, sandy islands have formed towards the east ends, and there are also extensive linear banks formed of encrusted gypseous kopi sands which have formed in earlier stages of deflation.

Tributary saline alluvial plains occur mainly on the north and west shores, partly because the feeder drainage generally comes from that direction, partly because it has elsewhere been obliterated by sand. Two levels can normally be distinguished on these plains—a lower one corresponding to normal lake-fill and a higher one due to deposition in exceptional floods. Satellite pans occur in the lower parts where there has been disorganization of drainage by sand banks.

(47) *Carnegie land system* comprises the main salt lakes and their marginal features.

(48) *Leeman land system* consists of numerous small salt pans with bounding sand banks, which are also saline in part, and of flanking saline alluvial plains. It occurs in Leemans valley and along Bonython Creek.

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PART VI. SOILS OF THE WILUNA–MEEKATHARRA AREA

By W. H. LITCHFIELD*

I. GENERAL FEATURES

The more outstanding features of the soils of this arid area are the leached nature of many of the soils and the widespread occurrence of a siliceous hard-pan. Teakle (1936) and Stephens (1956) have given general descriptions of these soils, which they term red and brown hard-pan soils. Since field observation was virtually restricted to the cover of uncemented soil, and since plant roots are largely confined to that part of the profile, the hard-pan is here treated as a substratum and the soils have been grouped according to the nature of the uncemented soil above.

Apart from the extensive hard-pan, most features of the soils are repeated elsewhere in arid Australia.

Leached coarse-grained red earths and red sands and clayey sands are the most extensive soils. They are derived from weathered rock material remaining on or transported off the old plateau, and also, on some of the lower levels, by an admixture of this material with fresher minerals derived from less weathered rocks exposed during the erosion of the new plateau. Only small areas of these soils on the old plateau contain ferruginous concretions or lateritic gravel.

In most of the main valleys on the new plateau, in clearly defined heavily alluviated areas that receive drainage, are calcareous earths, texture-contrast soils, coarse-structured clays, and saline soils. Calcareous earths occur also on basic rock and dolomite, and texture-contrast soils are developed at the foot of breakaways in lateritized rock.

Soils derived from fresh rock material are of small extent, being restricted to leached gritty soils surrounding granite outcrops and to calcareous soils on basic rocks and on dolomite.

The hard-pan is thickest in valleys on lower parts of the new plateau, where the shallow soils may be underlain by 30 ft or more of hard-pan. It thins out gradually on the slopes to a discontinuous crust, a few inches thick, covering the rock on gradients of 2 or 3%. The most common soils over hard-pan are red earths, mostly less than 2 ft deep. Hard-pan also extends below the red clayey sands of the sand plain on the old plateau. Hard-pan may or may not be present below texture-contrast soils, whilst calcareous earths and coarse-structured clays are never associated with hard-pan.

In general, depth to hard-pan is relatively uniform and variations appear to be related to present-day variations in internal drainage as controlled by slope, external drainage, and soil texture.

Weathering has given rise to various other types of consolidated substratum. A distinction is here drawn between weathering crusts, such as calcrete (travertine),

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silcrete (billy), and ferricrete (laterite), which are judged to have been formed as a result of changes in unconsolidated material, and weathered rock, in which an original rock structure is still discernible. The hard-pan may also be regarded as a weathering crust.

Stone pavements are widespread. Dense mantles of siliceous and ferruginous stone cover most hill slopes, which generally have little soil, and also extend onto stony plains of the new plateau eroded on granite and gneiss. Pavements also occur on many lower, soil-covered slopes, where they are remarkably extensive on leached soils as compared with other arid parts of Australia.

Most of the soils have massive structure with many fine vesicles, but a thin sealed crust less than ¼ in. thick is common and is particularly evident on finer-textured soils. The cracking clays show typical blocky structure, and locally have gilgai microrelief.

The chemical and the physical fertility of the soils is generally low. Shallowness, surface sealing, and unfavourable water relations are widespread. Many soils are strongly acidic; others are excessively alkaline or may present salinity problems. Most analysed profiles of leached soils were less acidic in their uppermost horizon than in the remainder of the profile.

None of the soils analysed showed a high phosphorus content: total phosphorus content ranged from 0·006 to 0·057%, which varies modestly around the low Australian average of 0·021% (Wild 1958). Most soil types have a nitrogen content of less than 0·05%, which reflects their small reserve of organic matter, a typical feature of desertic soils. Reserves of calcium and of potassium would generally appear to be low in very acid sandy soils on the criteria of Jackson (1957). In local situations, such as in red earths in vegetation groves and in non-saline depressions in calcreted valley fills, the chemical and physical fertility of the soil appears to be higher.

The very sandy soils in sand plain and on wanderrie banks are the only widespread deep soils. The former are strongly acidic and contain very little mineral nutrient; the latter appear to be more variable in reaction and to be not quite so strongly leached. The apparent difference would be consistent with the different histories of the two landscapes.

II. The Soil Groups

(*a*) *Arrangement and Terms*

The arrangement of soils is consistent with that previously used in an account of the soils in the Alice Springs area of central Australia (Litchfield 1962). Seven soil groups are defined on the basis of their unconsolidated "fine earth", but it is not intended that the descriptive terms applied to these groups should be considered as classificatory. The groups are divided into subgroups on a variety of criteria, such as the nature of their substrata, texture, depth, and the presence of a stone pavement or of a nodular horizon. Special soil conditions such as scalds, salt-pan soils, and gypseous kopi deposits have not been included in these groups.

In Table 14 the nomenclature in this chapter is compared with that used for comparable soils in central Australia by Litchfield (1962) and in this and other parts of arid Australia by Prescott (1944), Hallsworth and Costin (1950), Jessup (1951, 1960), Stewart (1953), and Stephens (1956).

TABLE 14

GROUPING OF SOILS AND THEIR CORRELATION WITH AUSTRALIAN CLASSIFICATIONS OF ARID ZONE SOILS

	Wiluna–Meekatharra Area	Names used by Other Authors
1	Alluvial soils (Regosolic forms; intergrade red earth forms; layered soils with a regosolic surface layer)	Alluvial soils* (Stephens 1956); fluvial regosols (Hallsworth and Costin 1950). The intergrade types are not mentioned in Stephens's or in Hallsworth and Costin's classifications. A salt crust on such soils may equate them with solonchaks
1*a*	Brown alluvial sands (regosolic), commonly on hard-pan (truncated soils)	Brown alluvial sands* (Litchfield 1962)
1*b*	Reddish alluvial sands, commonly on hard-pan (truncated soils)	Reddish alluvial sands* (Litchfield)
1*c*	Red-brown sandy alluvial red earths, commonly on hard-pan (truncated soils)	Leached brown levee soils* (Stewart 1953); red-brown sandy alluvial red earths* (Litchfield)
1*d*	Brown and red-brown alluvial loams and clays (regosolic), on red earths or hard-pan (truncated or buried soils)	Principally with brown alluvial loams over red earths* (Litchfield)
1*e*	Brown and red-brown alluvial loams and clays (regosolic) containing or over layers with carbonates, gypsum, or weakly-cemented soil	Partly with brown alluvial calcareous loams and clays (Litchfield)
2	Shallow, stony, undifferentiated soils	Lithosols (Hallsworth and Costin); undifferentiated skeletal soils (Stewart); arid ranges (Jessup 1951); desert tablelands and ranges (Prescott 1944); skeletal soils (Stephens; Jessup 1960); shallow, stony undifferentiated soils (Litchfield)
3	Red sands and clayey sands	
3*a*	Shallow gritty red clayey sands	Shallow gritty red clayey sands on crystalline rock (Litchfield)
3*b*	Shallow red clayey sands with stone pavements on weathered rock	Partly with shallow red clayey sands on sandstone (Litchfield)
3*c*	Red clayey sands on weathered rock	
3*d*	Reddish gravelly sands with ferruginous nodules on ferricrete or a mottled zone	Desert sand plain soils (Stephens)
3*e*	Red clayey sands on a nodular calcareous horizon	Red clayey sands on calcareous substrata (Litchfield)
3*f*	Shallow red clayey sands with stone pavement on hard-pan	Red and brown hard-pan soils (Stephens)
3*g*	Red clayey sands on hard-pan	Red and brown hard-pan soils (Stephens)
3*h*	Red clayey sands with ferruginous nodules on variably-cemented hard-pan	Affinities with Tertiary lateritic red sands (Stewart); principally with desert sand plains (Prescott); partly desert sand plain soils and partly red and brown hard-pan soils (Stephens)
3*i*	Red sands	Desert sand hills (Prescott; Stephens); affinities with seif dune soils (Hallsworth and Costin); red sands (Litchfield)

TABLE 14 (*Continued*)

	Wiluna–Meekatharra Area	Names used by Other Authors
4	Red earths	Red earths (Jessup 1960). The sandy and hard-pan soils are not necessarily equivalent to soils similarly named by Jessup
4*a*	Sandy red earths on weathered rock	Affinities with brown soils of light texture (Stephens; Hallsworth and Costin)
4*b*	Shallow red earths with stone pavement on weathered rock or on a weathering crust	
4*c*	Red earths on a calcareous horizon	Tertiary non-lateritic soils (Stewart); calcareous red earths (Stephens); arid red earths (Stephens, unpublished); red earths on calcareous substrata (Litchfield)
4*d*	Deep sandy red earths	Affinities with brown soils of light texture (Stephens; Hallsworth and Costin); deep sandy red earths (Litchfield)
4*e*	Deep red earths	Included with desert loams (Prescott); comparable to, or close affinities with, deep red earths (Litchfield) and arid red earths (Stephens, unpublished)
4*f*	Sandy red earths with ferruginous nodules on variably-cemented hard-pan	Affinities with Tertiary lateritic red earths (Stewart); principally with desert sand plain soils (Prescott); partly desert sand plain soils and partly red and brown hard-pan soils (Stephens)
4*g*	Sandy red earths on hard-pan	Red and brown hard-pan soils (Stephens)
4*h*	Shallow red earths on hard-pan	Included with desert loams (Prescott); red and brown hard-pan soils (Stephens)
4*i*	Shallow red earths with stone pavement on hard-pan	Included with desert loams (Prescott); red and brown hard-pan soils (Stephens)
4*j*	Deep red earths on hard-pan†	Included with desert loams (Prescott); red and brown hard-pan soils (Stephens)
4*k*	Deep red earths with gley horizons on hard-pan†	Included with desert loams (Prescott); red and brown hard-pan soils (Stephens)
5	Calcareous earths	Included with desert loams (Prescott)
5*a*	Brown sandy calcareous earths on crystalline rocks	Brown sandy calcareous earths (Litchfield)
5*b*	Brown calcareous earths on interbedded dolomite and shale	Grey-brown and red calcareous desert soils (Stephens); limestone calcareous desert soils (Stewart); affinities with brown loamy calcareous earths (Litchfield)
5*c*	Red calcareous earths	Grey-brown and red calcareous desert soils (Stephens)
5*d*	Brown sandy calcareous earths	Brown sandy calcareous earths (Litchfield)
5*e*	Red sandy calcareous earths	Calcareous arid soil (Jessup); red sandy calcareous earths (Litchfield)
5*f*	Brown loamy calcareous earths	Limestone calcareous desert soils (Stewart); grey-brown and red calcareous desert soils (Stephens); brown loamy calcareous earths (Litchfield)

TABLE 14 (*Continued*)

	Wiluna–Meekatharra Area	Names used by Other Authors
6	Texture-contrast soils (Solonetzic forms)	Solonetzic soils (Jessup 1960). Apedal and hard-pan soils are not necessarily equivalent to soils similarly named by Jessup
6*a*	Shallow texture-contrast soils on weathered rock	Included with stony deserts (Prescott) and desert loams (Stephens; Hallsworth and Costin)
6*b*	Sandy texture-contrast soils	Principally with arid red earths (Jessup 1951) and sandy texture-contrast soils without pavement (Litchfield)
6*c*	Texture-contrast soils with variable stone pavement	Principally with desert loams (Stephens; Hallsworth and Costin) and loamy texture-contrast soils (Litchfield)
6*d*	Shallow texture-contrast soils on hard-pan	Shallow texture-contrast soils with siliceous hard-pan (Litchfield)
7	Red coarse-structured clays (Grumusolic forms)	Affinities with grey and brown soils of heavy texture (Prescott); brown soils of heavy texture (Stephens); and brown sierozem (Hallsworth and Costin); red coarse-structured clays (Litchfield)

* Without hard-pan.

† The texture-profiles in these soils may be either uniform (medium- to fine-textured) or weakly gradational (medium, changing to fine).

(*b*) *Descriptions of Soils*

(1) *Alluvial Soils*.—Alluvial soils are of minor extent in valleys throughout the survey area. Truly regosolic alluvial soils are restricted, and such as do occur are generally layers only a few inches thick overlying a buried organized soil or hard-pan. This relative lack of young alluvia can be taken as evidence of lack of vigour in the present-day drainage.

Most of the few alluvial profiles examined showed differences of morphology, and the five subgroups listed below have been somewhat arbitrarily separated.

Small areas of alluvia near drainage channels in the upper sectors of valleys, on sites with reasonably free drainage, are typically weakly acidic or neutral (pH 6·0–7·5), and resemble adjacent red earths in their insignificant salt content. In contrast, alluvial deposits in low-lying trunk valleys with restricted drainage are alkaline (pH 8·4–9·5) and typically contain appreciable salts (greater than 0·2%).

Field textures vary widely, but indicate an appreciable silt content in some of the finer-textured deposits. A brown colour (Munsell hue 5YR) is more typical than red (Munsell hues 2·5YR and 10R), as in alluvial soils in other arid areas.

Restricted soils with weak organization and with redder colour on alluvial sites are recognized as intergrade soils.

(1*a*) *Brown alluvial sands* with much quartz grit were recorded only among texture-contrast soils below breakaways. Saline efflorescences were noted here.

(1*b*) *Reddish alluvial sands* occur as small tongues of coarser-textured deposits near drainage channels, in otherwise finer-textured alluvia. The texture may vary between sand and clayey sand, and colour may range from brown to red-brown in any one profile.

(1*c*) *Red-brown sandy alluvial red earths,* as in other arid areas, are distinguished from typical red earths by their less intense red colour and by their occurrence near watercourses. They have increasing fineness of texture with depth, from clayey sand to sandy clay.

(1*d*) *Brown and red-brown alluvial loams and clays* occur as layers of soil a few inches thick overlying buried red earths or hard-pan. They vary in their field textures from silty clay loam to soils with coarser grains, such as clays with some sand.

(1*e*) *Brown and red-brown alluvial loams and clays containing or over layers with carbonates, gypsum, or weakly cemented soil* occur in sites liable to flooding and with restricted drainage. They are subject to wind and water erosion, which cause many physical modifications and may result in the formation of multiple thin layers. At certain sites, remnants of texture-contrast soils or red earths were recognized under little-organized soil or gravel. Salt efflorescence is common. Weak cementation in an underlying clay horizon is shown by brittleness and a tendency to shatter into angular fragments.

(2) *Shallow, Stony, Undifferentiated Soils.*—These soils are found on all hill belts, ranges, and plateaux, and also on the edges of calcrete platforms in trunk valleys. On hillsides they consist of little more than a dense mantle a few inches thick, with varying proportions of siliceous and ferruginous stone. The soil on the edges of calcrete platforms is mainly a stony rubble of calcrete fragments on a layer of consolidated calcrete.

This group has not been further subdivided.

(3) *Red Sands and Clayey Sands.*—This soil group occupies about 6000 sq. miles, or one-quarter of the survey area.

Red sands commonly occur on dunes in sand plain or near salt lakes; gravelly sands occur on hill crests underlain by lateritic profiles; stony clayey sands occur on hill tops and slopes; gritty clayey sands overlie granite or gneiss; clayey sands, by far the most extensive of the group, occur widely in sand plain and on wanderrie banks. A field texture of clayey sand corresponded to a clay content of between 4 and 14% and to a silt content of between 1 and 3%.

Most of the sandy soils are freely drained, are acidic or neutral (pH 4·6–7·4), and have a very low salt content (less than 0·02%). Soils on sand plain and some dunes adjacent to areas with restricted drainage are alkaline (pH 8·0–8·9), with slight salt accumulation (less than 0·10%).

(3*a*) *Shallow gritty red clayey sands,* normally less than 2 ft deep to rock, are mainly found on gentle slopes at the foot of granite domes.

(3*b*) *Shallow red clayey sands with stone pavements on weathered rock* are almost lithosolic and are only a few inches deep. They occur on hill slopes and plateau crests formed mainly on sandstone, in situations favourable to slight soil accumulation.

(3*c*) *Red clayey sands on weathered rock* occur in sand plain where bedrock is close to the surface. They may not have originated from the rock on which they occur.

(3*d*) *Reddish gravelly sands with ferruginous nodules* vary in depth from between a few inches to more than 3 ft on ferricrete, mottled, or strongly ferruginized rock. The sands in these soils are fine-grained, being derived from lateritized volcanic rock, mudstone, or shale.

(3*e*) *Red clayey sands on a nodular calcareous horizon* were recorded in sand plain adjoining low-lying areas with impeded drainage. The topsoil may be acidic or alkaline, presumably depending on local drainage.

(3*f*) *Shallow red clayey sands with stone pavement on hard-pan* occur in close association with 3*b* where thin discontinuous crusts of hard-pan extend on to lower hill slopes.

(3*g*) *Red clayey sands on hard-pan* occur on wanderrie banks, where they are commonly between 2 and 4 ft deep. They also occur on alluvial plains fringing sand plain, and they may locally replace deeper red earths in thin vegetation groves on gentle slopes subject to sheet-flow. These sands are coarse-grained and locally contain gravel. Weakly cemented hard-pan was encountered at isolated sites.

(3*h*) *Red clayey sands with ferruginous nodules* resemble 3*g*, except that the underlying hard-pan shows greater variability in its degree of cementation. The continuity of the hard-pan could not be adequately tested on the extensive sand plain in which these soils occur. The nodular horizon occurs at a depth of between 2 and 4 ft and the hard-pan at between 3 and 5 ft. The nodular horizon may contain pellets of hard-pan as well as ferruginous nodules.

(3*i*) *Red sands* occur only in dunes and aeolian sandbanks. The sands are loose or only weakly coherent owing to the almost complete absence of clay. They are normally acidic, but may be alkaline near salt lakes.

(4) *Red Earths.*—Red earths are most prevalent in valleys and plains on the new plateau, although sandy red earths occupy appreciable areas on the plains of both the old and new plateaux. They occupy about 9000 sq. miles, or more than one-third of the survey area.

A normal red earth profile is recognized by its Munsell hue of 2·5YR or 10R and by its porous, apedal fabric. In this area, the deeper, coarser-textured red earths generally possess gradational texture profiles, with a sandy clay loam or finer-textured subsoil. Shallower red earths more usually have a uniform texture profile of sandy clay loam or sandy clay. These shallower, finer-textured soils commonly have a sealed surface crust which may reduce their permeability.

A characteristic feature of red earths on hard-pan on lower slopes subject to sheet-flow is the development of successive narrow transverse trenches of deeper, more permeable soil in vegetation groves, in contrast to the shallow sealed soils in the wider intergroves. The latter soils are generally less than 1 ft deep, whilst the soil in the trenches is generally between 2 and 5 ft deep and locally deeper. The silt content of a grove soil (4–9%) was found to be about half that of an intergrove soil (12–13%). The occurrence of gleying in the lower part of the trench indicates that the wetting front may here extend through the whole soil.

Most of these soils have a prominent coarse sand fraction. The clay content in three coarser-textured profiles ranged from between 4 and 17% in the topsoils to a maximum of between 18 and 27% in the subsoils. In three finer-textured red earths, the surface horizons contained between 21 and 23% clay and the finer-textured subsoils between 28 and 48%. The soil with the highest clay content was also the only one in this group recorded with peds (structural aggregates).

The silt content of the three coarser-textured red earths mentioned above was very low (between 1 and 4%) in all horizons, but higher percentages may be typical for shallow, sealed red earths, as in the intergrove soils already described.

Most red earths are moderately to strongly acidic, although soils with an underlying calcareous horizon may be neutral. Their salt content is usually insignificant (less than 0·02%). However, red earths adjacent to areas of restricted drainage may be alkaline and may have an appreciable salt content. Analysed red earths varied appreciably in their saturation percentages (27–100%) and in the estimated exchange capacity of their clays (9–43 m-equiv. per 100 g), but the proportion of potassium in the metal ions was relatively high, averaging 20%.

(4*a*) *Sandy red earths on weathered rock* occur in sand plain, together with red clayey sands (3*c*). Their distinguishing feature is a downwards increase in fineness of texture, from clayey sand to sandy clay loam or sandy clay above bedrock.

(4*b*) *Shallow red earths with stone pavement on weathered rock or on a weathering crust* are, like the shallow red clayey sands (3*b*), almost lithosolic and only a few inches deep. Their textures range from sandy clay loam to sandy clay with varying grain size. They occur on hill slopes where hard-pan is discontinuous or absent.

(4*c*) *Red earths on a calcareous horizon*, whether a horizon of lime nodules or a calcrete, are invariably free from hard-pan. The carbonate-free red earth horizon may vary from a few inches to more than 2 ft deep, and it is medium- or fine-textured at the surface. These soils occur locally on or adjacent to calcrete platforms in trunk valleys.

(4*d*) *Deep sandy red earths* have a surface texture of clayey sand, grading within a depth of 2 or 3 ft into a sandy clay loam or sandy clay which may continue for some feet, one profile exceeding 9 ft total depth. The deepest horizons may contain some gravel or hard-pan pellets. These soils are most likely to occur extensively in broad sandy alluvial depressions receiving run-on. They have a restricted occurrence in vegetation groves.

(4*e*) *Deep red earths* are distinguished from deep sandy red earths by a medium or fine texture at the surface. They occur in vegetation groves and in small confined alluvial flats receiving run-on.

(4*f*) *Sandy red earths with ferruginous nodules* are coarse-grained sand-plain soils like 3*h*, but are distinguished by an increase in fineness of texture from clayey sand at the surface to sandy clay loam above the hard-pan.

(4*g*) *Sandy red earths on hard-pan* have similar textural horizons to 4*a* and 4*d*. The hard-pan occurs at depths of between 2 and 4 ft, either fully cemented, or first in pellets, or as a fragmentary pan. These soils are found in sandy alluvial plains and near the lower margins and in broad depressions through sand plain.

(4*h*) *Shallow red earths on hard-pan* are generally uniform-textured sandy clay loams or sandy clays between a few inches and 2 ft deep on fully cemented hard-pan. These soils are widely spread on alluvial plains, wanderrie flats, and stone-free slopes between vegetation groves.

(4*i*) *Shallow red earths with stone pavement on hard-pan* are, like 4*h*, medium- and fine-textured soils, but they also have stone pavements. They occur principally on gentle slopes between thin vegetation groves or on higher slopes where hard-pan forms only a thin, discontinuous crust over bedrock. On wanderrie flats adjacent to rocky areas they may have pavements of quartz stones.

(4*j*) *Deep red earths on hard-pan* are defined as having more than 2 ft of medium- to fine-textured uncemented soil over hard-pan. Their differentiation from 4*h* on the basis of their depth is also generally associated with less pronounced sealing and hence presumably greater permeability. A gravelly horizon is commonly encountered above the hard-pan. Trenches of deeper uncemented soil in vegetation groves are typical sites for this soil, although other isolated occurrences were recorded throughout the alluvial plains.

(4*k*) *Deep red earths with gley horizons on hard-pan* are distinguished from 4*j* by a mottled red, yellow, and grey horizon above the hard-pan. They have a sporadic occurrence in vegetation groves.

(5) *Calcareous Earths*.—In this area, calcareous earths are shallow soils generally less than 1 ft deep. Their character is due to carbonate, which is finely dispersed through the soil and which comes from underlying calcrete or from weathering crystalline rock, dolomite, or calcareous shale. The fine carbonates impart a powdery consistence. Field textures and dominant sand grain sizes vary from coarse to fine depending on the underlying source material. There is generally a sparse to moderately dense stone pavement.

Calcareous earths in this area are generally brown (Munsell hue 5YR) when dry, but darker and reddish (2·5YR) when moist, and a pronounced red colour is uncommon. They are strongly alkaline (in the vicinity of pH 9), but are low in total salts (less than 0·06%).

They cover only a few hundred square miles in the survey area, mainly in the trunk valleys.

(5*a*) *Brown sandy calcareous earths on crystalline rock* form where such rocks weather to give a calcrete crust. The residual sands are usually coarse-grained.

(5*b*) *Brown calcareous earths on interbedded dolomite and shale* have a fine sandy clay or clayey texture.

(5*c*) *Red calcareous earths* with clay texture were only recorded on weathered rock material near lateritized greenstone.

(5*d*) *Brown sandy calcareous earths* are generally very shallow soils with much calcrete rubble in fine-grained sand, and they occur principally on calcrete platforms in trunk valleys.

(5*e*) *Red sandy calcareous earths* with coarse-grained sands occur sporadically on the sandy outer slopes of calcrete platforms.

(5*f*) *Brown loamy calcareous earths* resemble 5*d*, except for their finer texture. They tend to occur on the lower parts of calcrete platforms.

(6) *Texture-contrast Soils*.—This term refers to soils with an abrupt change in their profile (i.e. through less than 1 in.) from a coarse- or medium-textured topsoil to a finer-textured subsoil, referred to as the subsoil pan. This pan lies within a foot of the surface. It varies from thin and very compact, massive vesicular, sandy clay loams, commonly resting on cemented siliceous hard-pan, in coarser-textured soils, to thicker structured clays passing into horizons with carbonates, gypsum, or weak silica cementation in finer-textured soils.

In this area the topsoil is generally red-brown and the subsoil red-brown or brownish red (Munsell hue 2·5YR), and in some soils a thin bleached horizon occurs immediately above the subsoil pan. Mottled clay subsoils occur near salt pans.

They are regarded as varieties of solonetzic soil irrespective of their structure or of local re-salinization. Soil reaction varies widely in the topsoils (pH 6·3–8·7), where total salts may be low (0·01–0·05%) or high enough to cause efflorescence at the surface. The subsoil pans are mostly alkaline (pH 6·8–9·2), with a variable but appreciable concentration of salts (0·03–2·8%). These variations occur equally in soils with hard-pan and in soils without cementation.

Soils of this general type on flood-plains are very susceptible to water and wind erosion, the latter forming hard scalds and piling up low sand banks derived from surface soils. Elsewhere, the soils may be protected from erosion by stony pavements.

Texture-contrast soils cover somewhat less than 1000 sq. miles, and are regionally significant only on parts of the Salinaland plains and the inner lowland and Lake Carnegie lowland in the north-eastern upland province.

(6*a*) *Shallow texture-contrast soils on weathered rock* have stone pavements and thin subsoil pans. Their shallowness precludes the development of underlying carbonate or gypseous horizons. They occur on hill slopes below lateritic crests and locally near rock outcrops bordering saline alluvial plains.

(6*b*) *Sandy texture-contrast soils* without an underlying fully cemented hard-pan pass into a variety of carbonate, gypseous, or weakly-cemented horizons below the subsoil pan. Topsoils are between 2 and 10 in. thick, and have sand and clayey sand textures with much variation in grain size; the subsoil pans are usually less than 18 in. thick, and are very compact sandy clay loams and sandy clays. These soils occur around salt pans on adjoining saline alluvial plains, and on salt-affected drainage floors and flood-plains. They typically lack stone pavements and are hence very liable to wind erosion.

(6*c*) *Texture-contrast soils with variable stone pavement* have finer textures than 6*b*, with less than 3 in. of coarse- or medium-textured topsoil above a prismatic or columnar-structured clay subsoil passing downwards into variable saline clay horizons as in 6*b*. They occur on alluvial aprons below hills of lateritized rock and on saline alluvial plains.

(6*d*) *Shallow texture-contrast soils on hard-pan* have mainly similar textures to 6*b*. Stone pavements may occur, but not below breakaways in weathered crystalline rock. Hard-pan is usually encountered at less than 15 in. depth. The most extensive occurrences are together with 6*b* on saline alluvial plains and with 6*a* on alluvial slopes below hills of lateritized rock.

TABLE 15

SOIL ASSOCIATIONS IN RELATION TO LANDSCAPES AND SUBSTRATES, AND THEIR OCCURRENCE IN LAND SYSTEMS

Soil Association (Defined by Dominant Soil Subgroup)	Subdominant and Minor Soils	Soil Landscape	Land Systems in Which Soil Association is Dominant
1*d*	Minor 1*b*, 1*c*	Flat non-saline drainage floors	
Rock outcrop and 2		Moderate to steep slopes of hills, ridges, and breakaways with exposures of fresh and weathered rock and weathering crusts	Boondin, Doman, Gabanintha, Lynne, Norie, Princess, Tooloo, Weld, Wiluna, Wongawol, Yagahong
2	3*b*, 4*b*, 4*i*; minor rock outcrop	Erosional plains and gentle hill-foot slopes with exposures of weathered crystalline rock partially masked by very thin hard-pan	Koonmarra, Mindura, Sherwood, Yarrameedie
3*a*	Minor rock outcrop	Slopes at foot of granite or gneiss hills	
3*b*	Minor rock outcrop	Gently sloping plateau summits capped by silicified sandstone	Glengarry
3*c*	4*a*	Very gentle slopes merging into sand plain and underlain by weathering rock at relatively shallow depth	
3*d*	Minor rock outcrop	Flattish or gently rounded laterite-capped hill tops	Diamond, Fisher
3*g*	Minor 4*g*	Wanderrie banks; broader sandy alluvial plains adjoining sand plain; sandy alluvial fans with underlying hard-pan	Belele, Trennaman
3*h*	4*f*	Sand plain (and presumably dune swales) with underlying hard-pan	Bullimore, Heppingstone, Kalli, Waguin, Yelma
3*i*		Sand dunes and banks	Heppingstone, Leeman
4*b*	4*i*; minor 3*b*, 3*f*, 4*c*, 5*c*, 5*d*, 5*f*	Gentle hill slopes in weathered rock or with a weathering crust, including thin hard-pan principally on fine-grained rock	Edenhope, Gabanintha, Kalyaltcha, Killara, Sodary, Treuer

TABLE 15 (*Continued*)

Soil Association (Defined by Dominant Soil Subgroup)	Subdominant and Minor Soils	Soil Landscape	Land Systems in Which Soil Association is Dominant
4c		Alluvial drainage floors and plains with underlying calcrete	
4d	*4e*, *4g*	Drainage floors, including broad depressions in alluvial plains, free from or with variably cemented hard-pan	
4h	Minor *4i*, *4j*	Drainage floors and plains, including flats between wanderrie banks	Belele, Beringarra, Cole, Ero, Trennaman, Yandil
4h with *4j*	Minor *3g*	Very gentle, stone-free slopes subject to sheet-flow (generally less than 1%) on valley floors, alluvial fans, and plains with massive hard-pan at varying depths	Yandil
4i	*4j*; minor *3f*, *4e*, *4h*, *4k*	Gentle and very gentle stony slopes (generally less than 2%) subject to sheet-flow on lower hill slopes, alluvial fans, and plains with massive hard-pan at varying depths	Dural, Fisher, Jundee, Violet
5a		Gentle slopes and lower hill slopes, as for 2 and *3a*, but underlain by more basic crystalline rocks with calcrete weathering crusts	
5b		Erosional plains on interbedded dolomite and shale	Windidda
5d	2, *5f*; minor *4c*	Calcrete platforms in trunk valleys	Cunyu
6a	*6d*	Gentle slopes of hills with lateritic cappings; underlain by weathered rocks, locally masked by a thin hard-pan crust	

TABLE 15 (*Continued*)

Soil Association (Defined by Dominant Soil Subgroup)	Subdominant and Minor Soils	Soil Landscape	Land Systems in Which Soil Association is Dominant
6*b*	1*e*, 6*c*	Salt-affected alluvial floors, flood-plains, plains, and pan margins	Barwidgee, Beringarra, Mileura
6*c*	Minor 7	Alluvial fans below hills with laterite cappings	
6*d*	Minor 1*a*	Alluvial fans and plains underlain by massive hard-pan	Barwidgee, Kalyaltcha
7		Alluvial drainage floors with alluvium derived largely from dolomite	
Saline sediments and gypsiferous sands		Floors of salt lakes	Carnegie
Kopi		Kopi dunes flanking salt lakes	

(7) *Red Coarse-structured Clays*.—These have the same principal features as coarse-structured clays in central Australia (Litchfield 1962). Thus, they are more commonly red (Munsell hue 10R) than grey or brown; they crack deeply into a coarse blocky structure when dry; the clay content (28–39% in one profile) is lower than indicated by their field textures; the greater part of the profile is alkaline; flecks of carbonate occur throughout the soil, although gypsum crystals appear only in deep horizons; there is a marked increase in salt content in the lower part of the profile; they may be at least several feet deep.

Red coarse-structured clays mainly occur on alluvial flats derived largely from dolomite, and also locally as gilgais within saline alluvial plains and at the foot of greenstone hill slopes. They cover only a few square miles, mostly in the inner lowland of the north-eastern uplands.

(*c*) *Soil Geography*

The distribution of soils is most clearly expressed through soil associations, which consist of one or more specific soil subgroups geographically associated with a definite part of the landscape and with a particular range of substrata.

Within each association the specific soil subgroups occur in reasonably consistent proportions, and it has been possible to define soil associations in terms of dominant soil subgroups (more than 30% of the area) and associated subdominant (15–30%) or minor (less than 15%) soil subgroups. They are listed together with their soil landscapes, substrates, and the land systems in which they are dominant in Table 15, but are not described in the text.

TABLE 16

DISTRIBUTION OF SOILS BY PHYSIOGRAPHIC REGIONS

Physiographic Province and Region	Major Soil Groups or Subgroups, with Soil Associations	Minor Soil Groups or Subgroups, with Soil Associations
Murchison plains		
Whitestone ranges	Shallow stony undifferentiated soils (rock outcrop and 2)	Shallow stony undifferentiated soils (2); calcareous earths (5*a*)
Stony plains	Shallow stony undifferentiated soils (2)	Shallow stony undifferentiated soils (rock outcrop and 2). Alluvial soils (1*d**); red sands and clayey sands (3*a*, 3*h**, 3*i*); red earths (4*h**, 4*h** with 4*j**, 4*i**); calcareous earths (5*a*); texture-contrast soils (6*d**)
Main flood-plains	Red earths (4*h**); calcareous earths (5*d*); texture-contrast soils (6*b*)	Alluvial soils (1*d**); red sands and clayey sands (3*g**, 3*h**, 3*i*); red earths (4*c*, 4*h** with 4*j**); texture-contrast soils (6*d**); saline sediments, gypsiferous sands, and kopi
Tributary alluvial plains	Red clayey sands (3*g**); red earths (4*h**)	Alluvial soils (1*d**); red clayey sands (3*h**); red earths (4*h** with 4*j**); texture-contrast soils (6*b*)
Salinaland		
Hill belts	Shallow stony undifferentiated soils (rock outcrop and 2); red earths (4*b*)	Alluvial soils (1*d**); reddish gravelly sands (3*d*); red earths (4*h**, 4*h** with 4*j**, 4*i**); calcareous earths (5*a*); texture-contrast soils (6*a*, 6*c*)
Trunk valleys	Red earths (4*h**); texture-contrast soils (6*b*, 6*d**)	Alluvial soils (1*d**); red sands and clayey sands (3*g**, 3*i*); red earths (4*c*, 4*h** with 4*j**, 4*i**); calcareous earths (5*d*); saline sediments; gypsiferous sands and kopi
Sand plain	Shallow stony undifferentiated soils (2); red clayey sands (3*g**, 3*h**); red earths (4*h** with 4*j**)	Alluvial soils (1*d*); shallow stony undifferentiated soils (rock outcrop and 2); red sands and clayey sands (3*c*, 3*i*); red earths (4*d*, 4*h**); texture-contrast soils (6*d**)
Central uplands		
Outer plateaux	Stony red clayey sands (3*b*)	Shallow stony undifferentiated soils (rock outcrop and 2); red earths (4*b*, 4*d*, 4*h**)
Inner lowlands and northern plains	Red earths (4*i*)	Alluvial soils (1*d**); shallow stony undifferentiated soils (rock outcrop and 2); reddish gravelly sands and red clayey sands (3*d*, 3*g**); red earths (4*b*, 4*c*, 4*h**, 4*h** with 4*j**); calcareous earths (5*d*); texture-contrast soils (6*b*)
Basalt hills	Red earths (4*b*)	Shallow stony undifferentiated soils (rock outcrop and 2); reddish gravelly sands (3*d*); red earths (4*h**, 4*i**)

TABLE 16 (*Continued*)

Physiographic Province and Region	Major Soil Groups or Subgroups, with Soil Associations	Minor Soil Groups or Subgroups, with Soil Associations
North-eastern upland		
South-western plateaux	Shallow stony undifferentiated soils (rock outcrop and 2)	Red clayey sands (3*c*); red earths (4*b*, 4*h**, 4*h** with 4*j**, 4*i**); texture-contrast soils (6*b*)
Inner lowland	Shallow stony undifferentiated soils (rock outcrop and 2); red earths (4*b*)	Alluvial soils (1*d**); reddish gravelly sands and red clayey sands (3*d*, 3*g**); red earths (4*h**, 4*h** with 4*j**, 4*i**); calcareous earths (5*b*); texture-contrast soils (6*a*, 6*b*, 6*d**); red coarse-structured clays (7)
Princess Ranges	Shallow stony undifferentiated soils (rock outcrop and 2); red earths (4*b*)	
Lake Carnegie lowland	Saline sediments and gypsiferous sands	Shallow stony undifferentiated soils (rock outcrop and 2); red sands and clayey sands (3*g**, 3*i*); red earths (4*h**, 4*h** with 4*j**); texture-contrast soils (6*b*); kopi

* With hard-pan.

The soil associations have been given the same number/letter identification as their dominant soils, and are also referred to in this way in the following parts of this report and in the tabular descriptions of the land systems. Three of the soil associations have been defined by the occurrence of rock outcrop, saline lake sediments, and kopi dunes. Thus, the land system map can be used to gain a picture of the distribution of the soils.

In Table 16 the major and minor soil associations are listed for the main land forms in each physiographic province and region as defined in Part V, and the major soil associations are also included in the reference to the map of land forms and physical provinces and regions. These afford a more generalized picture of the distribution of the soils in the area.

III. Soils and Land Use

(*a*) *General*

The effects of the arid climate are accentuated by the general shallowness of the soils and by their relative infertility. The former mainly results from the occurrence of massive hard-pan, the latter from the pre-weathering of many of the rock materials which formed the soils. As a result, mulga and other plant species which are normally tolerant of drought and of a fairly wide range of infertile soils are here in a precarious balance with their physical environment.

A well-developed vegetative cover in the Wiluna–Meekatharra area is always associated with a favourable combination of soil and drainage. Such are the deep soils in vegetation groves (soil associations 4*h* with 4*j*, and 4*i*), on confined drainage floors (soil association 4*d*), and to a lesser degree on wanderrie banks and in the sandier parts of alluvial plains (soil association 3*g*). Alkaline soils on saline flood-plains and other salt-affected areas (soil association 1*d*) are of particular value in that they support protein-rich chenopodiaceous plants in spite of being unfavourable for many other plants.

Any planned improvement in the use of these lands will be influenced considerably by the occurrence of such edaphic oases, and conservation methods should aim at preserving and improving such sites, even at the expense of adjacent unproductive surfaces.

(*b*) *Chemical Fertility*

A reconnaissance survey of soils in a little-utilized area is of limited diagnostic value in a consideration of plant nutrition, and available analyses can only indicate trends and major differences between the nutrient reserves of different soils.

(i) *Phosphorus*.—It can be assumed that all soils will require phosphatic fertilizer for intensive production. There is no indication that the various alluvial soils (soil associations 1*d* and 4*b*) and cracking clay soils (soil association 7) have significantly more phosphorus than the other soils. Deficiencies are likely to be most acute in very acid sand-plain soils (soil associations 3*c* and 3*h*).

(ii) *Nitrogen*.—The work of Birch (1959) indicates that mineralization of organic nitrogen is greatly accelerated by alternations of long hot dry periods and short wet periods such as occur in this area. Thus the rate of turn-over of soil nitrogen is probably rapid, both in the widespread soils of lower soil nitrogen content and in favoured sites with higher soil nitrogen levels, and the general availability of nitrogen is likely to be higher than might be expected from such low total nitrogen values.

(iii) *Calcium and Soil Acidity*.—Deficiencies of calcium are most likely to occur in strongly acid sandy soils with very little organic matter and with very low exchange capacity, in particular in red clayey sands and sandy red earths in and marginal to sand plain (soil associations 3*c*, 3*h*, and, to a lesser degree, 3*g*). Rubbly calcrete would be a ready local source of agricultural lime where superphosphate did not supply adequate calcium.

(iv) *Potassium*.—Potassium deficiencies might be expected broadly to correlate with calcium deficiencies, since the exchange capacity of the calcium-deficient sand-plain soils would appear to be related much more to constituent clay minerals than to organic matter. It would appear that sand-plain soils with very low exchange capacity have dominantly kaolinitic clay, which does not contain potassium, whereas many of the other soils would appear to have potassium-yielding illitic clays. A modifying factor might be the relatively high proportion of potassium to other exchangeable metal ions in many soils of the area, including some sandy soils.

(v) *Soil Salinity and Alkalinity*.—These are commonly associated with texture-contrast soils with intractable subsoil pans, and they preclude any intensive use of soils in associations 6*b* and 6*d* other than for adapted plants such as chenopods. The calcareous earths (soil associations 5*a*, 5*b*, and 5*d*) and some cracking clays (soil association 7) are also highly alkaline.

It is considered improbable that areas of saline soil will increase, except locally from the use of saline irrigation water on poorly drained soils. Distribution of salt appears to have reached an apparent equilibrium over a geological period, the salts now being concentrated in definite tracts and layers, and foreseeable land use should not alter this situation.

(*c*) *Physical Fertility*

Since no measurements relating to the tilth or to the water relations of these soils are available, it is only possible to anticipate their behaviour under cultivation from their field properties. Most of the soils would have low available water storage because of their shallowness, owing to the presence of hard-pan or of subsoil pans in texture-contrast soils. In addition, water stress would be imposed by the chemical barrier of certain highly saline subsoils.

Apart from natural regeneration, the establishment of a denser vegetation must depend on some form of irrigation or water-spreading. With regard to surface tilth, the red earth disperses very quickly following run-on or raindrop impact, and forms a sealed crust. The siltier the soil, the stronger such crusts appear to be. The worst of the soils in this regard would be shallow red earths in intergroves (soil associations 4*h* with 4*j*, and in 4*h* and 4*i*, and silty alluvial soils in 1*d*).

The type of vegetation most likely to be successfully established will consist of relatively deep-rooting plants capable of making most use of short-lived natural water supplies or of limited supplies of irrigation water. The most favourable soils, therefore, will be those which permit rapid moisture and root penetration and which have at least a moderate water-holding capacity in their subsoils. Deeper red earths with coarse to medium surface textures (soil associations 3*g*, 4*d*, 4*h* with 4*j*, and 4*i*) are probably the best in this area. Porosity in the fabric of the red earth presumably compensates for its lack of water-stable structure. Deep coarse-grained sands and clayey sands are less suitable by virtue of their very low water-holding capacity.

(*d*) *Irrigation Sites*

The soils most suited to irrigation have been described in the section above, and it would be necessary for such soils to occur close to the ground-water supply. Seed-bed characteristics and chemical fertility are presumably of secondary importance, since greater control of these factors should be possible on relatively small irrigation plots under intensive production. The suitability for irrigation of the soil associations is stated in Table 17.

Unfortunately, the soil associations in the calcreted valley fills, which form the principal aquifers, are mainly unfavourable. Very shallow stony soils on calcrete platforms (soil association 5*d*) and saline and alkaline soils on alluvial floors (soil association 6*b*) are clearly unsuitable, and fine-textured red earths on hard-pan and calcrete (soil association 4*c* and 4*h*) suffer from shallowness and a strong tendency to sealing. Red earths on calcrete (soil association 4*c*) may locally be more freely drained depending on the nature of the calcareous horizon.

Irrigation in these valleys would thus depend either on making the best possible use of the relatively shallow soils or else on finding deeper, freely-drained soils within exploitable distance of the water supply.

TABLE 17

EROSION HAZARD OF SOILS AND SUITABILITY FOR IRRIGATION AND CONSTRUCTION PURPOSES

Characteristic Soils and Soil Associations	For Intensive Production from Irrigation or Water-spreading	Erosion Hazard	For Formed Road and Airstrip Construction
Shallow stony soils: 2, rock outcrop and 2, 3*b*, 4*b*, 5*a*, 5*d*	Unsuitable	Susceptible where not protected by heavy stone mantle	Adequate, apart from rough surfaces; calcrete in association 5*d* is a source of road-surfacing material
Relatively shallow sandy soils: 3*a*, 3*c*	Unsuitable	Stable	Adequate for light traffic
Shallow soils with iron-stone gravel: 3*d*	Unsuitable	Stable	Adequate; the thin gravel layer is a minor source of road material
Deeper sandy soils: 3*g*, 3*h*	Possibly suitable for spray irrigation	Stable under existing vegetation	Adequate for light traffic
Deep sands: 3*i*	Unsuitable	Stable under existing vegetation	A local problem only; sand banks make unstable road surfaces in the Leemans valley
Relatively shallow red earths over calcrete: 4*c*	Prospects for flood irrigation and water-spreading	Moderately stable	Adequate
Relatively deep red earths: 4*d*	Generally suitable for spray or flood irrigation, depending on soil texture	Stable	Adequate
Shallow hard-pan red earths with trenches of deeper soil in mulga groves: 4*h* with 4*j*, 4*i*	Prospects for small-scale use of the larger grove trenches; run-off into groves may possibly be increased by small diversion banks	Susceptible on shallow red earths on hard-pan; groves moderately stable where vegetated, with rill erosion the principal hazard	Adequate
Various shallow finer-textured soils: 1*d*, 4*h*, 5*b*	Flood irrigation possible in some areas	Subject to advanced erosion	Adequate; the larger, even-surfaced drainage floors are particularly suitable for airstrips

TABLE 17 (*Continued*)

Characteristic Soils and Soil Associations	For Intensive Production from Irrigation or Water-spreading	Erosion Hazard	For Formed Road and Airstrip Construction
Shallow soils with subsoil pans: 6*a*, 6*d*	Unsuitable	Subject to water and wind erosion, giving rise to scalds	Unstable; require surfacing for improvement
Deeper soils with subsoil pans: 6*b*, 6*c*	Unsuitable	Subject to moderate and severe scalding	Unstable; require surfacing for improvement
Cracking clay soils: 7	Unsuitable	Stable	Require surfacing; present hazards as airstrips due to cavities
Saline sediments in salt pans	Unsuitable	Intractable	Unsuitable; dry crusts may be treacherous
Kopi dunes	Unsuitable	Stable owing to thin surface crusts	Unsuitable

(*e*) *Earthen Structures*

Suitability of the soils for formed road and airstrip construction is given in Table 17. Owing to their suitable proportions of sand and clay and their lack of sodium clay, red earths provide adequate formed dry-weather roads and airstrips in much of the area. Red clayey sands on sand plain, as distinct from loose sands, also have sufficient clay to form a stable track for light traffic. The least satisfactory road sections are those across certain trunk valleys, where unstable texture-contrast and other alkaline and saline soils are encountered, as well as some very sandy soils. Calcretes are used for road surfacing in these areas.

No earth tanks have been constructed because of the impracticability of excavating the hard-pan. Owing to its porous fabric, the hard-pan is apparently too permeable to function as a cistern without some form of sealing. However, the construction of earth tanks may be possible on saline alluvial plains with texture-contrast soils lacking hard-pan, particularly near drainage entrances to salt lakes.

(*f*) *Erosion Hazards*

The sands of the sand plain and dune fields are effectively fixed by vegetation, while many of the shallow soils are protected by stone pavements. The prominent coarse sand veneer on the red clayey sands on wanderrie banks also appears to provide protection against wind-blowing. Strong wind erosion is mainly confined to texture-contrast soils on flood-plains (soil association *6b*) and to shallow red earths on wanderrie flats (soil association *4h*). In the former, sand piles around the base of shrubs and forms low sand banks whilst the subsoil pan exposed by erosion forms hard scalds. On wanderrie flats, the shallow soil is further thinned by deflation of finer materials and by sand drift on to adjacent wanderrie banks. Pedestalling and destruction of the sparse vegetation may follow, and the surface becomes a scald, superficially masking hard-pan.

Severe water erosion occurs only in or near larger drainage channels. Elsewhere, the very gentle slopes are subject only to sheet run-off.

IV. Acknowledgment

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PART VII. VEGETATION OF THE WILUNA–MEEKATHARRA AREA

By N. H. SPECK*

I. INTRODUCTION

The area falls within the Eremean botanical province (Gardner 1942). Its vegetation has been described as mulga bush (Gardner 1942), as mulga scrub (Christian, Donald, and Perry 1960), and as arid scrub (Department of National Development 1955). The communities embrace woodlands, shrublands, and spinifex grasslands, with other grassland types of extremely local occurrence.

The upper layers of most communities are dominated by *Acacia* spp., the most common of which is *Acacia aneura*† or mulga. Eucalypts are comparatively unimportant. Two species occur as scattered trees in the spinifex sand plain; several mallee species occur with mulga in slightly favoured parts of the sand plain; another species locally dominates the kopi dunes; and two species form narrow fringing communities along drainage lines.

Most communities have well-developed shrub layers. *Eremophila*, of which there are about 100 species in the area, characterizes the shrub layer of most communities. Many of the *Eremophila* spp. are selective as to habitat and because of this indicator value, as well as their abundance, they have been freely used with the ubiquitous *Acacia aneura* in the naming of plant communities. Many other shrubs are present, including several *Cassia* spp., *Dodonaea* spp., and several of the family Malvaceae. Forming a part of this layer, yet somewhat distinct from it, is a group of plants which are not entirely woody and so fall midway between shrubs and forbs. These have been referred to in this paper as herbaceous shrubs.

Except for spinifex grasslands in the Salinaland plains, grasslands are not well developed. Other perennial grasses, including the two palatable species *Danthonia bipartita* and *Eragrostis lanipes*, characterize several important communities.

Seventy-five communities have been recognized and are briefly described. These communities are commonly associations or very closely related groups of associations which have been arranged in alliances and sub-alliances on the basis of their floristics. Because of the widespread dominance of the tree layer by *Acacia aneura*, it has been necessary in most cases also to use characteristic species of one or more of the other layers to define communities.

In general, there is a good correlation between the floristic groups and habitat. This has been brought out in Table 18, which summarizes the arrangement of alliances and sub-alliances and appropriately introduces the descriptions of the vegetation communities.

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† Common equivalents of botanical names are given in Appendix I.

TABLE 18

SUMMARY OF ARRANGEMENT OF ALLIANCES AND SUB-ALLIANCES AND CHARACTERISTICS OF COMMUNITIES

Alliance	Sub-alliance	Communities	Characteristics	Habitat
Acacia aneura	*Acacia aneura–Eremophila leucophylla*	1–5	Mulga communities characterized by edible shrubs and mostly by palatable perennial grasses	Wanderrie banks, deep red earths, and sand plain margins throughout the area but principally in west and centre
	Acacia aneura–Eremophila fraseri	6–9	Poor mulga communities characterized by inedible shrubs and paucity of palatable grasses	Shallow red earths on hard-pan on wanderrie flats and broad alluvial plains throughout the area
	Acacia aneura–A. tetragonophylla	10–14	Group of mulga communities characterized by curara (*Acacia tetragonophylla*)	Shallow red earths on hard-pan near drainage lines and on alluvial plains throughout the area.
	Acacia aneura–A. craspedocarpa	15–17	Mulga communities characterized by bowgada (*Acacia craspedocarpa*)	Deeper red earth soils in drainage tracts in centre and west of the area
	Acacia aneura–A. sclerosperma	18–20	Mulga communities characterized by calciphilous species	Calcrete platforms and other limestone areas
	Acacia aneura	21–38	A loosely knit group of mulga communities dominated by *Acacia aneura*	A wide range of habitats
	Acacia aneura–A. linophylla	39–42	Mulga communities characterized by *Acacia linophylla*	Rocky greenstone and sandstone hills throughout the area
	Acacia aneura–Callitris hugelii	43–44	Small, distinctive group of mulga communities characterized by cypress pine (*Callitris hugelii*)	Restricted to the rocky, yet sheltered environments of breakaways throughout the area

Eucalyptus kingsmillii–Acacia aneura		45–56	Hard spinifex ground storeys with upper storeys of a few shrubs, sparse eucalypts, scattered mallee, or dense mulga	Coarser-textured soils in the sand plain throughout the area
		57–59	Feathertop spinifex ground storeys with upper storeys of a few shrubs, sparse eucalypts, scattered mallee, or dense mulga	Deep, coarse-textured soils receiving run-on, throughout the area
Acacia aneura–Kochia pyramidata		60–69	Mostly halophytic shrublands with a very sparse or patchy mulga tree layer, characterized by bluebush, saltbush, and other halophytes	Saline alluvial plains throughout the area
Samphire		70	Samphire meadows with associated forbs	Salt lakes and their margins throughout the area
Fringing communities		71–75	A group of unrelated communities of varying structure and floristics	Fringing draining lines and lakes throughout the area

II. Vegetation Communities

(*a*) Acacia aneura *Alliance*

Within this alliance eight sub-alliances have been recognized.

(i) Acacia aneura–Eremophila leucophylla *Sub-alliance*.—This consists of a group of mulga communities characterized by the edible *Eremophila leucophylla* complex* and in most cases also by the palatable perennial grasses *Danthonia bipartita* and *Eragrostis lanipes*. It occurs on wanderrie banks, in areas of deep red earths, and on sand plain margins.

(1) Acacia aneura–Eremophila leucophylla–Eragrostis lanipes *Community*.—This is an open mulga (*Acacia aneura*) woodland community with trees 10–12 ft high, which consistently dominates wanderrie banks, slight depressions with run-on, and some vegetation groves in Belele, Ero, Millrose, and Lorna land systems. The community is characterized by edible shrubs (*Eremophila leucophylla*) and palatable perennial grasses (*Eragrostis lanipes*, *Danthonia bipartita*). Several other species of *Eremophila* may be present in the shrub layer. Other perennial grasses (*Eragrostis eriopoda, Eriachne helmsii*) may be present, and there is commonly a variable layer of short annual grasses (*Aristida arenaria*, *Eriachne pulchella*) and, following good winter rains, an abundance of forbs, including succulents (*Calandrinia* spp.).

(2) Acacia aneura–Eremophila *Spp*.–Eragrostis lanipes *Community*.—This open mulga community, composed of several very closely related associations, differs from (1) mainly in that it lacks edible shrubs (*Eremophila leucophylla*). The shrub layer is composed of assorted *Eremophila* spp. (*E. maitlandii*, *E. macmillaniana*, *E. spathulata*, *E. fraseri*) and the ground storey is characterized by the same palatable perennial grasses as in (1). It is mainly limited to Belele land system.

(3) Acacia aneura–Eremophila leucophylla–Danthonia bipartita *Community*.—This community occurs in two forms: firstly, it occurs as moderately dense mulga woodland on gently rounded hill crests, sand plain, and sand banks in Trennaman, Kalli, Lorna, and Jundee land systems; secondly, it forms minor groves on deep red earths on the alluvial fans and zones of sheet-flow in Yanganoo, Dural, Diamond, Kalyaltcha, and Treuer land systems.

The community is characterized by the prominence of edible shrubs (*Eremophila leucophylla*) and of the palatable perennial grass *Danthonia bipartita*. There are commonly other associated perennial grasses (*Eragrostis eriopoda* and *Eriachne helmsii*) and even patches of spinifex (*Triodia basedowii*) in the eastern part of its distribution. Short annual grasses (*Aristida arenaria*, *Eriachne pulchella*, and *Eragrostis dielsii*) and forbs are consistently present but vary in density from season to season.

(4) Acacia aneura–Eremophila leucophylla *Community*.—This community is closely related to (3), but differs from it principally in that it lacks the palatable perennial grass *Danthonia bipartita*. It occurs on dunes and sand banks in Carnegie and Wadjinyanda land systems in the east of the survey area, on parts of the sand plain of Kalli land system, and on the stable interfluves and plains of Killara, Violet, Jundee, and Windidda land systems.

* Comprising *E. leucophylla*, *E. xanthotricha*, and *E. hastieana*. Further references to *E. leucophylla* include this closely related group of species.

(5) Acacia aneura–Eremophila leucophylla–Plectrachne melvillei *Community*.—This is a mulga community with trees 10–15 ft high, varying from open to dense mulga woodland or, in some cases, in diffuse groves. The shrub layer is dominated chiefly by the edible *Eremophila leucophylla*. The community has close affinities with (1)–(4) but differs in that its grass layers are dominated by feathertop spinifex (*Plectrachne melvillei*), although it may also have varying amounts of other perennials (*Danthonia bipartita*, *Eragrostis lanipes*, *E. eriopoda*, and *Eriachne helmsii*). Forbs and short annual grasses are present but vary in amount with the season.

It is an important community of the sand plain and dunes of the Murchison plains (Kalli land system), on sandy banks in Trennaman and Barwidgee land systems in the Salinaland plains, and in Yanganoo, Dural, and Fisher land systems.

(ii) Acacia aneura–Eremophila fraseri *Sub-alliance*.—This group of communities is characterized by the predominance of the inedible shrub *Eremophila fraseri* (poverty bush). It is widely distributed on shallow red earths on hard-pan or wanderrie flats and broad flood-plains and is commonly very degraded.

(6) Acacia aneura–Eremophila fraseri *Community*.—This widespread community consists of an upper layer of very open, stunted mulga, and of sparse unpalatable shrubs (*Eremophila fraseri* and in some cases *Cassia* spp.). Perennial grasses are mostly absent, but there are sparse short annual grasses (*Aristida arenaria*, *Eragrostis dielsii*, and *Eriachne pulchella*). Forbs also are generally sparse but there may be a seasonal abundance of prostrate succulents (*Calandrinia* spp.).

This community is dominant on shallow red earths on hard-pan on wanderrie flats and in intergroves in Belele, Trennaman, and Millrose land systems, on the alluvial plains of Yandil, Mindura, and Cole land systems, and on the shallow stony soils on hills and slopes of Edenhope and Sherwood land systems.

(7) *Gidgee*–Acacia aneura–Eremophila fraseri *Community*.—This is an open mulga woodland with taller gidgee trees 15–20 ft high, in some places forming an indistinct grove pattern. The shrub layer is open and consists commonly of *Eremophila maitlandii*, *E. fraseri*, *E. leucophylla*, and *Scaevola spinescens*, most of which are inedible. Perennial grasses are absent, but there are numerous chenopods (*Kochia georgei*, *K. triptera*, and *Bassia* spp.) and other forbs (*Ptilotus exaltatus*) and sparse short annual grass (*Aristida arenaria*). The recorded distribution is limited to lower slopes in Wiluna land system.

(8) *Gidgee*–Acacia aneura–Eremophila fraseri–Danthonia bipartita *Community*.—This community commonly forms diffuse groves of mulga 10–12 ft high, with scattered higher gidgee trees. *Eremophila fraseri* and *E. latrobei* characterize the moderately open shrub layer, and *Danthonia bipartita*, *Eragrostis eriopoda*, numerous forbs (*Ptilotus* spp.), and the annual *Aristida arenaria* are typical of the ground layers. It is largely limited to shallow soils on the stripped crests and slopes of Fisher land system.

(9) Acacia sibirica–Eremophila fraseri *Community*.—The fastigiate form of *Acacia sibirica*, with sparse shrubs (*Eremophila fraseri*) and a few forbs (*Ptilotus* spp.), forms a very distinctive community limited to rocky ridges in Weld land system.

(iii) Acacia aneura–A. tetragonophylla *Sub-alliance.*—This is a group of mulga communities characterized by *Acacia tetragonophylla* occurring either as a tree or tall shrub. It typically occurs in broad flood-plains and along drainage lines throughout the area, but is very characteristic of Yandil land system.

(10) Acacia aneura–A. tetragonophylla *Community.*—Although variable, this is generally a very open, depauperate community. Where it forms a fringing community along drainage lines it is more vigorous and is richer in shrubs and grasses. The upper storey of mulga and curara is commonly stunted and seldom exceeds 6–10 ft in height. Shrubs, if present, are sparse and inedible. The most common shrub is *Eremophila fraseri*, but other *Eremophila* spp. (*E. margarethae*, *E. georgei*) and *Cassia* spp. may be present in small numbers. In many cases the only plants in this layer are herbaceous shrubs, *Solanum ellipticum* and *Ptilotus obovatus.* The characteristic grasses are the short annuals *Aristida arenaria*, *Eragrostis dielsii*, and *Eriachne pulchella.* Small chenopods, mostly *Bassia* spp., succulents, and composites may also be present in this layer, and there may be a seasonal abundance of forbs, mostly *Ptilotus* spp. and composites.

The community is typical of shallow red earths on hard-pan in the alluvial plains of Yandil land system, and is widespread on similar land units elsewhere. It is also extremely widespread as an intergrove community in Sodary, Treuer, Waguin, Ero, Yanganoo, Wongawol, and Dural land systems.

(11) *Gidgee*–Acacia aneura–A. tetragonophylla *Community.*—Floristically this community very closely resembles (10), but differs from it in the presence of a taller layer of scattered gidgee trees up to 20 ft in height and in the greater number and variety of shrubs. It is also rarely as depauperate as (10). It occurs on slightly deeper soils on alluvial plains and fans in Cunyu, Jundee, Sodary, Wiluna, and Yandil land systems.

(12) Hakea lorea–Acacia tetragonophylla–Triodia basedowii *Community.*—This community commonly consists of a moderately dense spinifex layer (*Triodia basedowii*), with *Danthonia bipartita* and sparse forbs occupying the spaces between spinifex clumps. The tree layer (*Hakea lorea* and *Acacia tetragonophylla*) is very open and shrubs (*Eremophila fraseri* and *E. maitlandii*) are few. This community is restricted to broad sandy tracts in Yandil land system in the east-central part of the area. Further west, similar habitats are occupied by wanderrie-type communities (1) and (2).

(13) Grevillea striata–Acacia aneura–A. tetragonophylla *Community.*—In this open woodland community, *Grevillea striata*, gidgee, and *Hakea lorea* form a very open tree layer 15–20 ft high. *Acacia aneura* as a low tree, 10–12 ft high, and *A. tetragonophylla* as a tall shrub tend to form clumps. *Eremophila fraseri* and several *Cassia* spp. are the main elements of an open shrub layer. Perennial grasses are commonly very sparse or absent, and the ground storey consists of the seasonal crop of forbs and short annual grasses (*Aristida arenaria*, *Eragrostis dielsii*). Except for minor occurrences on drainage floors in Norie land system, this community is restricted to alluvial floors in Cunyu land system. Where these locally grade into saline alluvial plains, there may also be a number of halophytic species in the lower layers of the community.

(14) Acacia tetragonophylla–A. burkittii–Atriplex rhagodioides–Rhagodia *Sp. Community*.—This community appears to have suffered considerable and general degradation. It probably once carried a much denser tree layer and more palatable saltbush and bluebush. It now consists of a very sparse upper tree layer (*Acacia burkittii*), a sparse tall shrub layer (*A. tetragonophylla*), and an open shrub layer, mostly of halophytic or at least salt-tolerant species (*Rhagodia* sp., *Atriplex rhagodioides*, *Eremophila laanii*, *E. macmillaniana*, and *Cassia sturtii*). Perennial grasses are absent and short annual grasses are limited to *Eragrostis dielsii*. Forbs (mainly *Ptilotus macrocephalus*), chenopods (*Atriplex inflata*, *Chenopodium* spp., and *Salsola kali*), and succulents (*Calandrinia* spp.) are abundant in season. The community is limited to saline or slightly saline alluvial flats and flood-plains in Beringarra, Ero, and Koonmarra land systems.

(iv) Acacia aneura–A. craspedocarpa *Sub-alliance*.—*Acacia craspedocarpa* (bowgada bush) characterizes a group of communities commonly occurring near drainage lines, particularly in the centre and west of the area.

(15) Acacia aneura–A. craspedocarpa *Community*.—This community consists of a moderately dense tree layer 15–20 ft high (*Acacia aneura*), a dense tall shrub layer 6–10 ft high (*A. craspedocarpa* and, less commonly, *A. tetragonophylla*), and sparse low shrubs (*Eremophila fraseri*, *E. platycalyx*, *Rhagodia* sp., and *Cassia* spp.). Grasses are limited to short annuals (*Aristida arenaria*, *Eriachne pulchella*) in more open patches. Forbs and annual chenopods are sparse, even in favourable seasons. This widely distributed community is found in more favoured tracts on the margins of drainage channels.

(16) Acacia aneura–A. craspedocarpa–Danthonia bipartita *Community*.—This is closely related to (15) and is another community of the favoured habitats, but the tree layer (*Acacia aneura*) is dense and the tall shrub layer (*A. craspedocarpa* and *A. tetragonophylla*) is more open. The low shrub layer is dominated by the edible *Eremophila leucophylla*, and forbs and annual grasses are more abundant than in (15). This community is known to be characteristic of zones of concentrated run-on in Yanganoo land system, but it probably has a wider distribution.

(17) Acacia aneura–A. craspedocarpa–Eremophila maculata *Community*.—This community has a dense *Acacia aneura* tree layer 10–12 ft high and a tall shrub layer of *A. craspedocarpa* and *A. tetragonophylla*. *Eremophila maculata* and some *Sida* spp. characterize the open low shrub layer. The few annual grasses and forbs (*Ptilotus exaltatus*, *P. roei*, and *Zygophyllum* spp.) are not abundant. It is restricted to saline alluvial plains in Cunyu land system.

(v) Acacia aneura–A. sclerosperma *Sub-alliance*.—Associated with calcrete platforms and other limestone areas is a group of mulga communities in which upper-storey dominance is shared by other calciphilous acacia species, or in one case by a eucalypt, but which have a calciphilous understorey in common.

(18) Acacia aneura–A. sclerosperma *Community*.—Calciphilous plants characterize this community. *Acacia aneura* and *A. sclerosperma* with scattered *Condonocarpus continifolius* form an open tree layer 10–15 ft high; *A. sclerosperma*, *A. tetragonophylla*, *A. victoriae*, *Scaevola spinescens*, *Eremophila duttonii*, *E. pantoni*, and *E. longifolia* are commonly found in an open tall shrub layer; the low shrub

layer is sparser and consists of *Eremophila leucophylla*, *Cassia* spp., and *Ptilotus obovatus*. Perennial grasses are absent, but there is a dense layer of forbs and short annual grasses (*Helipterum sterilescens, Enneapogon caerulescens, Bassia paradoxa* and other *Bassia* spp., *Zygophyllum* spp., and *Calandrinia* spp.).

The community is found on calcareous earths on calcrete platforms and limestone outcrop bands in Cunyu, Mileura, and Windidda land systems. In modified form, it also occurs on alluvial fans with texture-contrast soils in Boondin and Wiluna land systems.

(19) Acacia inophloia *Community*.—The upper layer of this community consists of dense tall shrubs of *Acacia inophloia* with other scattered *Acacia* spp. The sparse low shrub layer contains only *Ptilotus obovatus*. Perennial grasses are absent, and the ground layer consists of calciphilous forbs and short annual grasses as in (18). It occurs on limestone ridges in Windidda land system and more rarely on calcrete platforms of Cunyu land system.

(20) Eucalyptus striaticalyx *Community*.—This is an open woodland community with *Eucalyptus striaticalyx* forming an upper tree layer 20–25 ft high. *Acacia aneura* may be present as a very sparse lower tree layer. The shrub layer is commonly sparse and variable and includes *Cratystylis subspinescens, Plagianthus helmsii*, and *Cassia* spp. Where the tree layer is dense, shrubs may be absent. The ground storey is markedly calciphilous and is similar to that described for (18). The community occurs in patches on calcrete tables in Cunyu and Mileura land systems and dominates kopi dunes in Carnegie land system.

(vi) Acacia aneura *Sub-alliance*.—This is a loosely knit group of mulga communities with various characteristic plants occupying a wide range of habitats.

(21) Acacia aneura *Community*.—This is characterized by a sparse upper shrub layer of stunted *Acacia aneura*, 6–8 ft high. The low shrub layer, if present, is limited to scattered *Cassia* spp., *Ptilotus obovatus*, and *Solanum ellipticum*. The ground storey consists of a few forbs (*Ptilotus* spp. or *Bassia* spp.), sparse short annual grasses (*Aristida arenaria, Eragrostis dielsii*), and prostrate succulents (*Calandrinia* spp.). It is commonly a very degraded community, and could locally be a degenerate form of another association. The community has been recorded extensively on shallow soils on alluvial plains, on shallow stony soils on hills and slopes, and as an intergrove community in Wadjinyanda and Jundee land systems.

(22) Acacia aneura–Eremophila macmillaniana *Community*.—This community is characterized by a shrub layer dominated by the inedible *Eremophila macmillaniana*. *Acacia aneura* may form a well-developed tree layer, or may be extremely sparse. In many places this mulga was partly or wholly dead. There is a low shrub layer consisting of sparse inedible species (*Cassia desolata, Eremophila fraseri*) and the ground layer is limited to sparse short annual grass (*Aristida arenaria*), a few forbs, and succulents.

This community is limited to the shallow soils of stony plains and ridges, and to wanderrie flats and sandy banks in Yandil and Belele land systems, mainly in the Murchison plains.

(23) Acacia aneura–Eremophila spathulata *Community*.—This community is similar to (22). The upper layer of *Acacia aneura* 8–12 ft high is very open, and may have occasional taller gidgee trees. The shrub layer is characterized by the stiff-

leaved, inedible *Eremophila spathulata*, although the edible *E. leucophylla* may be present. The herbaceous layer is limited to forbs, a few annual chenopods, and sparse annual grass (*Aristida arenaria*). It occurs on drainage floors and alluvial fans in Koonmarra and Mindura land systems, on hills in Wiluna land system, and probably in groves and intergroves in Yarrameedie land system.

(24) Acacia aneura–Eremophila forrestii *Community*.—This community has a dense mulga layer 10–12 ft high, with sparse scattered gidgee trees rising above this level. The sparse shrub layer is dominated by *Eremophila forrestii* and also includes *Cassia sturtii*, *Eremophila latrobei*, *Sida* sp., and *Hibiscus* sp. Grasses are represented by sparse *Eriachne pulchella* and forbs are also few. The community occurs upon lateritic hill-cappings in Wiluna land system.

(25) Acacia aneura–Eremophila platycalyx *Community*.—This community contains a dense mulga layer 10–15 ft high, an open layer of tall shrubs (*Eremophila platycalyx*), and sparse low shrubs (*Rhagodia* sp. and *Eremophila latrobei*). The lower layers consist of a few herbaceous shrubs (*Ptilotus obovatus*, *Solanum ellipticum*), forbs (*Ptilotus exaltatus*, *Kochia* spp., and composites), and a short annual grass (*Aristida arenaria*). The community occurs on drainage floors in Sodary land system.

(26) Acacia quadrimarginea–Eremophila platycalyx *Community*.—This community contains isolated bushy trees 10–12 ft high (*Acacia quadrimarginea*), a discontinuous shrub layer (*Eremophila platycalyx*, *Dodonaea* spp., and *Cassia* spp.), and clumps of perennial grasses (*Cymbopogon exaltatus* and *Plectrachne melvillei*). *Ptilotus obovatus*, *P. helipteroides*, and succulents (*Calandrinia* spp.) are also present, whilst a fern (*Cheilanthes* sp.) is common in shallow rock crevices. The short annual grasses *Aristida arenaria* and *Eriachne pulchella* are abundant. It occurs on granite hills and outcrops in Sherwood, Mindura, Waguin, and Norie land systems and also in Yanganoo land system.

(27) Acacia aneura–Eremophila foliosissima *Community*.—This community commonly forms groves of dense *Acacia aneura*, 10–12 ft high, and dense shrubs 3–4 ft high dominated by *Eremophila foliosissima*. The edible *Eremophila leucophylla* and several other shrubs may also be present. The density of the upper layers limits the herbaceous plants to a few forbs and some *Danthonia bipartita*, and *Danthonia* becomes more abundant in the more open intergroves.

The community is widespread in the centre and east of the area, on zones subject to sheet-flow, on lower slopes, and in drainage floors.

(28) Acacia aneura–Eremophila gilesii *Community*.—Commonly, this community forms a groved or diffusely groved pattern. The tree layer of *Acacia aneura* and several other *Acacia* spp. (*A. tetragonophylla*, *A. linophylla*) may have scattered taller gidgee. The shrub layer is commonly moderately dense and is characterized by *Eremophila gilesii*, although the edible *E. leucophylla* may be present. The most common perennial grasses are *Eriachne helmsii* and/or *Eragrostis eriopoda*, but *Danthonia bipartita* is also a minor element in this layer. Short annual grasses are sparse, but forbs (*Ptilotus macrocephalus*, *P. exaltatus*, and composites) produce patches of abundant herbage in favourable seasons. Minor clumps of spinifex (*Plectrachne melvillei* and *Triodia basedowii*) may occur.

The community is widespread in groves and on lower slopes and alluvial plains.

(29) Acacia aneura–Eremophila cuneifolia *Community*.—This community consists of open low mulga 6–10 ft high, a very open shrub layer (*Eremophila cuneifolia* and scattered *Cassia* spp. with sparse *Ptilotus obovatus* and *Solanum ellipticum*), and a short grass layer of *Aristida arenaria*. It occurs on slopes and drainage floors in Boondin, Doman, Kalyaltcha, and Lynne land systems.

(30) Acacia aneura–Eremophila margarethae *Community*.—This community typically has an open to moderately dense mulga layer with scattered taller gidgee. The shrub layer is usually moderately dense and is characterized by *Eremophila margarethae*, although many other species may be present (e.g. *Scaevola spinescens*, *Tribulus platypterum*, *Cassia chatelainiana*, and *Eremophila latrobei*). Perennial grasses (*Eriachne mucronata*, *Eragrostis eriopoda*), forbs (*Ptilotus* spp.), and short annual grass (*Aristida arenaria*) are sparse. It is widespread in the east of the area, particularly on summits and hill slopes in Glengarry and probably in Princess, Boondin, Dural, Sodary, and Treuer land systems, on sand banks in Cole land system, and in groves in Trennaman, Cole, Lorna, and Yanganoo land systems.

(31) Acacia aneura–Eremophila compacta *Community*.—This contains a dense layer, 8–10 ft high, of *Acacia aneura* and *A. linophylla*. *Eremophila compacta* characterizes the shrub layer, but *E. leucophylla*, *Ptilotus obovatus*, and *Solanum ellipticum* may also be present. Grasses are limited to clumps of *Plectrachne melvillei* or *Triodia basedowii* and to sparse short annual grasses (*Aristida arenaria*). Forbs are sparse.

The community is found on lateritic hill-cappings and on hill slopes in Wiluna and Glengarry, and probably in Princess and Treuer land systems.

(32) Acacia aneura–Eremophila latrobei *Community*.—This community consists of a tree layer of *Acacia aneura*, 10–15 ft high, with scattered taller gidgee trees. Although *Eremophila latrobei* is everywhere characteristic of the shrub layer, a wide range of other shrubs may be present (*Eremophila fraseri*, *E. forrestii*, *E. metallicorum*, *Cassia* spp., *Ptilotus obovatus*, *Dodonaea* spp.). Perennial grasses are sparse and variable. The most usual is *Eriachne mucronata*, but others (*Eragrostis eriopoda*, *Eriachne helmsii*, or clumps of *Triodia basedowii*) may be present. Forbs and short annual grasses occur sparsely. The community is characteristic of crests, summits, ridges, and stripped dissected surfaces in Boondin, Cole, Dural, Gabanintha, Sodary, Treuer, Tooloo, and Yelma land systems.

(33) Acacia grasbyi–Eremophila latrobei *Community*.—Very closely related to (32) is another community which differs mainly in that dominance in the tall shrub layers is shared by *Acacia grasbyi*. It characteristically occupies similar but more rocky crests, summits, ridges, and stripped surfaces in Boondin, Dural, Doman, Glengarry, Lynne, and Sodary land systems.

(34) Acacia grasbyi–Plectrachne melvillei *Community*.—This community is closely related to (32) and (33), but differs in the almost complete absence of tree layers and in the dominance of the ground storey by feathertop spinifex (*Plectrachne melvillei*). It consists of a moderately dense, tall shrub layer (*Acacia grasbyi*), 6–8 ft high, with scattered taller trees of *Acacia aneura* and gidgee. There is an open low shrub layer (*Eremophila latrobei*, *E. margarethae*, and *E. metallicorum*). Perennial

grasses are limited to moderately dense tussocks of *Plectrachne melvillei*, with sparse short annual grasses and forbs between them. This community is found on rocky summits and on stable crests in Wiluna, Killara, Sodary, and Gabanintha land systems.

(35) Acacia aneura–A. burkittii *Community*.—*Acacia burkittii* and *A. aneura* 15–20 ft high dominate the tree layer in varying proportions. As with most communities occurring along drainage lines in the area, the under-storey is variable. The edible shrub *Eremophila leucophylla* may be present, and also *Eremophila latrobei*, *Rhagodia* sp., and *Cassia* spp. Perennial grasses are sparse, but small patches of *Themeda australis* are common. Forbs, chenopods (*Bassia* spp.), and short annual grasses vary with the season. The community is distributed along channels and drainage floors in Sherwood, Glengarry, Mindura, and probably in Princess, Treuer, Wadjinyanda, Sodary, and Yelma land systems.

(36) Acacia aneura–Eucalyptus carnei *Community*.—This community consists of open small trees (*Acacia aneura* and gidgee) with clumps of mallee (*Eucalyptus carnei*) and with tall shrubs characterized by *Dodonaea* sp., *Eremophila latrobei*, and *Cassia eremophila*. The low shrubs, so distinctive of (43) and (44) on breakaways, are absent from this community. Grasses are limited to sparse *Eriachne mucronata*, but forbs (*Ptilotus exaltatus*, *Kochia* spp., and *Bassia* spp.) and herbaceous shrubs (*Ptilotus obovatus* and *Solanum ellipticum*) are moderately abundant.

This community has been seen only on breakaways in Sodary land system.

(37) Acacia aneura–Eremophila miniata *Community*.—This community has affinities with (38). There is a variable but typically moderately dense tree layer 10–15 ft high (*Acacia aneura*, *Acacia* sp., and *Grevillea* sp.). The characteristic feature is the tall shrub layer of *Eremophila miniata* with scattered *Melaleuca* sp., *Acacia* sp., and *Grevillea* sp. The low shrub layer has numerous halophytic elements (*Rhagodia* sp., *Scaevola spinescens*, *Frankenia* sp., and *Atriplex paludosa*). The grasses are varied, but consist chiefly of *Paractaenum novae-hollandiae*, *Eragrostis lanipes*, *E. dielsii*, *Aristida arenaria*, *Eriachne aristidea*, and scattered clumps of *Triodia basedowii*. Herbaceous shrubs (*Ptilotus obovatus*) and forbs (*P. alopecuroides* and *Salsola kali*) are numerous following rain, and succulents (*Carpobrotus* sp. and *Calandrinia* spp.) are also commonly present. The community is limited to dunes in Carnegie and Barwidgee land systems.

(38) Acacia aneura–Melaleuca *Spp. Community*.—On dunes next to salt lakes in Carnegie land system is a community with an open tree layer of the silver-leafed form of *Acacia aneura*, 10–12 ft high. Spreading, bushy *Melaleuca microphylla* and *M. uncinata* form a well-developed tall shrub layer, but the low shrubs are few (e.g. *Kochia pyramidata*, *Olearia subspicata*). Grasses are limited to scattered clumps of *Paractaenum novae-hollandiae* and *Tragus australianus*, whilst forbs are sparse.

(vii) Acacia aneura–A. linophylla *Sub-alliance*.—This group of communities occurs on rocky hills and slopes.

(39) Acacia aneura–A. linophylla *Community*.—The tree layer, 10–15 ft high, of *Acacia aneura* varies from open to moderately dense with very sparse scattered groves. The community is characterized by the moderately dense tall shrub layer with *Acacia linophylla*. The sparse low shrub layer commonly consists of the edible *Eremophila leucophylla* and scattered *E. latrobei*, *E. exilifolia*, *Calytrix* sp., *Ptilotus*

obovatus, *Dodonaea* spp., and *Cassia* spp. Perennial grasses (*Eriachne helmsii*, *E. mucronata*, *Eragrostis eriopoda*, *E. lanipes*, and *Danthonia bipartita*) are sparse and patchy. Short annual grasses (*Aristida arenaria*) and forbs, including succulents (*Calandrinia* spp.), are constant but sparse. The community is restricted to the shallow stony soils on hills, slopes, and plains of Gabanintha, Weld, and Edenhope land systems.

(40) Acacia aneura–A. linophylla–Ptilotus rotundifolius *Community*.—Floristically, this community is closely related to (39), but the tree layer and tall shrub layer are more open and stunted, whilst the sparse low shrub layer is dominated by *Ptilotus rotundifolius*, which is an extremely attractive shrub when in flower. Perennial grasses are extremely sparse or absent, and the ground storey is limited to sparse forbs and short annual grasses. This community has been recorded on rocky ridges in Edenhope and Mindura land systems.

(41) Acacia linophylla–Eriachne mucronata *Community*.—This consists of a dense tall shrub layer 6–8 ft high of *Acacia linophylla*, a moderately dense low shrub layer (*Eremophila latrobei* and *E. metallicorum*), and grasses characterized by *Eriachne mucronata*, with *Eragrostis eriopoda* and patches of *Plectrachne melvillei* locally. It was observed on stripped interfluves in Violet land system. This community has affinities with (32), but differs in the absence of *Acacia aneura*.

(42) Acacia linophylla–Eremophila compacta *Community*.—This community differs from (31) mainly in the absence of an *Acacia aneura* tree layer, which is here replaced by a well-developed tall shrub layer of *Acacia linophylla*. Like (31), it is found on rocky crests and slopes in Dural land system.

(viii) Acacia aneura–Callitris hugelii *Sub-alliance*.—This small but distinctive group of communities is restricted to the environs of the lateritic breakaways scattered through the area, but is best developed in the centre and west, where it is possibly favoured by greater winter rainfall.

(43) Acacia aneura–Callitris hugelii *Community*.—This community is characterized by an upper tree storey (20–30 ft) of *Callitris hugelii* (cypress pine) which in this area is restricted to the rocky, yet sheltered environment of the breakaways. The lower trees vary in type and density. Typically, they consist of patches of *Acacia aneura* and other *Acacia* species. The shrubs are distinctive, and such species as *Eremophila latrobei*, *E. ramosissima*, and *Dodonaea* spp. form an open layer 6–8 ft high. The low shrub layer, 2–4 ft high, is similar to that in (44). Grasses are either extremely sparse or absent. This community is limited to breakaway zones in Kalli, Norie, Sherwood, and Waguin land systems.

(44) Acacia aneura–Eriostemon *Spp*.–Calytrix *Spp*. *Community*.—This extremely interesting community is restricted to the rocky environment of the breakaway and the stripped zone above. The presence of representatives of the families Rutaceae and Stylidiaceae suggests that these special habitats are possibly refuges of a once more extensive south-western flora.

Acacia aneura is sparse and is reduced to a tall shrub. The tall shrub layer is always open and is characterized by several species of Myrtaceae and by *Eremophila latrobei*, *Dodonaea* spp., and *Acacia* sp. The low shrub layer is extremely interesting because of the south-western elements *Eriostemon brucei*, *E. difformis*, *Philotheca* *miniata, Calytrix* spp., *Mirbelia microphylla, Prostanthera* sp., *Sida* sp., and *Ptilotus obovatus.* Grasses are sparse and are limited to short annuals (*Eriachne pulchella, Enneapogon* sp.). Forbs are not abundant and are limited to *Anguillaria* sp. and *Stylidium* sp.

This community is restricted to Kalli, Norie, Sherwood, and Waguin land systems.

(*b*) Eucalyptus kingsmillii–Acacia aneura *Alliance*

Spinifex is here the characteristic plant and in most cases forms a moderately dense grass layer. In communities (45)–(56) two species of hard spinifex are represented (a third species occurs in community (61) in another alliance). In communities (57)–(59) feathertop spinifex dominates the grass layers. The upper storeys range from sparse eucalypt trees to scattered mallee or moderately dense mulga.

(45) Eucalyptus kingsmillii–Acacia aneura–Triodia concinna *Community.*—This community consists of closely spaced spinifex clumps, giving the appearance of an almost complete grass cover about 3 ft high. Scattered throughout is a patchy tree layer of *Acacia aneura* 10–12 ft high, with an occasional clump of mallee (*Eucalyptus kingsmillii*). Low shrubs (*Eremophila leucophylla* and *Acacia* sp.) are sparse. In the spaces between the spinifex are clumps of other grasses (*Amphipogon caricinus, Danthonia bipartita,* and *Eragrostis eriopoda*). Forbs and herbaceous shrubs are sparse, except as a response to rain following a fire, when they become abundant.

This community has only been recorded from sand plains of the Bullimore land system along the old railway line west of Wiluna.

(46) Acacia aneura–Triodia concinna *Community.*—This community is similar to (45) except that it lacks the clumps of mallee and that it has a denser tree layer (*Acacia aneura*). *Danthonia bipartita* and *Amphipogon caricinus* are plentiful between the spinifex clumps. The community occupies areas with significant amounts of run-on in Bullimore land system along the railway west of Wiluna.

(47) Acacia aneura–A. adsurgens–Triodia basedowii *Community.*—This community consists of a moderately dense cover of spinifex clumps about 3 ft high. The tree layer (*Acacia aneura*) about 10–12 ft high is open, but there is a moderately dense lower layer of smaller trees or tall shrubs 6–10 ft high (*A. adsurgens*). Other shrubs, particularly *Grevillea* sp., may occur sparsely. The spaces between the spinifex clumps are sparsely occupied by other grasses such as *Danthonia bipartita* and by annuals, chiefly composites.

This community commonly occupies sand plain with significant amounts of run-on in Bullimore and Heppingstone land systems.

(48) Eucalyptus dichromophloia–Acacia adsurgens–Triodia basedowii *Community.*—This community consists of dense spinifex (*Triodia basedowii*) and of numerous tall and low shrubs (*Acacia adsurgens, Hakea* spp., *Grevillea* spp., Myrtaceae species, and *Calothamnus* sp.). *Acacia adsurgens,* although irregular in distribution, tends to dominate the tall shrub layer. *Eucalyptus dichromophloia,* a tree 20–30 ft high, forms a very sparse upper storey. Herbaceous shrubs and forbs (*Keraudrenia integrifolia, Brachysema chambersii, Newcastlia cephalantha, Bonamia rosea, Dicra-*

stylis flexuosa, *Kennedia prorepens*, and numerous composites) are common following a burn. This community occurs throughout the sand plain of Bullimore and Cole land systems and locally on dunes in Heppingstone land system.

(49) Eucalyptus kingsmillii–Acacia adsurgens–Triodia basedowii *Community*.—This is an open spinifex community with scattered clumps of mallee (*Eucalyptus kingsmillii*) 15–20 ft high, sparse tall shrubs (*Acacia adsurgens* and *Grevillea juncifolia*), and a very open low shrub layer, mostly of species of Myrtaceae and Solanaceae and of *Eremophila leucophylla*. Other grasses (*Danthonia bipartita*, *Plagiosetum refractum*, and *Eragrostis eriopoda*) are present in minor degree. Forbs, particularly composites, are numerous following rain. This mallee–spinifex community is typical of sand plain with slight run-on in Bullimore land system.

(50) Eucalyptus kingsmillii–Acacia *Sp*. (*Speck* 1316)–Triodia basedowii *Community*.—This differs from (49) mainly in its tall shrubs, which include irregularly-scattered *Acacia* sp., *Hakea lorea*, *Calothamnus chrysantherus*, and *Duboisia hopwoodii*. It has been found on sand plain with slight run-on in Bullimore land system, and probably occurs in similar situations in Lorna, Waguin, and Yelma land systems. Modified forms of this community, in which mallee may be sparse or absent, extend into the areas down-slope from breakaways (unit 2 of Bullimore land system).

(51) Eucalyptus kingsmillii–Acacia aneura–Triodia basedowii *Community*.—This community closely resembles (45), but with *Triodia basedowii* instead of *T. concinna*. It is much more extensive than (45) and has been recorded in sand plain with run-on and in dissected tracts in Bullimore, Lorna, Waguin, and Millrose land systems.

(52) Hakea *Spp*.–Grevillea *Spp*.–Triodia basedowii *Community*.—This could be considered as a number of closely related associations which have the characteristic spinifex (*Triodia basedowii*) and other ground-storey species in common but differ mainly in the tall shrub species, which appear to have a fortuitous distribution. It differs from the other sand plain communities in the almost complete absence of mallee and *Acacia aneura*. The upper layer consists of tall shrubs 6–10 ft high (*Hakea multilineata*, *H. rhombalis*, *H. lorea*, *Grevillea juncifolia*, *G. pinifolia*, *Grevillea* spp., and *Acacia* spp.). The low shrub layer is also variable and may be related to the burn patterns which may be seen throughout the sand plains. Following burning, there is an extremely rich response of small shrubs, herbaceous shrubs, and forbs, principally in the families Myrtaceae, Verbenaceae, Goodeniaceae, Brunoniaceae, and Compositae. This community occurs throughout the open sand plain and dune fields of Bullimore, Heppingstone, Lorna, Millrose, Waguin, and Yelma land systems.

(53) Eucalyptus gongylocarpa–Triodia basedowii *Community*.—This community and (48) are the only spinifex communities in which the eucalypt of the sparse upper storey is a tree and not a mallee. The other layers are similar to those in (49), (50), and (52). Recorded distribution is limited to Bullimore land system, north-east of Millrose homestead.

(54) Acacia aneura–A. linophylla–Triodia basedowii *Community*.—This has a dense low tree layer (*Acacia aneura*) 10–12 ft high, with scattered taller gidgee. The tall shrub layer is characterized by *Acacia linophylla* and the edible *Eremophila leucophylla* is abundant in the low shrub layer. Although *Triodia basedowii* is prominent in the ground storeys, it shares dominance with several other perennial grasses includ-

ing *Eriachne helmsii*, *Eragrostis eriopoda*, and also the palatable *E. lanipes* and *Danthonia bipartita*. The community has been recorded on sand plain with significant run-on in Bullimore land system, in narrow dune swales in Heppingstone land system, and on stable interfluves in Violet land system.

(55) Eucalyptus oleosa–E. lucasii–Acacia aneura–Triodia basedowii *Community*.—This community has a dense low tree layer of *Acacia aneura* with scattered clumps of mallee (*Eucalyptus oleosa* and *E. lucasii*). Although there is considerable mixing of these two, the mallee tends to dominate the rises and the mulga the hollows. *Eremophila decipiens* and *Cassia eremophila* form a sparse shrub layer. *Triodia basedowii* and *Plectrachne melvillei* are co-dominants of the ground storey, with *Plectrachne melvillei* favouring the shelter of the mallees and *Triodia basedowii* the more open parts of the community. *Ptilotus obovatus*, *P. alopecuroides*, and other forbs are also numerous. This community is limited to tracts receiving run-on in Bullimore land system.

(56) Eucalyptus leptopoda–Triodia basedowii *Community*.—The very low mallee (*Eucalyptus leptopoda*) which characterizes this spinifex community occurs as scattered low clumps 4–6 ft high. Other typical shrubs are *Calothamnus* sp., *Grevillea juncifolia*, and various species of Myrtaceae. Apart from these features, this community differs little from the other spinifex sand plain communities already described. It was observed only in zones behind breakaways in Bullimore land system.

(57) Eucalyptus kingsmillii–Acacia aneura–Plectrachne melvillei *Community*.—This community, in which the ground layers are marked by a very mixed assortment of perennial grasses, commonly occurs on alluvial plains. *Plectrachne melvillei*, *Eragrostis eriopoda*, or *Eriachne helmsii* are most abundant and are commonly all present in varying proportions. *Danthonia bipartita* and *Eragrostis lanipes* may also be present.

The tree layer consists of *Acacia aneura* 10–12 ft high, with scattered taller gidgee trees and clumps of mallee (*Eucalyptus kingsmillii*). *Eremophila leucophylla* and *E. foliosissima* constitute an open low shrub layer.

It has been observed on sandy crests in Violet land system and on alluvial plains transitional to sand plain in Yanganoo land system.

(58) Eucalyptus lucasii–Acacia aneura–Plectrachne melvillei *Community*.—The only important difference between this community and (57) is the difference in the mallee species. It similarly occupies marginal slopes transitional to sand plain in Yanganoo land system and wanderrie banks and sand plain in Mitchell land system.

(59) Acacia aneura–A. linophylla–Plectrachne melvillei *Community*.—The dense grass layer in this community is dominated by *Plectrachne melvillei*, but *Danthonia bipartita* and *Eragrostis eriopoda* are also present. Forbs and short annual grasses (*Aristida arenaria*) are also important. A dense tall shrub layer (*Acacia aneura* and *A. linophylla*) 6–8 ft high is interspersed with clumps of mallee (*Eucalyptus leptopoda*) 8–10 ft high. Lower shrubs (*Eremophila leucophylla* and *Cassia eremophila*) are open or moderately dense. It occurs in more favoured habitats than (57) and has been recorded only in areas of significant run-on in sand plain in Bullimore and Millrose land systems.

(*c*) Acacia aneura–Kochia pyramidata *Alliance*

Because of the particular understoreys of this group of communities, they are here considered as a separate alliance. *Kochia pyramidata* was used in naming the alliance because of the importance and dominance of this species in these communities in the past, although exploitation of these pastures has resulted in great reduction and in some cases elimination of the palatable species. The alliance is widespread in those parts of the area with saline soils.

(60) Acacia aneura–Kochia pyramidata *Community.—Acacia aneura* forms a sparse open tree layer, or may occur in scattered clumps. The tall shrubs are sparse *Eremophila fraseri* and *Cassia* sp., whilst the distinctive low shrub layer 2–4 ft high is characterized by halophytic species (*Kochia pyramidata, K. triptera, K. georgei, Rhagodia* spp.), although other shrubs (*Eremophila leucophylla* and *Cassia* sp.) are commonly present. Grasses are limited to the short annual *Aristida arenaria* and *Eragrostis dielsii,* but forbs (*Ptilotus alopecuroides, P. exaltatus, P. macrocephalus, P. helipteroides, P. roei, Bassia* spp.) and succulents (*Calandrinia* spp.) are normally abundant. The community is widespread, although locally modified, on the texture-contrast soils of saline alluvial plains (Barwidgee and Beringarra land systems) and in similar habitats in Cunyu, Carnegie, Lynne, and Wiluna land systems.

(61) Acacia aneura–Triodia plurinervata *Community.*—This spinifex community (*Triodia plurinervata*) has a sparse tree layer consisting of the silver-leafed form of *Acacia aneura,* 10–15 ft high, which is restricted to the crests of sand banks. Tall shrubs (*Eremophila miniata*) are very sparse, but low shrubs (*Kochia pyramidata, Enchylaena tomentosa, Lycium* sp., and *Frankenia* spp.) are moderately abundant and sporadically distributed, although *Triodia plurinervata* dominates the ground layer. Other perennial grasses (*Eragrostis lanipes*), short annuals (*Aristida arenaria*), a few legumes, and succulents (*Aizoon quadrifidum* and *Calandrinia* spp.) occupy the spaces between spinifex clumps. This community is restricted to Leeman land system.

(62) Kochia pyramidata–Eremophila maculata *Community.*—This halophytic shrubland is somewhat variable, possibly owing to varying degrees of degradation. It is characterized by low rounded bushy shrubs (*Kochia pyramidata, Atriplex rhagodioides, A. vesicaria, Eremophila maculata,* and *E. pantoni*) 2–4 ft high. Tall shrubs are few, and trees are absent. Grasses are sparse, although *Danthonia bipartita, Eragrostis eriopoda,* and the short annual *Aristida arenaria* are normally present. Forbs include *Ptilotus* spp. and annual chenopods (*Atriplex inflata, Kochia carnosa, K. excavata, K. amoena, Bassia paradoxa, B. eriacantha*) in abundance. The community has been observed on saline alluvial plains in Cunyu, Mileura, and Windidda land systems.

(63) Eremophila maculata–Frankenia *Spp. Community.*—This halophytic community is similar to (62), but the palatable *Kochia pyramidata* is replaced by other less palatable types. The upper layer consists of rounded shrubs 2–4 ft high (*Eremophila maculata, Plagianthus incanus, Scaevola spinescens, Cratystylis subspinescens,* and scattered *Acacia sclerosperma*). The low shrub layer is dominated by low rounded bushes of *Frankenia cinerea, F. fecunda,* and *F.* aff. *irregulans.* Grasses are limited to the short annuals, *Aristida arenaria* and *Eragrostis dielsii.* Forbs (*Ptilotus exaltatus, Goodenia* spp., *Zygophyllum* spp.), composites, and chenopods

(*Atriplex inflata, Kochia carnosa, K. triptera, K. georgei*) are abundant. It has been observed throughout the saline alluvial plains of Boondin, Barwidgee, Mileura, Kalyaltcha, and Mitchell land systems.

(64) Frankenia cinerea *Community*.—This is a very simple community consisting of an open layer of low rounded shrubs 18 in. high characterized by *Frankenia cinerea, F. fecunda*, and *F.* aff. *irregulans*. Chenopods (*Atriplex inflata, Kochia carnosa*, and *Bassia* spp.), short annual grasses (*Eragrostis dielsii* and *Aristida arenaria*), and numerous small composites compose the ground storey. Its observed distribution includes the higher pan margins of Carnegie land system, slopes below breakaways in Tooloo land system, and some wanderrie flats and intergroves in Mitchell land system.

(65) Plagianthus incanus–Frankenia *Spp. Community*.—This community differs from (64) in that it has a layer of taller shrubs (*Plagianthus incanus, Cratystylis subspinescens*) 2–4 ft high. It occupies parts of the saline alluvial plains in Leeman and Barwidgee land systems.

(66) Acacia victoriae–A. tetragonophylla–Kochia pyramidata *Community*.—This community could probably be considered as community (62) with variable low trees (*Acacia victoriae, A. tetragonophylla*, and an occasional *Pittosporum phillyraeoides*) commonly in clumps or rings around gilgais. It was observed in Barwidgee land system.

(67) Acacia victoriae–Eremophila pterocarpa *Community*.—This halophytic shrubland is characterized by *Eremophila pterocarpa*, which forms a moderately dense to open tall shrub layer 6–8 ft high. *Acacia victoriae* and *A. tetragonophylla* may form a sparse taller layer. The low shrubs (*Eremophila maculata, Cassia sturtii, Scaevola spinescens*) are sparse. The only grasses are the short annuals *Aristida arenaria* and *Eragrostis dielsii*. Forbs, including *Ptilotus* spp., chenopods (*Atriplex inflata, Salsola kali, Kochia paradoxa*), and legumes are abundant in season. The community is restricted to saline alluvial plains in Mileura, Ero, and Beringarra land systems.

(68) Acacia aneura–Eremophila duttonii *Community*.—This community, which is commonly found on texture-contrast soils, is characterized by *Eremophila duttonii*, which forms a distinctive, open shrub layer 2–4 ft high with sparse taller shrubs or small trees (*Acacia aneura, Hakea lorea*). The lower shrub layer (*Scaevola spinescens, Cassia chatelainiana*) is very sparse. The ground layers are composed of annual chenopods (*Atriplex inflata, Bassia eurotioides, B. divaricata*), short annual grasses (*Aristida arenaria*), and succulents (*Calandrinia* spp.). Its known distribution comprises the saline alluvial plains with some gilgais in Barwidgee, Wiluna, Kalyaltcha, Carnegie, and Mitchell land systems.

(69) Eremophila maculata–Eragrostis xerophila *Community*.—This consists of a moderately dense grass layer 12–18 in. high (*Eragrostis xerophila, E. setifolia*, and *Dichanthium humilius*) with clumps of the shrubs *Eremophila maculata* and *Kochia pyramidata* 2 ft high. Other minor elements in the lower grass layer are *Tragus australianus, Eragrostis japonica, Pterigeron liatrioides, Kochia paradoxa, Velleia* spp., and *Bassia* spp.

This community was observed only on the cracking clay plains of Windidda land system.

(*d*) *Samphire Alliance*

Because of taxonomic difficulties, no attempt has been made to divide the samphire flats into communities, and for the practical purpose of this survey it is satisfactory to regard them as a single community. Samphire (probably *Arthrocnemum* spp.) occupies the upper margins and, seasonally, the floors of the pans and salt lakes which are widely distributed in the survey area, in Carnegie, Leeman, and Mileura land systems.

(70) *Samphire Community*.—Samphire occupies parts of some pan floors and pan margins, forming a moderately dense layer 2–3 ft high. Several species are included, but have not been determined, although they are probably *Arthrocnemum* spp. and *Pachycornia* spp. Commonly the samphire stands are pure, but they may form ecotones with the *Frankenia* sp. and *Kochia pyramidata* communities of the higher pan margins. A few annuals and ephemerals (*Kochia carnosa*, *Ptilotus exaltatus*, *Eragrostis dielsii*, and composites) are found in the lower layers.

(*e*) *Fringing Communities*

No attempt has been made to classify these communities beyond naming them from the dominants of the upper layers. The understoreys are generally extremely variable and are commonly influenced considerably by adjacent communities.

(71) Melaleuca uncinata *Fringing Community*.—This commonly consists of a pure stand of *Melaleuca uncinata* forming a dense fringe 8–12 ft high between the upper margins of lakes or pans and adjacent dunes and calcrete platforms. Grasses are absent except for sparse short annuals (*Eragrostis dielsii*). There are sparse forbs (*Erodium* sp.) and a few legumes, and there may be abundant composites (*Helipterum splendidum*, *H. humboldtianum*). It was observed only in these special habitats in Carnegie and Mileura land systems.

(72) Eucalyptus camaldulensis *Fringing Community*.—As a tree 25–40 ft high, *Eucalyptus camaldulensis* forms an open fringe to most of the major drainage channels in the area. Locally, there is a dense low tree layer (*Acacia aneura*, *A. burkittii*), and *A. tetragonophylla* is common as a tall shrub 6–8 ft high. The low shrub layer (*Eremophila maitlandii*, *Cassia* spp.) is open and variable. Perennial grasses (*Eragrostis setifolia*, *E. leptocarpa*, *Setaria carnei*, *Eriachne flaccida*, *E. aristidea*) are common but not always abundant. Forbs (*Ptilotus alopecuroides*, *Swainsona* spp., and other legumes and composites) and short annual grasses (*Aristida arenaria*, *Eragrostis dielsii*) are sparse. This community occurs in Beringarra, Barwidgee, Cunyu, Mileura, Violet, Yandil, Lynne, and Windidda land systems.

(73) Eucalyptus aspera *Fringing Community*.—*Eucalyptus aspera* and *Eucalyptus* sp. (Speck 1084), with *Acacia aneura* and gidgee, form a dense fringe 15–25 ft high along channel banks, with some eucalypts growing inside the channel. Other *Acacia* spp. and *Santalum* sp., as tall shrubs 6–10 ft high, add considerably to the density of the community. Several smaller shrubs (*Grevillea deflexa*, *Eremophila foliosissima*, and *Cassia* spp.) are present but are not abundant. Grasses are sparse or absent, except for short annual grasses (*Eragrostis dielsii* and *Aristida arenaria*). Forbs are also sparse. The community was observed along drainage channels in Wiluna land system north of Meekatharra.

(74) Eucalyptus microtheca *Fringing Community.*—*Eucalyptus microtheca* forms an open fringe to calcrete platforms of Cunyu and Mileura land systems and to drainage channels of some other land systems. A low tree–tall shrub layer is formed by *Acacia tetragonophylla* and/or other *Acacia* spp. Typical lower shrubs are *Scaevola spinescens*, *Atriplex* sp., *Rhagodia* sp., *Eremophila* spp., and *Pimelea* spp. Grasses (*Eragrostis leptocarpa*) are moderately abundant along the channels, but are commonly replaced by forbs (*Ptilotus macrocephalus*, *Atriplex* sp., *Helipterum humboldtianum*, *Swainsona* sp., *Euphorbia* sp., *Pterigeron liatrioides*).

(75) Eucalyptus oleosa–E. lucasii *Fringing Community.*—Locally, this mallee community also forms fringes to calcrete platforms. It is commonly very dense and plant growth beneath it is limited to very sparse *Cassia* sp. and other shrubs, and forbs (*Zygophyllum* spp.). Where the canopy is more open the number of shrubs and forbs increases. It was observed only in Cunyu and Mileura land systems.

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PART VIII. PASTURES AND PASTURE LANDS OF THE WILUNA–MEEKATHARRA AREA

By D. G. Wilcox* and N. H. Speck†

I. Natural Pastures

Pastures consisting only of grass layers, as known in higher-rainfall areas, do not exist in the arid area under survey. Even spinifex sand plain has no extensive areas without over-storeys of shrubs, mallee, or mulga trees. Grasses and forbs are, however, preferentially grazed by stock when available. Most species of the ground layers are either ephemeral and drought-evading, and thus available for only a short season, or highly sclerophyllous and drought-resistant, and therefore unpalatable to stock. Only a few species of palatable perennial grasses are present to respond to rain and to persist as dry fodder. During dry periods the grazing animal finds it necessary, to a greater or less degree, to depend upon the available trees and shrubs. Accordingly, all layers of the vegetation need to be included in any description of natural pastures.

The pastures of the area fall naturally into four types, based primarily on their response to the arid climate.

(*a*) *Pastures Characterized by Ephemeral Drought-evading Plants*

This type includes plants which are capable of completing their life cycles during short periods after rain and of surviving the following dry periods as seeds. Two closely related types can be distinguished.

(*a*1) *Short Grass–Mixed Forb Pastures.*—Although short annual grasses and forbs form at least part of the lower ground layer in most communities, there are a number of communities in which they dominate the ground storey and where perennial grasses are sparse or absent. The species are all annuals or, in this arid environment, behave as annuals. Following summer rains, these pastures consist mainly of *Aristida arenaria*, *Eragrostis dielsii*, *E. falcata*, and *Eriachne pulchella* in varying proportions. Except after good rains or on favoured sites, they are short (seldom above 6 in.) and sparse. They are grazed while green but are unpalatable and of low nutrient status during dry seasons. After winter rains, forbs are common, particularly *Ptilotus* spp. and composites, and in areas of run-on these may become abundant and form dense stands up to 2 ft high. With good rain, these provide a lush though temporary pasture which is both palatable and nutritious. The normally bare, scalded areas may also carry significant amounts of small succulents (*Calandrinia* spp.) which are readily eaten by sheep.

Drought resistance of these pastures is low and stock would need to subsist on sparse top feed between rains. The mulga upper storey is commonly very open and

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stunted, and the shrubs (*Eremophila fraseri*, *Eremophila* spp., *Cassia* spp., *Ptilotus obovatus*, and *Solanum ellipticum*) are mostly unpalatable and are sparse. The pastures accordingly have a low carrying capacity.

These pastures are typical of shallow red earths on hard-pan in Yandil, Wadjinyanda, Cunyu, and Ero land systems.

(*a*2) *Short Grass–Chenopod Pastures.*—These pastures closely resemble *a*1, but the short grasses are sparser because of the stony ground surfaces. They also commonly lack the favoured areas of run-on, with their corresponding lush response of forbs. These shortcomings are balanced by the greater number of small annual chenopods, chiefly *Bassia* spp. and *Kochia* spp., which are very numerous although inconspicuous among the stones. There is some evidence that under climax conditions these pastures contained sparse perennial chenopods. Forbs are present, but never abundant. The top feed is commonly unpalatable and consists of *Eremophila macmillaniana* and other poverty bushes, *Cassia* spp., *Ptilotus obovatus*, and *Solanum ellipticum*.

These pastures have a greater drought resistance than *a*1. They characterize stony plains in Sherwood, Mindura, Koonmarra, Yarrameedie, and Edenhope land systems, and parts of Cunyu and Ero land systems.

(*b*) *Pastures Characterized by Perennial Drought-evading Plants*

Such plants may be trees, shrubs, or tussock grasses; truly deciduous species do not occur in the area. Tussock grasses grow rapidly from root bases or rhizomes following adequate rain, but dry off with the onset of a dry season and persist in the dry state. Their nutritive value is moderate when green and low when dry, but they may still be a source of bulk fodder in the dry state. They do not form continuous grass layers, as in higher-rainfall areas, but occur as sparse or scattered tussocks. They can respond both to summer and to winter rains.

(*b*1) Eriachne helmsii *Pastures.*—*Eriachne helmsii* is extremely widespread in the area, occurring in varying proportions with other tussock grasses, *Eragrostis eriopoda* and *Danthonia bipartita*, and with *Triodia basedowii* on sand plain margins. Although it occurs with a great variety of overstoreys, it is best developed in communities of the *Acacia aneura–Eremophila leucophylla* and *Acacia aneura* sub-alliances. It forms loose, erect tussocks 16–24 in. high and 12–18 in. in diameter. Forbs and short annual grasses are commonly present but are not abundant. *Eriachne helmsii* itself does not appear to be eaten by stock, even under drought conditions.

These pastures are prominent in Kalli, Yanganoo, Jundee, Glengarry, and Wadjinyanda land systems, and form a minor element in many other land systems.

(*b*2) Eragrostis eriopoda *Pastures.*—*Eragrostis eriopoda* is also extremely widespread and commonly forms pastures in association with the other perennial grasses *Danthonia bipartita* and *Eriachne helmsii*, but it seldom forms pure stands. These pastures are never extensive. They commonly occur in complexes with the *Eriachne helmsii* and *Danthonia bipartita* pastures, and may grade into them. *Eragrostis eriopoda* forms tight, erect tussocks 9–15 in. high and 6–9 in. in diameter and very openly spaced. Forbs are present in season, and short annual grasses (mainly *Aristida arenaria*) form a variable lower layer.

These pastures are moderately palatable in the growing season. They are best developed as understoreys in the *Acacia aneura–Eremophila leucophylla* and the *Acacia aneura* sub-alliances.

(*b*3) Eragrostis xerophila *Pastures*.—These pastures are recorded only from small areas of red coarse-structured clays in Windidda land system, and locally from small pans and depressions in numerous land systems. The dominant species very closely resembles *Eragrostis eriopoda*, with which it is sometimes confused.

The tussocks of *Eragrostis xerophila* are small and erect, 12–18 in. high and 4–6 in. in diameter, and are more closely spaced than in other pastures. Associated grasses include *Eragrostis setifolia* and *Dichanthium humilius* and variable amounts of short annual grasses (*Aristida arenaria* and *Eragrostis dielsii*). A limited amount of top feed is provided by the shrubs *Eremophila maculata* and *Kochia pyramidata*. The carrying capacity is high after good rains but very low during long dry periods.

(*b*4) Eragrostis setifolia *Pastures*.—These pastures are restricted and relatively unimportant. They are limited to small, special habitats such as depressions and gilgais in Barwidgee and Kalyaltcha land systems. Because of the great variety of associated species, including top feed, the carrying capacity will be moderately high, but of limited value because of sporadic distribution.

(*b*5) Danthonia bipartita–Eragrostis lanipes *Pastures*.—These two perennial grasses occur on wanderrie banks and in other sandy habitats in the Murchison plains.

Danthonia bipartita forms small, loose, erect, leafy tussocks, 12–18 in. high and 6–12 in. in diameter. It is palatable and the tussocks may be almost eaten out during a long dry season, but it regenerates readily from seed and is therefore able to respond rapidly to a good season or to a series of good seasons and so regain lost ground or even extend its area. This ability to respond to good seasons, and its high palatability, make it an extremely valuable pasture grass.

The co-dominant *Eragrostis lanipes* is also highly palatable, but is affected more seriously by drought. The tussocks of this species are loose and open if ungrazed, but readily assume a prostrate habit when grazed.

Eragrostis eriopoda and *Eriachne helmsii* are also present in these pastures, as well as a moderately dense layer of short annual grasses. Characteristically, the upper storeys consist of open mulga and edible shrubs (*Eremophila leucophylla*) which supplement the palatable grasses and make these among the most attractive pastures in the area.

(*c*) *Pastures Characterized by Drought-resistant Sclerophyllous Grasses*

The only drought-resistant grasses are the various types of spinifex (*Triodia* spp. and *Plectrachne melvillei*). They are all strongly lignified and this area lacks the soft spinifex (*Plectrachne pungens* and *Triodia pungens*) of areas with more than 12 in. rainfall, such as the northern part of the Alice Springs area and the Kimberleys (Perry 1960; Speck *et al.* 1960).

(*c*1) *Hard Spinifex Pastures*.—Two species of *Triodia* fall within this category: *Triodia basedowii*, which is the more widely distributed and which has a variety of upper storeys as described in vegetation communities (47)–(56), and *Triodia concinna*, with habit and environment similar to *T. basedowii*, described in vegetation communities (45) and (46).

Hard spinifex forms tussocks 2–3 ft high (including flowering spikes) and 1–3 ft in diameter, or it may form rings 5–20 ft in diameter. The tussocks are not continuous and the intervening spaces commonly have an equal or greater area than that covered by the tussocks. These spaces are sparingly occupied by other perennial grasses (*Amphipogon caricinus*, *Danthonia bipartita*, *Eriachne helmsii*) and by forbs, particularly composites.

The highly lignified foliage of these sclerophyllous grasses is of low nutritive value and is not palatable to stock, except in the case of young plants regenerating from seed following a burn. At this time there is also response by numerous herbaceous shrubs and forbs which are not conspicuous in the mature community. Parts of these pastures receiving run-on may have an open upper layer of mulga and mallee and numerous edible shrubs.

These drought-resistant pastures have a widespread though discontinuous distribution in the Salinaland plains, where they are characteristic of sand plain in Bullimore and Heppingstone land systems.

(*c*2) *Feathertop Spinifex Pastures*.—These pastures are very similar to better-watered areas of *c*1, and the top-feed species are the same. Feathertop spinifex is highly lignified, sclerophyllous, and unpalatable to stock.

The factors controlling the distribution of feathertop spinifex (*Plectrachne melvillei*) are not fully understood. These pastures are characteristic of parts of Yanganoo land system transitional to sand plain, which are commonly favoured areas with run-on. They are also an important constituent of parts of Kalli, Bullimore, Millrose, Violet, and Mitchell land systems.

(*d*) *Pastures Characterized by Drought-resistant Semi-succulent Low Shrubs*

The saline alluvial plains and similar saline habitats associated with the salt lakes, pans, and some drainage lines in the area are characterized by various kinds of halophytic shrubland. These semi-succulent, drought-resistant shrubs are very attractive to stock and because of their palatability, general convenience to watering points, and restricted occurrence they have suffered severe degradation. Throughout much of these pastures the more palatable species have been greatly reduced or entirely eliminated and the present pastures may vary greatly from their original composition. Descriptions will be limited to three pastures which form complexes in Cunyu, Mileura, Barwidgee, Beringarra, Carnegie, and Leeman land systems.

(*d*1) *Samphire Pastures*.—These consist of an upper layer, 18–24 in. high, of closely spaced succulent shrubs of *Arthrocnemum* spp. and closely related genera. This layer is not much grazed by sheep, since the pastures contain numerous more palatable forbs (*Ptilotus exaltatus*, *Zygophyllum* spp., composites, and Swainsonas) which vary in amount according to the season but which always provide a picking.

They occupy parts of dry beds and the margins of salt lakes throughout the area, in particular in Carnegie and Leeman land systems.

(*d2*) *Low Halophytic Shrubland Pastures.*—Adjoining the samphire flats and occupying upper pan margins or lower parts of the tributary alluvial plains are communities dominated by *Frankenia* spp. These low, rounded, openly-spaced shrubs, 12–18 in. high, are palatable to sheep, as are also the numerous forbs (*Ptilotus* spp., *Zygophyllum* spp., *Euphorbia drummondii*, composites, legumes, annual *Atriplex* spp., *Kochia* spp., and *Bassia* spp.) of the ground storey. Grasses are limited to sparse short annual grasses (*Aristida arenaria*, *Eragrostis dielsii*, and *Eriachne pulchella*). More detailed descriptions of these pastures are given in communities (63) and (65).

(*d3*) *Tall Halophytic Shrubland Pastures.*—Up-slope from the areas of low halophytic shrubland, and in places extending over the adjoining saline alluvial plains with texture-contrast soils, are several communities of tall halophytic shrubs. The most important of these is the palatable, highly nutritious *Kochia pyramidata.* This bushy shrub, 2–4 ft high, occurs in a number of communities in various proportions. It is believed that it was previously much more extensive in the area and that in some cases at least it has been largely replaced by less palatable species (*Eremophila pterocarpa*, *Cratystylis subspinescens*, *Plagianthus* spp., *Eremophila duttonii*). There is commonly considerable overlapping of communities, and *Frankenia* spp. and other low halophytic shrubs may form a low shrub layer in these pastures. Short annual grasses (*Aristida arenaria* and *Eragrostis dielsii*) are unimportant, but forbs (*Ptilotus* spp., *Kochia carnosa*, *Bassia* spp., and annual *Atriplex* spp.) may be moderately abundant. These pastures are characteristic of Barwidgee, Mileura, Beringarra, and Kalyaltcha land systems and of parts of Cunyu, Ero, Carnegie, and Leeman land systems.

II. Pasture Attributes

The pastoral industry is based almost entirely upon the natural vegetation. As stated in the description of natural pastures, all layers of the vegetation are utilized and need to be included in any statement of pasture resources.

From the viewpoint of the wool-growing industry, the following attributes of the natural pastures are significant.

(*a*) *Drought Resistance*

In this arid environment pasture production will always be low and will fluctuate widely with the incidence of effective rainfall. The primary requisite of the pasture is that it maintains sheep during periods of stress. Accordingly, its value depends upon its ability to persist during a dry period and to respond to rains which follow, even where these rains are slight.

In the foregoing section, the pastures of the area are classified as ephemeral drought-evaders, perennial drought-evaders, sclerophyllous drought-resistant grasses, and drought-resistant semi-succulent shrubs. Although the ephemerals represent the most efficient counter to the aridity of the environment and for this reason tend to become dominant in degraded pastures, they are unable to fulfil the primary requisite stated above. They contribute to production only at times of low stress and therefore do not greatly affect stocking rates, which are determined rather by the ability to maintain sheep during dry periods. It is the perennial components which have these more enduring qualities. In particular, the perennial drought-evading grasses are valuable in that they have the ability to maintain production for longer periods and to resume production rapidly with light falls of rain. The role of the tree and shrub components is primarily to provide a reserve between periods of grass growth. This is critical in ephemeral pastures and is a valuable supplement on dry perennial drought-evading pastures.

Both the sclerophyllous grasses and the semi-succulent low shrubs have high drought resistance.

(*b*) *Ability to Respond to Rain at any Season*

As shown in Tables 1, 9, and 10 in Part III, there is no strong seasonal rainfall dominance and effective rains are fairly evenly distributed throughout the year. For this reason, the usefulness of a pasture is increased by its ability to respond both to summer and to winter rain.

In this respect the perennial grass pastures of wanderrie country are outstanding, while the halophytic shrubland pastures are only slightly less efficient. Poor response to winter rain seriously limits the usefulness of the short grass pastures.

(*c*) *Palatability and Resistance to Grazing*

Sheep will use the most palatable components of the pasture and even under drought stress will ignore those which are distasteful. Considering the pure pastures on this basis, the semi-succulent shrubs must be rated highest. Accordingly, and since they occur in relatively restricted frontage tracts, they are normally subject to heavy grazing pressure. To a degree these pastures withstand grazing well. The perennial shrubs respond quickly to rain, they occur in favoured areas receiving considerable run-on, and they are physiologically adapted to severe moisture stress; for these reasons fairly continuous production is possible. However, should deterioration progress too far, re-establishment is difficult and tedious on saline and often scalded soils.

The sclerophyllous spinifex grass pastures can be dismissed as of little value, for the spinifex itself is not eaten even when young, and grazing is restricted to sparse volunteer species between the grass clumps. Since it is little grazed, the resistant qualities of the spinifex are irrelevant.

In mixed pastures, uncontrolled selective grazing leads to a depletion of the palatable perennial grasses and shrubs and hence causes lower drought resistance and basic carrying capacity.

Each mixed pasture presents its specific problems. Wanderrie country is rich in palatable perennial grasses, particularly *Danthonia bipartita* and *Eragrostis lanipes*, and it also contains durable and palatable shrubs such as *Eremophila leucophylla* and *Kochia tomentosa*. These species withstand reasonable grazing pressure, but under range conditions they are subject to selective and continuous grazing until eventually they are unable to compete with the ungrazed, less desirable species. This leads to a prominence of unpalatable grasses such as *Eragrostis setifolia* and to a decrease in palatable shrubs.

The short grass–mixed forb pastures are palatable, although of limited value because of their ephemeral character. There is no apparent deterioration of the self-regenerating annual species under grazing, but the minor perennial grass element can be lost where grazing pressure and soil deterioration combine to oppose regeneration.

(*d*) *Nutritive Value*

The pastoral industry requires a pasture which is capable under low and unreliable rainfall of maintaining sheep, allowing flocks to increase, and producing wool. These requirements can be expressed as bulk and quality.

At a stocking rate of one sheep to 50 ac, a pasture must yield 15–20 lb/ac/yr to supply the essential daily dry matter intake of 2·5 lb per sheep. All pastures in the area can supply this bulk in their undegraded state.

By quality is meant the proteins, minerals, fats, and vitamins which are needed at all times, but which are of particular significance to breeding and development. In the growing state, under favourable moisture conditions, all pastures supply these quality requirements, but with moisture stress some pastures decline rapidly in feeding value.

The halophytic pastures maintain their quality content except when defoliation occurs under very severe drought. Crude protein levels of between 10% and 22% are associated with high mineral status (Snook, unpublished data). These represent the most valuable pasture elements, and because of their restricted area must be regarded as breeding grounds and drought reserves rather than as free range.

The particular value of the perennial grass elements of wanderrie country resides in their ability to maintain growth for longer periods following rains, and to respond to light falls; in this way their quality is maintained for longer periods. With prolonged moisture stress they endure as supplies of roughage. The carry-over of quality in the pastures resides in their perennial shrubs and trees, which enable the roughage from the ground storey to be utilized during dry spells.

Although their production of quality and bulk is essentially short-lived, the ephemeral pastures fall into two groups on the basis of nutritive value. The short grass–chenopod pastures of the stony plains are more enduring and more nutritious than the short grass–mixed forb pastures.

(*e*) *Accessibility of Pasture Components*

The grass and shrub layers are always accessible, but the mature mulga which forms the dominant element of the tree layer in almost all pastures is mainly beyond the reach of sheep. This seriously reduces the value of the mulga during drought, as it has been shown that the dried fallen leaves which form the only contribution to the drought pasture are significantly lower in nutriment than the living leaf (Wilcox 1960). It is unlikely that the seeds, which are dropped immediately after rain, can survive insect attack sufficiently long to contribute to the nutrient status of the pasture during the following dry spell.

(*f*) *Cattle Pastures*

The above remarks apply equally to pastures used for cattle-grazing, the main difference being an increased ability to use top feed, in particular mulga. This should confer increased durability on wanderrie and short grass pastures in cattle country. However, the value of mulga as cattle fodder is largely unknown.

III. Pasture Lands

The pastures described earlier in this part are not mappable at the scale of the survey, but since they are normally expressive of the physical environment each land system contains a definite pattern of them. By grouping together land systems with similar patterns of pastures we are able to establish the nine pasture lands described below. These are grouped on the basis of broad similarity of physical environment and of pasture content into five types of country, namely, saltbush country, wanderrie country, short grass–forb country, hill country, and spinifex country.

The attributes of the pasture as described above allow a grading by quality, and the pasture lands are here described in order of decreasing value.

(*a*) *Saltbush Country*

(i) *Halophytic Shrubland*

(1) *Area.*—900 sq. miles.

(2) *Distribution.*—Comprises Kalyaltcha, Barwidgee, Mileura, and Beringarra land systems, throughout the area.

(3) *Environment.*—Mainly saline alluvial plains with some stony plains. Situated mainly in the lower drainage sectors.

(4) *Composition.*—More than half of this pasture land consists of drought-resistant semi-succulent low shrubs, including samphire pasture (*d*1)* and low and tall halophytic shrubland pastures (*d*2 and *d*3). There are minor areas of annual short grass–mixed forb pastures (*a*1), *Eragrostis setifolia* pastures (*b*4), and *Danthonia bipartita–Eragrostis lanipes* pastures (*b*5).

(5) *Stock Waters.*—Ground water is readily available in this pasture land, usually at shallow depths, but may be of limited use because of salinity. Stock waters are adequate in Mileura and Beringarra land systems, but less developed elsewhere.

(6) *Potential Productivity.*—This pasture land can support higher stocking intensities than any other in the area, provided that its vegetation is in good condition. Used as drought reserves and breeding locations, it is of the utmost value in the pastoral environment.

(7) *Present Use and Condition.*—These saltbush pastures on alluvial plains have been and still are subject to continuous heavy grazing and have deteriorated considerably. Degradation is a twofold process of plant and soil deterioration. Uncontrolled grazing results in the elimination of perennial species, an increase in the area of bare ground, and excessive trampling by stock. Severe wind and water erosion ensue, as evidenced by severe surface scalding, pedestalling, and scouring adjacent to drainage lines.

* Letter–number designations in parenthesis refer to pastures as classified above.

The inherent drought resistance and high nutritive properties of the saltbush pastures have generally been lost, and most of this pasture land can now be described only as an ephemeral drought-evading pasture. This dictates, in most cases, a stocking management aimed at removing the ephemeral growth when it is available, which is not conducive to the rehabilitation of the valuable species.

In some instances the pastures have been preserved, but usually only as relict small paddocks within areas of extensive devastation.

Elsewhere in this pasture land, the vegetation on the calcrete platforms of Mileura land system is liable to degradation only in the shrub and tree storeys. The stony plains and alluvial trains above the saline areas in Kalyaltcha land system have as yet been little grazed but could under heavy stocking suffer deterioration, chiefly as a loss of shrubs.

(ii) *Salt·Lakes and Halophytic Shrubland*

(1) *Area.*—1600 sq. miles.

(2) *Distribution.*—Comprises Carnegie and Leeman land systems, mainly in the Salinaland plains and the north-eastern uplands and also at Lake Annean in the Murchison plains.

(3) *Environment.*—Salt lakes, adjacent sandy country, and saline alluvial plains.

(4) *Composition.*—More than half of this pasture land consists of the bare floors of the salt lakes. The tributary alluvial plains and lake margins support pastures characterized by drought-resistant semi-succulent low shrubs, including samphire flats (*d*1) and low and tall halophytic shrubland pastures (*d*2 and *d*3). The sandy country surrounding the salt lakes has hard spinifex pastures (*d*1) in Leeman land system, and various perennial pastures (*b*1, *b*2, *b*5) and short grass–chenopod pastures (*a*2) in Carnegie land system.

(5) *Stock Waters.*—Water occurs at shallow depth in most parts but is commonly too saline for stock, and stock waters are at present inadequate. In the upper reaches of the alluvial plains, brackish water suitable for stock can sometimes be found. The difficulty of obtaining suitable water is enhanced in that on halophytic pastures the grazing animal is unable to tolerate the level of water salinity which would be practicable on grass pastures. Man-made surface storages, at present not used, might offer some remedy.

(6) *Potential Productivity.*—Where the climax vegetation has been restored or has not been disturbed, this pasture land is capable of supporting high numbers of sheep. With proper management, stocking densities of up to 1 sheep to 8 ac are possible. The pastures are highly prized, since they possess the attributes of high drought resistance and high nutritive value. This refers to the lower alluvial areas in particular, but the pastures of the higher parts of the constituent land systems are also useful.

Because of their high nutritive value and drought resistance, the pastures are particularly valuable for drought reserves and breeding grounds. There is no known form of plant introduction which could increase their productivity.

(7) *Present Use and Condition.*—In general the saltbush pastures resist grazing well but there are variations in the degree of resistance, *Frankenia* spp. and *Kochia pyramidata* being the most resistant and *Atriplex* spp. the most prone to removal.

However, the high qualities of the pasture have led to heavy and continuous stocking in much of Carnegie land system since development of the area began. The valuable perennial species have been removed and their seed supplies reduced, and they have been replaced by annual drought-evading species of scant nutritive value, such as *Atriplex inflata*. Grazing management at present involves the removal of available fodder at every opportunity and there is very little effort towards conservation.

Wind and water erosion have become increasingly active on extensive bared alluvial areas subject to trampling by stock. Bare, scalded surfaces have formed on flood-plains, and sand hummocks have grown around the bases of the remaining perennial shrubs.

The pastures of the dunes and sand banks have suffered a loss of palatable shrubs, with a tendency for unpalatable shrubs to become dominant, but there has been no major change towards annual species.

Pastures in Leeman land system are largely untouched, since it occurs in an area of little pastoral development.

(iii) *Short Grass–Forb Pastures with Minor Halophytic Shrubland*

(1) *Area*.—1000 sq. miles.

(2) *Distribution*.—Comprises Cunyu and Ero land systems, in main flood-plains throughout the area.

(3) *Environment*.—Mainly alluvial plains and calcreted valley fills, with minor saline alluvial plains.

(4) *Composition*.—The non-saline alluvial plains carry short grass–mixed forb pastures (*a*1) and short grass–chenopod pastures (*a*2), whereas the minor saline alluvial plains have low and tall halophytic shrubland pastures (*d*2 and *d*3). There are minor areas of *Eragrostis eriopoda* and *Danthonia bipartita* pastures (*b*2 and *b*5) on wanderrie banks in Ero land system.

(5) *Stock Waters*.—There is abundant ground water, which has been extensively developed for stock water, particularly in the calcreted valley fills of Cunyu land system. Ground water may be saline in the lower parts of the pasture land.

(6) *Productivity*.—The pasture land contains valuable halophytic shrubland and perennial grass pastures, but the isolated areas in which they occur are too small to be fenced into manageable units. It would be appropriate to regard them as minor inclusions in a short grass–mixed forb pasture and to evaluate the pasture land on this basis. However, if productivity of the perennial grass pastures were raised, as by water-spreading or tree-clearing in the wanderrie banks and groves of Ero land system, these relatively small areas could be fenced and their grazing controlled.

The usefulness of the pasture land is likely to be overshadowed by the returns from irrigation water in Cunyu land system.

(7) *Present Use and Condition*.—The occurrence of patches of more palatable halophytic shrubland and perennial grass pastures within large areas of ephemeral drought-evading pastures has led in effect to very high stocking rates on the better pastures. In most localities, the valuable perennial halophytes have been removed from the saline alluvial plains and severe wind and water erosion have set in, with scalding, sand-piling, and gullying marginal to drainage tracts.

The perennial grass pastures of the wanderrie banks and mulga groves of Ero land system have in most areas degenerated to ephemeral short grass–mixed forb pastures characterized by annual grasses and forbs. However, the soils here are not likely to deteriorate, save for restricted aeolian sand movement during droughts.

The short grass–mixed forb pastures of the non-saline alluvial plains are relatively unchanged save for reduction in the number of edible shrubs, with unpalatable species of *Cassia* replacing species of *Rhagodia*, *Kochia*, and *Eremophila*. Generally, these areas are not liable to severe deterioration, although in some cases severe rilling and sealing of the soil surface may occur. Beyond protection from fire there is no conscious management programme, and the most common practice consists of using the ephemeral growth following rains.

(*b*) *Wanderrie Country*

(i) *Open Mulga with Wanderrie Shrubland*

(1) *Area*.—3100 sq. miles.

(2) *Distribution*.—Comprises Belele, Trennaman, Millrose, Cole, Mitchell, and Windidda land systems, developed throughout the survey area.

(3) *Environment*.—Alluvial plains with wanderrie banks and mulga groves.

(4) *Composition*.—Perennial pastures on wanderrie banks and in groves, including *Eragrostis eriopoda* pastures (*b*2) and *Danthonia bipartita–Eragrostis lanipes* pastures (*b*5); short grass–mixed forb pastures (*a*1) on more open alluvial tracts; very minor areas of sand plain with hard spinifex (*c*1) and feathertop spinifex (*c*2) pastures, and halophytic shrubland pastures (*d*2).

(5) *Stock Waters*.—Plentiful stock waters are available along the drainage floors and channels of Belele and Trennaman land systems, whilst adequate supplies occur in Millrose and Windidda land systems. There is some possibility of salinity locally, particularly in Mitchell land system.

Stock waters are almost entirely undeveloped in Cole and Mitchell land systems, but it should be possible to establish them along the drainage lines.

(6) *Potential Productivity*.—Good perennial grass pastures of this type can support high numbers of stock, and up to 1 sheep to 10 ac has been found feasible under good conditions. With proper management, this stocking rate should be possible throughout this pasture land.

Water-spreading could be used to advantage in parts of the pasture land where the wanderrie banks are large enough to make this project economically sound, and there is scope in such areas for introduced plants which could utilize the added water.

(7) *Present Use and Condition*.—Almost two-thirds of this pasture land consists of Belele land system, which is very extensive in the Murchison plains, where it has been subject to continuous heavy stocking and has commonly been allowed to deteriorate to ephemeral drought-evading pastures in which the place of *Danthonia bipartita* and *Eragrostis lanipes* has been taken by *Aristida arenaria* and to a lesser extent by *Eragrostis setifolia*. The palatable shrubs (*Eremophila leucophylla* and *Rhagodia* spp.) have disappeared and have been replaced by such ephemerals as *Solanum ellipticum*.

In current practice, these perennial pastures are still not distinguished from ephemeral pastures and are grazed to obtain the current growth, no account being taken of the survival requirements of its components. But although they have deteriorated they are still prized, for growth after rain is fastest on them and more prolonged. Whilst management is still directed mainly at fire prevention, there is a growing tendency towards the preservation of the vestiges of the original plant associations.

Soil deterioration on the wanderrie banks and groves which support these perennial pastures has been restricted to minor wind-piling in drought seasons.

On wanderrie flats and intergrove areas there has been a decline in the shrub population and this denudation of upper-storey elements has resulted in extremely low production from these ephemeral pastures. There has been extensive erosion and surface sealing of the shallow soils.

The constituent land systems of this pasture land in the east of the area have escaped heavy stocking owing to their later exploitation and have not deteriorated to the same degree.

(ii) *Dense Mulga with Wanderrie Shrubland*

(1) *Area.*—4100 sq. miles.

(2) *Distribution.*—Comprises Yanganoo, Dural, Violet, Kalli, Lorna, Diamond, and Fisher land systems, mainly in the Salinaland plains and in the lower parts of the central upland province.

(3) *Environment.*—Rather sandy undulating terrain, and alluvial plains with prominent mulga groves.

(4) *Composition.*—Characterized by perennial pastures, including *Danthonia bipartita–Eragrostis lanipes* pastures (*b*5) with lesser areas of *Eriachne helmsii* pastures (*b*1) and *Eragrostis eriopoda* pastures (*b*2), and by short grass–mixed forb pastures (*a*1) on shallow, finer-textured soils.

(5) *Stock Waters.*—Ground water should generally be available in the lower drainage areas and channels of the component land systems. In most cases, however, they have not been developed for stock.

(6) *Potential Productivity.*—This pasture land contains large areas of valuable perennial grass pastures capable of supporting at least 1 sheep to 15 ac under suitable management. Increased production could be effected by water-harvesting in areas of sheet run-on, and also by the removal of the upper storey in thick mulga groves to promote the growth of perennial grasses and shrubs more accessible to sheep. There is scope for plant introduction in areas where water-harvesting or tree removal is practised.

(7) *Present Use and Condition.*—Where these pastures have been subjected to heavy and uncontrolled grazing over long periods they show signs of serious deterioration, mainly expressed as an increase in the frequency of unpalatable species which may now constitute most of the available grazing.

While these pastures do not have the drought-resisting properties of the saltbush pastures, they are capable of quick and prolonged response to rain at all seasons of the year. The common management practice of using all available grazing immediately has resulted in depletion of the valuable perennials and their replacement by undesirable species. Soil conditions have not deteriorated to any extent under stocking, except perhaps in intergrove areas which are unimportant to total production.

(c) *Short Grass–Forb Country*

(i) *Alluvial Plains with Short Grass–Mixed Forb Pastures*

(1) *Area.*—1700 sq. miles.

(2) *Distribution.*—Comprises Yandil, Jundee, and Wadjinyanda land systems, and is widely spread through the survey area.

(3) *Environment.*—Alluvial plains subject to sheet-flow and with shallow soils, and minor wanderrie banks and mulga groves.

(4) *Composition.*—Mainly short grass–mixed forb pastures (*a1*) with minor areas characterized by perennial pastures, including *Eriachne helmsii* pastures (*b1*), *Eragrostis eriopoda* pastures (*b2*), and *Danthonia bipartita* pastures (*b5*).

(5) *Stock Waters.*—Underground supplies are plentiful in this pasture land, although they can be saline locally in Yandil land system, and stock waters are generally adequately developed except in Wadjinyanda land system.

(6) *Potential Productivity.*—These pastures are unlikely ever to carry large numbers of stock and the most suitable form of management will involve grazing of the ephemeral growth when it occurs. In this way, more valuable adjoining range, such as wanderrie and saltbush country, can be spelled.

The handicap of ephemeral pastures in this pasture land may be partly offset by water-spreading on areas of deeper soil such as wanderrie banks and sand banks. This would involve the selection of suitable introductions to take advantage of better water relations, and would entail fencing and controlled grazing to aid the establishment of these pastures. The size and distribution of these patches of deeper soil will dictate the extent and pattern of such pasture improvement.

(7) *Present Use and Condition.*—There is no conscious attempt to foster any of the more desirable elements in the pasture land, the pastures being normally grazed to remove any available ephemeral growth after rain. This has resulted in depletion of palatable shrubs in areas of shallow soils and in a loss of perennial grasses in the minor sandier environments.

The extensive surfaces subject to sheet flooding in this pasture land are usually heavily sealed, in some cases the shallow hard-pan is exposed, and there is some pedestalling around the trees and perennial shrubs. The sealing and erosive processes have probably been accelerated by increased run-off from land systems occurring upslope. Many of the shrubs and trees which once occurred in this already inhospitable environment have disappeared following deterioration of their growing conditions owing to surface sealing and lower infiltration. As a further result, the ground flora in such areas now responds only to heavy falls of rain and to extensive flooding.

The perennial grass pastures of the wanderrie banks and groves have been subject to selective grazing and have deteriorated to annual drought-evading pastures in no way different from the ephemeral pastures of the flood-plains.

(ii) *Stony Plains with Short Grass–Chenopod Pastures*

(1) *Area.*—3600 sq. miles.

(2) *Distribution.*—Comprises Sherwood, Mindura, Koonmarra, Yarrameedie, and Edenhope land systems, mainly in the Murchison plains, but with smaller occurrences in the Salinaland plains.

(3) *Environment.*—Stony granite plains with breakaways and low hills.

(4) *Composition.*—Mainly short grass–chenopod pastures (*a*2), with short grass–mixed forb pastures (*a*1) in alluvial drainage tracts.

(5) *Stock Waters.*—Ground water is available and stock waters are adequate in most parts of this pasture land. They are more concentrated in the drainage plains, flood-plains, and channels, but also occur on the stony plains. There is some occurrence of salinity locally in Sherwood land system.

(6) *Potential Productivity.*—Although in general these are low-value pastures, providing ephemeral growth as in *c*1, the existence of a chenopod element makes them more nutritious, durable, and attractive.

Some improvement in production can be expected following tree removal in groves on the alluvial plains in Yarrameedie land system.

In many instances this pasture land occurs up-slope from other land systems where water-spreading is feasible, and it may be possible to direct run-off from it to potentially more productive areas down-slope.

(7) *Present Use and Condition.*—This pasture land has its maximum development in areas of early settlement in the Murchison plains, and has consequently been subject to heavy and uncontrolled grazing over a long period. Normally it is grazed to remove as much of the ephemeral growth as possible.

The pastures are commonly degraded in their upper storeys. On most of the stony plains the tree species have disappeared and only unpalatable shrubs such as *Eremophila macmillaniana* and *E. fraseri* remain. However, it is doubtful whether these upper storeys ever played a significant role.

Of far greater importance is the death or depletion of the chenopods. There is evidence that low perennial chenopods formerly occurred sparsely on the stony plains, but they have now disappeared and the chenopods are restricted to annual species. The halophytic vegetation on the texture-contrast soils below breakaways has also severely deteriorated. The extremely local distribution of these communities has caused overgrazing of the palatable perennials, but it is difficult to see how this could have been avoided.

In most areas, wind-piling can be observed around the bases of the perennial plants, but apart from minor rilling in areas bordering channel zones in the flood-plains, this is the only evidence of soil erosion.

(*d*) *Hill Country*

(i) *Hill Pastures with Stunted Mulga Shrubland*

(1) *Area.*—4000 sq. miles.

(2) *Distribution.*—Comprises Wiluna, Glengarry, Killara, Sodary, Boondin, Gabanintha, Lynne, Princess, Treuer, Wongawol, Tooloo, Doman, Weld, Yagahong, and Norie land systems, and occurs throughout the survey area.

(3) *Environment.*—Rocky or stony uplands comprising some inaccessible areas.

(4) *Composition.*—Mainly short grass–mixed forb pastures (*a*1) with an unusually dense and varied shrub layer; minor areas of perennial grass pastures (*b*) and feathertop spinifex pastures (*c*2), with low halophytic shrubland pastures (*d*2) on included lowlands.

(5) *Stock Waters.*—Ground water is likely to be mainly restricted to the drainage lines, and most stock waters occur in such situations. In general, supplies are underdeveloped. Saline ground water occurs in some areas, particularly in the north-eastern uplands.

Ephemeral surface waters are likely to occur in most of the constituent land systems following rains.

(6) *Potential Productivity.*—Stocking densities will always remain low, but the shrub layer can support these low densities for extended periods even under drought conditions and this pasture land may be regarded as a useful grazing reserve. Relief is rarely so strong as to render large areas inaccessible to grazing.

In some instances, as in Weld land system, there is scope as catchments for water-spreading on pasture lands down-slope.

(7) *Present Use and Condition.*—The pastures are managed so as to graze as much of the ephemeral growth as possible after rains, whilst at other times stocking rates are reduced to levels based on the composition of the shrubs in the pasture.

Degradation under constant stocking is generally expressed as a decline in the shrub layer, which forms the most valuable and enduring parts of the pastures. This has occurred most extensively on lower slopes, particularly those with halophytic elements. Deterioration in the higher parts has been restricted to some loss of perennial grasses and probably to a reduction in the palatable shrubs, but because of inaccessibility these pastures are likely to remain as climax communities.

Erosion of the rocky summits and slopes is generally unlikely and soil deterioration is restricted to the minor alluvial plains, where some sealing may take place. On the extremely localized areas of texture-contrast soils some irreversible damage has occurred from wind and water erosion, but these are not sufficiently extensive to be significant.

(*e*) *Spinifex Country*

(i) *Spinifex Sand Plain*

(1) *Area.*—5800 sq. miles.

(2) *Distribution.*—Comprises Bullimore, Waguin, Yelma, and Heppingstone land systems, situated mainly in the Salinaland plains.

(3) *Environment.*—Spinifex sand plain and minor dune fields.

(4) *Composition.*—Hard spinifex pastures (*c*1) and feathertop spinifex pastures (*c*2). Very minor areas of perennial grass pastures in localities receiving significant run-on.

(5) *Stock Waters.*—This pasture land has only recently been developed and its stock waters have not been fully exploited. In Bullimore land system adequate ground water appears to be widespread, although at some depth, but can be saline locally. Supplies are usually obtained by boring, most commonly near low breakaways.

Elsewhere, the water supplies are undeveloped but should be adequate in drainage floors and alluvial plains. There might be some salinity locally.

(6) *Potential Productivity.*—The pastures consist mainly of unpalatable, sclerophyllous, drought-resisting grasses and their value resides in the ability of the grazing animals to use the more palatable volunteer shrubs and grasses which follow burning and the valuable shrubs and grasses which occur in areas receiving run-on. A figure of 1 sheep to 50 ac is a realistic estimate of carrying capacity under normal conditions.

This productivity could be improved by water-spreading and plant introduction in areas of significant run-on, combined with a programme of controlled grazing aimed at perpetuating the valuable species. Water-spreading through check banks and leaders from regions of concentrated flow to deep soils is feasible in the minor alluvial plains, as in Yelma land system, and in mulga groves, as in Waguin land system. In plant introduction, emphasis should not only be placed upon summer-growing perennial grasses, but also upon winter-growing species. *Triodia* is dormant in the colder season, so that it is then that useful production could be expected from the soil water stored.

(7) *Present Use and Condition.*—Generally, these pastures are used only after burning, when the volunteer growth of palatable species of *Kennedia, Danthonia,* and *Sida* can outstrip *Triodia* in production. Under these conditions, stocking rates as high as 1 sheep to 10 ac are feasible. This high productive capacity is transitory, however, since *Triodia* is able effectively to exclude these palatable species within 5 yr. A return to sufficient density of *Triodia* to carry a fire takes a further 10 yr, during which time the carrying capacity of this pasture is less than one sheep to 50 ac. Experiments in progress indicate that protection of the volunteer species from grazing in the early stages of growth does not appear to confer any extension in the useful life of this pasture.

There is no sign of deterioration in these pastures, and the return of *Triodia* dominance after burning has always occurred. It is reasonable to assume that there could be some loss of the valuable perennials with repeated burns and uncontrolled grazing.

Apart from burning and subsequent stocking to utilize the volunteer species, there is no conscious management of this pasture land.

Deterioration may occur as wind erosion of burnt areas if rains do not follow within a year of burning. Sand-piling around the spinifex rings is already apparent in some localities. Depletion of the store of valuable shrubs and grasses in areas of run-on may occur with uncontrolled stocking.

Otherwise the pasture land withstands grazing well. Its chief virtue lies in the deep soils, which are able to store greater supplies of water than is possible in other areas. This store of water enables the pastures to survive periods of stress.

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PART IX. WATER SUPPLY IN THE WILUNA–MEEKATHARRA AREA

By Muriel Brookfield*

I. Introduction

Reports on underground water in the area have been made by Simpson (1916) on the Meekatharra district, and on an area immediately east of Wiluna by Ellis (1951).

This account is partly based on a census of wells and bores carried out by J. Sofoulis† during the survey. Positions of many wells and bores were obtained from the Lands Department, W.A. Information on yield and quality was kindly supplied by station owners through the liaison of the Regional Agricultural Adviser, D. G. Wilcox. The correlation of water points with land units largely rests on air-photo interpretation.

Deductions from such a census as to ground-water resources are subject to two limitations: in the first instance, the figures must to some extent reflect the pastoral usefulness of the type of country and hence the need for stock water; secondly, they will reflect station practice.

II. Surface Waters for Stock

(a) *Natural Storages*

Surface waters are of little importance to the pastoral industry in this area because of low rainfall and ephemeral surface drainage.

As a result of the small relief and drainage energy, the defined drainage channels in the hilly areas tend to give place rapidly down-valley to alluvial floors with only shallow runnels and to broader alluvial plains with very restricted channelling. In consequence, much run-off takes the form of widespread shallow flooding which is subject to rapid evaporation and which is of negligible value as water supply for stock.

Longer-lasting surface supplies are provided by pools left in drainage channels after floods. The western part of the survey area is better endowed with such supplies, for many of the plains tributary to the Murchison River have anastomosing, impersistent, narrow channels which are mainly shallowly incised into hard-pan but which have small deepened sectors. Berrin pool in the Hope River east of Belele homestead, and Ponthoon pool on Whela Creek are good examples. In the less-organized interior drainage which prevails in the east of the area, such pools are fewer and are restricted to piedmont or intermont tracts. The largest pools may survive all but the most severe droughts, but most of them contain water only for shorter periods. In general, quality is good for only a short time following flooding, and the water becomes saline during the early stages of drying out.

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A second source of surface water is provided by small pans on the margins of the large salt lakes or in valleys tributary to them, particularly in the east of the area. These pans are filled only after heavy flooding. They may remain fresh for some time, but become brackish as their levels fall. Lindsay Gordon lagoon, south-west of Lorna Glen homestead, provides a supply of this nature.

Small supplies of little value are obtained from rock holes, which generally originate as weathering cavities. They are numerous on the summits and margins of granite domes in the south-west of the area and in uneven breakaway tracts formed in the mottled zones of weathered gneiss and granite.

(*b*) *Man-made Storages*

Widespread plentiful supplies of shallow ground water have made the construction of surface storages generally unnecessary, such features being restricted to roof catchments for human use. The excavation of earth dams would be difficult owing to the presence of hard-pan and the dispersed nature of surface drainage. An exception might be the saline alluvial plains, where hard-pan is less developed and where ground water is commonly saline; valuable halophytic pastures might in this way be made available to stock.

Table 19

PERCENTAGE OF COUNTRY WATERED (I.E. LYING WITHIN $2\frac{1}{2}$ MILES OF A WELL OR BORE ON SHEEP STATIONS, OR WITHIN 5 MILES ON CATTLE STATIONS)

4-Mile Sheet	No. of Water Points	Percentage Watered	Percentage Unwatered
Belele	412	70	30
Glengarry	297	55	45
Wiluna	254	50	50
Kingston	60	30	70

III. Underground Water for Stock

The pastoral industry is largely dependent on ground water from bores and wells. The amounts needed for stock water are small and the ground-water supply is generally adequate, and few parts of the area are likely to remain undeveloped on this account.

There are over 1000 wells and bores in the survey area. As shown in Table 19, the frequency of water points and the percentage area effectively watered decrease eastwards. This is in part due to the fact that the west was earlier settled, while the east remains remote and less developed; also, the amount of country of low pastoral value increases eastwards, particularly the proportion of sand plain. In saline alluvial plains and sand plain there are still considerable areas in which no wells and bores occur.

Wells outnumber bores by more than two to one but modern practice favours the sinking of bores, particularly where greater depth is necessary. The cost of sinking a bore is about 30*s*. per ft and that of a well approximately £5 per ft. The total cost of equipping and establishing an average water point is about £500.

Stock-route wells, such as those along the Canning Stock Route, were originally provided by the State, but wells and bores are now the responsibility of station owners. Some mine wells and shafts have been taken over by stations.

(*a*) *Aquifers*

As reflected in the widespread distribution of stock waters shown in the land system map, there is little localization of ground-water supply. The main aquifers are the hard-pan beneath tributary alluvial plains, deep weathering profiles, particularly in granitic rock, and the fine gravel and opaline silica layers in calcreted valley fills.

(*b*) *Recharge and Storage*

Influent seepage directly from rainfall is probably unimportant, and most recharge is from run-on after heavy falls of rain. A small proportion of concentrated run-off may replenish the ground water in rocky upland areas, but most of it drains to the alluvial plains by sheet flowage, channels, or subsurface flow, and the alluvial lowlands are the main zones of influent seepage. The amounts pumped for stock are extremely small in comparison with storage, and year-to-year fluctuations in recharge are unlikely to affect water-table levels.

(*c*) *Depth of Water*

The water-table generally lies at a depth of between 20 ft and 50 ft, though it may be as little as 2 ft deep, particularly in calcreted valley fills, or as deep as 100 ft in weathered granitic rock, as below sand plain, and more than 120 ft in weathered metamorphic rock. In erosional land systems the water-table is related to surface slopes and to the junction of weathered and unweathered rock, and is therefore at varying depth. In alluvial areas, the water-table has uniform low hydrologic gradients and is everywhere at little depth.

(*d*) *Yield*

Three yield classes of wells and bores are indicated on the land system map:

Below 1000 gal/day
1000–4000 gal/day
Above 4000 gal/day

Assuming that at least 2 gal/day are needed per sheep (15 gal/day for each head of cattle), wells yielding 1000 gal/day can water only 100 sheep without risk, if allowance is made for wind droughts. Wells and bores of this small yield are widespread in the survey area and are not limited to any type of country.

Nearly two-thirds of the wells and bores fall into the first two categories, but it must be borne in mind that stated yields are likely to reflect demand rather than potential supply. Very few figures for yield are based on sound pumping tests.

TABLE 20

DISTRIBUTION OF WELLS AND BORES BY LAND SYSTEMS

Land System	Area (sq. miles)	No. of Wells and Bores	Sq. Miles per Well or Bore	Saline Wells and Bores with over 3575 p.p.m. Total Salts	No. of Wells and Bores with Yield over 4000 gal/day	No. of Wells and Bores with Yield over 5000 gal/hr	Total Yield ('000 gal/day)
Uplands							
Weld	100	1	95	—	—		1
Princess	180	1	185	1	1		5
Yagahong	60	—	—	—	—		—
Gabanintha	300	12	25	—	4		57
Glengarry	650	9	75	1	5		36
Lynne	250	4	60	1	2		30
Doman	120	—	—	—	—		—
Wongawol	120	1	120	1	—		1
Wiluna	700	43	15	4	20	1	153
Killara	540	15	35	—	11		60
Sodary	400	3	135	1	3		15
Tooloo	120	—	—	—	—		—
Boondin	300	1	305	—	—		20
Norie	40	—	—	—	—		—
Treuer	150	—	—	—	—		—
Total	4030	90	45	9	47	1	378
Undulating terrain							
Dural	850	17	50	2	14		65
Fisher	150	2	70	—	2		9
Lorna	180	—	—	—	—		—
Diamond	180	—	—	—	—		—
Total	1360	19	70	2	16		74
Breakaways and plains							
Sherwood	2200	79	30	4	21		190
Violet	850	36	25	7	12		113
Millrose	280	7	40	2	2		21
Mindura	750	36	20	2	16		114
Edenhope	40	9	5	2	4		21
Koonmarra	600	35	15	3	8		91
Yarrameedie	80	5	15	—	—		11
Windidda	80	4	20	—	3		15
Kalyaltcha	280	5	55	2	3		48
Total	5160	216	25	22	69		624

TABLE 20 (*Continued*)

Land System	Area (sq. miles)	No. of Wells and Bores	Sq. Miles per Well or Bore	Saline Wells and Bores with over 3575 p.p.m. Total Salts	No. of Wells and Bores with Yield over 4000 gal/day	No. of Wells and Bores with Yield over 5000 gal/hr	Total Yield ('000 gal/day)
Alluvial plains							
Jundee	550	31	15	1	9	2	247
Trennaman	300	26	10	4	8		109
Yanganoo	1600	113	15	11	17	1	482
Cole	220	1	220	—	1		20
Yandil	1100	93	10	7	46		417
Ero	400	38	10	1	24		130
Wadjinyanda	100	3	30	—	2		12
Mitchell	180	2	90	1	1		1
Belele	2000	131	15	9	40		368
Total	6450	438	15	34	148	3	1786
Sand plain and dunes							
Bullimore	5400	94	60	20	24	1	270
Kalli	250	9	30	—	1		18
Yelma	100	—	—	—	—		—
Waguin	200	—	—	—	—		—
Heppingstone	80	—	—	—	—		—
Total	6030	103	60	20	25	1	288
Saline alluvial plains and salt lakes							
Barwidgee	260	5	50	2	2		14
Beringarra	120	14	10	3	9		45
Carnegie	1400	13	110	8	6		75
Leeman	200	1	190	—	—		2
Total	1980	33	60	13	17		136
Calcreted valley fills							
Cunyu	600	99	10	26	44	5	1701
Mileura	240	25	10	8	14		90
Total	840	124	5	34	58	5	1791
Total of all types of terrain	25,850	1023	25	134	380	10	5077

Of the wells producing over 4000 gal/day, several in fact yield between 10,000 and 20,000 gal/day; 10 yield over 5000 gal/hr and are mostly used for small irrigation plots.

The total yield from all wells and bores in the area is over 5 million gal/day (Table 20), but the potential yield of equipped bores and wells is considerably higher.

A number of bores have never been equipped, and a few have been equipped but abandoned because of insufficient yield or high salinity, particularly in the vicinity of the salt lakes.

(e) *Quality of Water*

Table 21 gives the measures of salinity used in this part and gives a brief summary of the comparative tolerance of saline water by humans and stock.

TABLE 21

COMPARATIVE TOLERANCE OF SALINITY OF WATER BY HUMANS, STOCK, AND IRRIGATION CROPS*

	Max. Grains per Gal	Max. p.p.m. Total Salts	Max. Conductivity (micromhos/cm at 25°C)	U.S.D.A. Classification
Human, all-purposes, and good-quality irrigation water	100	1430	2250	C1–C3
Fair-quality irrigation water	225	3200	5000	C4
Human in arid areas, under drought conditions	250	3575		
Stock	900	12,870		

* Based on Northern Territory Administration Animal Industry Branch (1956), and United States Department of Agriculture (1954) classification.

Two salinity categories of stock water are distinguished on the land system map:

Below 3575 p.p.m. total salts, or good stock water,

Above 3575 p.p.m. total salts, or poor stock water.

Sodium chloride generally forms about 50% of the contained salts in ground water in the area.

There are two main sources of salts in the ground water in the area: the slow accumulation of cyclic salts from the atmosphere, and salts leached from fresh rocks such as sodic granite and from the lower parts of laterite profiles, resulting in the sporadic occurrence of saline water close to the source rocks. Where ground water is trapped in weathering pockets, as often occurs in crystalline rock below sand plain where there is also normally little recharge, a fairly high incidence of salinity may result.

Salinity increases on a regional scale towards the lower parts of trunk valleys, particularly in the vicinity of salt lakes, as is to be expected in an area of interior drainage. In areas with a shallow water-table, the concentration may be considerably increased by evapotranspiration from phreatophytes.

TABLE 22

DISTRIBUTION OF WELLS AND BORES WITHIN LAND SYSTEMS BY LAND FORM TYPES

Land System	Land Form Type									
	Rocky Uplands, Hills, Hill Slopes	Lower Slopes, Inter-fluves	Stony Plains	Alluvial Plains, Fans, Wanderrie Tracts	Flood-plains, Drainage Floors	Channel Zones	Sand Plain	Tracts with Run-on	Sand Banks	Platforms
Uplands										
Weld					1					
Princess		1								
Gabanintha		3			7	2				
Glengarry		4			5					
Lynne					4					
Wongawol					1					
Wiluna	2	9		7	18	7				
Killara		5			8	2				
Sodary				2	1					
Boondin					1					
Total	2	22		9	46	11				
Undulating terrain										
Dural		6		9	2					
Fisher				1	1					
Total		6		10	3					
Breakaways and plains										
Sherwood	7	6	17	3	40	6				
Violet		23			12	1				
Milrose				4	3					
Mindura	1		13		20	2				
Edenhope		1	1		7					
Koonmarra			9		26					
Yarrameedie				1		4				

Windidda				4						
Kalyaltcha			2	2	1					
Total	8	30	42	14	109	13				
Alluvial plains										
Jundee				19	6	6				
Trennaman				12	14					
Yanganoo				68	45					
Cole						1				
Yandil				55		38				
Ero				20	13	5				
Wadjinyanda				3						
Mitchell				2						
Belele				64	67					
Total				243	145	50				
Sand plain and dunes										
Bullimore							56	38		
Kalli				2			7			
Total				2			63	38		
Saline alluvial pans and salt lakes										
Barwidgee				3		2				
Beringarra					6	8				
Carnegie				7					6	
Leeman									1	
Total				10	6	10			7	
Calcreted valley fills										
Cunyu				76		6				17
Mileura				13	6	2				4
Total				89	6	8				21
Grand total	10	58	42	377	315	92	63	38	7	21

The majority of the wells and bores were classified as good or poor stock water on information supplied by station owners. Samples from about 10% of the wells and bores were analysed by Chapman (1962). He found that the best-quality waters, with salinity less than 2000 p.p.m., came from tributary alluvial plains with hard-pan, including wanderrie tracts, and from areas of little-weathered granite. Those with salinity above 2000 p.p.m. came, in decreasing order of quality, from areas of Nullagine rock, from weathered granitic rock below sand plain, from calcreted valley fills, from gneiss, from Permian grit and tillite, and from saline alluvium. These results are not based on an equal number of samples from each type of aquifer.

Only wells and bores which give water suitable for stock have been equipped, and most have a salinity of between 1400 and 4300 p.p.m. About 10% are suitable for stock only, and of the remainder many are close to the upper limit of human tolerance. Few wells giving water with a concentration of above 7150 p.p.m. total salts are equipped.

(*f*) *Distribution and Yield of Stock Waters in Relation to Types of Country*

In Table 20, the distribution of stock waters broadly grouped according to salinity and yield is classified under geomorphologically similar types of country represented by related groups of land systems.

Table 22 analyses the distribution of stock waters in terms of land-form types constituted by related land units. It reveals a marked concentration in the alluvial areas.

(i) *Uplands*.—Some of the more inaccessible parts of the survey area fall into this group of land systems. Pastures are of poor to very low grade and stocking density is low. However, these are the only areas which are likely locally to have inadequate supplies of ground water, particularly the uplands of little-weathered, compact rock. Because of complex geological structure and varied relief, the water-table is similarly variable and is often at some depth. There has been little drilling into hard rock and most of the wells and bores are concentrated in the alluvial land units (Table 22). However, old mine shafts sunk into rock have been used locally. Quality of water is fairly good, although saline ground water may be associated with weathered greenstone. From the point of view of water supply, the main importance of the uplands is as water-shedders to adjacent lowlands.

(ii) *Undulating Terrain*.—Although pastures are mainly good to very good in this small group of land systems, water supplies are little developed. Some of the areas are in the remote south-east, but even in the more accessible occurrences west of Wiluna there is little pastoral development. However, ground water is likely to be adequate under exploitation. The few wells and bores are found mainly in the alluvial tracts.

(iii) *Breakaways and Plains*.—Although containing pastures of generally moderate or low value with only small areas of better-quality grazing, this group of land systems comprises extensive tracts of very accessible country in the more developed western part of the survey area, and the stocking rate and frequency of water points are considerably higher than in the foregoing groups. Where these plains are situated at the foot of uplands providing run-off, stock-water supply appears to be relatively abundant.

The main source of ground water is again the alluvial fills of the narrow drainage floors, which account for only 30% of the area but contain 60% of the water points. These are normally low-yielding wells of good or average quality and small depth. Of the remaining water points, 20% are situated on the stony interfluves, and from these water is usually obtained at greater depths.

(iv) *Alluvial Plains.*—This extensive group of land systems has good to moderately good pastures, waters of good quality, and a high density of wells and bores. It consists mainly of extensive tributary plains subject to sheet flooding and traversed by unchannelled drainage tracts, and is particularly well developed in the west of the survey area, where land-use pressure is higher. The plains are underlain by hard-pan, increasing in thickness from a few feet in the higher parts to more than 50 ft in the lower parts. Wells and bores are of moderate, often shallow depth, yields are good and sometimes high, and there is little salinity.

(v) *Sand Plain and Dunes.*—This group of land systems contains extensive pastures of low value, mainly in the east of the area. There is little surface drainage apart from run-on on the margins, and probably very little recharge in normal years. Recharge in years of exceptional rainfall is, however, apparently adequate to maintain a water supply for stock.

Table 22 shows that bores are not unduly concentrated in areas with run-on, and most of the supplies come from the widespread weathering profile in the underlying granitic rock. This may exceed 100 ft in thickness and bores are accordingly deep. Quality of water is generally fair, but isolated occurrences of salinity are probably related to saline weathering profiles, particularly where ground water is stored in weathering pockets.

The low average density of water points reflects the remoteness and poor pastures of much of the sand plain and its low intensity of pastoral development rather than its potential water supply.

(vi) *Saline Alluvial Plains and Salt Lakes.*—Pastures here are mainly of good quality, but waters are poor. These plains represent the lower drainage elements in the area, with finer-textured alluvium and with a smaller development of hard-pan; they include inaccessible areas in and around salt lakes. This group of land systems is relatively little developed from the point of view of stock water, with only a few wells of minor yield and with considerable areas where waters are too saline even for stock. No attempt has been made to increase the use of pastures by earth dams although this is one of the few types of country in which they could more easily be constructed, owing to the limited occurrence of hard-pan and to the greater run-on.

(vii) *Calcreted Valley Fills.*—The pre-eminence of these as aquifers is evident from Table 20. They are physically suited to water storage and they have extensive catchments, since they occupy trunk valleys. Yields are high and water is generally available at depths of only a few feet. Many supplies are saline, however, particularly in lower central tracts. The calcreted valley fills have moderate to good pastures, but their long narrow outlines result in increased pastoral significance, since they front upon and water considerable adjoining tracts.

IV. Underground Water for Irrigation

In contrast to the general availability of stock water, supplies adequate for irrigation are likely to be restricted to a very few areas. The five main criteria to be applied in evaluating possible irrigation waters are yield, recharge, storage, depth, and quality, and these are considered in turn in relation to the Wiluna–Meekatharra area.

(*a*) *Yield*

A minimum requirement of 5000 gal/hr has been arbitrarily adopted as the smallest flow which could maintain an irrigation plot, this being the yield of the smallest single well at present supporting such a plot in the area, at Lake Violet homestead. A well of this yield would give about 160 ac.ft./yr with continuous pumping, but in practice pumping could not continue at this rate and the total amount of water available for irrigation would accordingly be smaller.

The yield of an aquifer at any point is controlled by its permeability and by its storage coefficient. At Lorna Glen, Chapman (1962) found that the storage coefficient of vesicular opaline silica in Cunyu land system was 17%, whilst that of the fine underlying gravel was 5%. Hard-pan had a storage coefficient of only 3%. Permeability is also highest in the opaline silica and fine gravel of the calcreted valley fills, in which rates of 350 ft/day were determined by Chapman at Lorna Glen and east of Wiluna, whereas those in hard-pan were as low as 13 ft/day.

It seems likely, therefore, that the calcreted valley fills in Cunyu and Mileura land systems will be the only aquifers extensively providing adequate yields for irrigation. On the irrigation plot at Lorna Glen homestead, Cunyu land system contains a bore with a yield of 20,000 gal/hr, the highest in the area, and another at Karralundi Mission yields 15,000 gal/hr. Mileura land system, although geologically similar, has not yet been sufficiently tested and present yields are small.

The calcreted valley fills locally extend beneath other land systems. For instance, each of a group of bores on the irrigation plot east of Millbillillie homestead yields about 3000 gal/hr from an extension of such a fill beneath sand plain of Bullimore land system, whilst at Lorna Glen a calcreted valley fill also occurs beneath hard-pan underlying Belele land system.

Yields from tributary alluvial plains underlain by hard-pan are generally smaller, as is to be expected from their lower storage coefficients and permeability rates. There will, however, be a more localized occurrence of supplies sufficient for small plots; one irrigation well in Jundee land system yields 7000 gal/hr and another from Yanganoo land system yields 5000 gal/hr.

The erosional land systems would not normally be expected to yield adequate supplies but at Garden Gully, in Wiluna land system north of Meekatharra, four wells yielded a maximum total of 250,000 gal/day for a short time during the mining period.

(*b*) *Recharge*

Ground-water supplies in amounts sufficient for irrigation will generally be restricted to areas of high recharge from extensive catchments. Recharge rates have been calculated by Chapman (1962) for catchments at Lorna Glen and east of Wiluna, based on determinations of average ground-water flow which have been taken as equal to long-term average recharge. At Lorna Glen the calculated recharge is 1·3% of the mean annual rainfall on the catchment, while that east of Wiluna, with more widespread erosional land surfaces, is about 3·3%, which may well be closer to the average for the survey area. For the calculation of potential recharge on which Table 23 is based, a recharge coefficient of 1% of the mean annual rainfall was taken for the depositional land systems and 5% for the erosional land systems, although this latter figure may prove too high. Sand plain is considered to make no significant contribution to underground water and has been excluded in calculating recharge.

The calcreted valley fills of the trunk valleys, with the largest catchments, are clearly most likely to receive adequate recharge, and recharge will decrease in tributary alluvial plains and towards the heads of drainage systems. The main trunk valleys with their catchments are shown on the map of ground surface types in drainage catchments and are listed with their potential recharge in Table 23. It must be borne in mind that these recharge figures represent the maximum possible recharge above the outflow points of the catchments.

(*c*) *Storage*

A uniform supply will be dependent on adequate storage. Where the ratio of storage to annual flow through the aquifer is less than 40 yr, continuous pumping may not be possible in dry periods. This figure has been calculated by Chapman (1962) as 60 yr at Lorna Glen, and the storage/flow ratios for the other aquifers in the Wiluna–Meekatharra area are likely to be equally high.

(*d*) *Depth*

Depth to water is not likely to present a problem as the water-table is nowhere far below the surface in the alluvial areas, which are the main source of water supply. It is often little more than 20 ft deep and in the calcreted valley fills may be within 5 ft of the surface.

(*e*) *Quality*

For the purpose of this chapter, "good" quality irrigation water is taken to be that with a salinity of less than 1430 p.p.m. (Table 21), which should permit cultivation of crops of low to moderate salt tolerance (Durand 1959). "Fair" quality irrigation water is defined as that with between 1430 and 3200 p.p.m. total salts, which should permit cultivation of large-scale crops and fodder crops of much higher salt tolerance on well-drained soils, provided that the proportion of harmful salts is not too high (Durand 1959). Waters with salinities higher than this are considered unsuitable for irrigation, as only the most salt-resistant crops can survive them. It is noted that this limit accords closely with that used to define poor-quality stock waters as shown on the land system map, so that the distribution of such waters yields some information as to the extent of ground water too saline for irrigation. It has also been assumed that ground water in the saline alluvial plains and salt lakes land systems will generally be unsuitable.

TABLE 23
CATCHMENTS AND POTENTIAL RECHARGE

Catchment	Designation on Catchment Map	Area of Erosional Land Systems (sq. miles)	Area of Non-saline Alluvial Land Systems (sq. miles)	Estimated Potential Recharge (ac. ft./yr)	Notes
Class 1 catchments					
Cunyu	G	170	70	4500	Only small part of catchment in survey area; good-quality water at Old Cunyu well, but quality lower up-valley
Wiluna	E III	125	30	2350*	C3-S1 waters in west (average conductivity 1620 micromhos/cm); million gal/day from Town wells on Cunyu land system, 1933–46, without noticeably lowering water-table or increasing salinity
Lorna Glen	K III	—	50	350*	C3-S1 waters (average conductivity 1090 micromhos/cm); small northern extension of Cunyu land system between Lindsay Gordon lagoon and Lorna Glen homestead already partly developed for irrigation; detailed study of this aquifer made (Chapman 1962)
Class 2 catchments					
Yalgar–Hope River	C I	1000	1000	29,000	Present use, including small-scale irrigation at Karralundi Mission plus withdrawal by stock wells, less than 1000 ac. ft./yr
West Creek above Crow well	E I	1000	270	25,500	
Pindabarn Creek	A II	380	510	11,500	Mainly Mileura and Beringarra land systems, and water accordingly likely to be near lower limit of fair quality
Murchison Downs	D	260	330	8000	
Mooloogool	C IV	280	110	7000	
Mt. Wilkinson–Abercrombie well	F	100	80	2500	
Lindsay Gordon lagoon north	K II	130	30	2500	
Kukabubba Creek	E IV	100	40	2500	C4-S1 and C4-S2 waters (average conductivity 3310 micromhos/cm) (Chapman 1962); irrigation on small scale on Bullimore sand plain site, water from buried calcreted valley fill

Class 3 catchments					
Muggabullin swamp and Belele	C II	730	810	21,500	
Whela Creek	A I	240	260	7000	Also receives recharge from A II; ground water probably improves to fair quality in lower part of catchment
Leemans valley west	H I	210	110	5500	Lake Violet homestead in north-west of catchment has single irrigation well on Yanganoo land system (exceptional in this land system as catchments are usually too small); probable recharge here 1800 ac.ft./yr
Sodary Creek	M	160	20	4000	
Lake Ward north	J I	60	—	1500	
Lake Ward south	J II	60	10	1500	
Lake Ward west	J III	110	70	3000	Small irrigation well at Jundee homestead in west of catchment, on Jundee land system
Madoonga	B	110	60	3000	
Lake Jeffries	L	100	50	2500	
Lower Banjo Creek	H IV	80	70	2500	Out-flow of Leemans valley; fair to poor-quality water in Mileura land system on margins
Class 4 catchments					
Lake Annean (Hope River)	C III	500	420	14,000	
Leemans valley east	H III	560	320	13,000	
Bonython Creek	Q	260	170	7000	
West Creek below Crow well	E II	280	150	7500	Also receives recharge from E I; fair-quality water between Lake Violet and Lake Way, but area liable to floods
Lindsay Gordon lagoon west	K I	210	100	5500	
Leemans valley centre	H II	180	70	4500	
Milgarrie Creek	O	190	60	5000	
Windidda Creek	P	160	60	4000	
Fourteen-Mile Creek	N	120	10	3000	

* As calculated by Chapman (1962).

The United States Department of Agriculture (1954) classification has been applied by Chapman (1962) to samples of water from the area. He found that the waters tested had specific conductivities either between 750 and 2250 micromhos (C3) or between 2250 and 5000 micromhos (C4). The C3 waters mostly had low (S1) or moderate (S2) alkali hazard whilst for the C4 waters the alkali hazard is generally high (S3) or very high (S4).

From the analyses it appears that there are considerable variations of ground-water quality within each land system. The better-quality waters tested came from the tributary alluvial plains of Belele, Yandil, and Yanganoo land systems. There were single samples of only slightly lower quality from sand plain and from an erosional land system on granite. The calcreted valley fills show marked variation; some waters from Cunyu land system, for example, would be far too saline for irrigation and can only be used for stock. Salinities are generally much higher in Mileura than in Cunyu land system.

In general, the results of the analyses are consistent with the pattern to be expected in an area of interior drainage, namely a down-valley increase in salinity towards the drainage foci. The distribution of saline waters on the land system map is consistent with this pattern, but also indicates that the occurrences are somewhat irregular within the trunk valleys, sometimes occupying disconnected tracts along valley axes and in other areas having a more general extent in the lower sectors.

In Table 23 the main catchments in the Wiluna–Meekatharra area have been classified according to ground-water quality in their central alluvial aquifers—mainly calcreted valley fills—in the following way:

Class 1 has good-quality water (C3);

Class 2 has fair-quality water (C4);

Class 3 has fair-quality water, with discontinuous areas of saline water;

Class 4 has saline water throughout.

Incomplete and smaller catchments have not been included in this assessment. Sand plain, calcreted valley fills, and saline alluvial land systems have been disregarded in calculating potential recharge.

The presence of nitrate in ground water in the Wiluna–Meekatharra area is significant, as 1 p.p.m. of nitrogen represents 0·1 cwt of ammonium sulphate/ac.ft. For an annual crop requiring 5 ft of water this would be equivalent to a surface dressing of ½ cwt/ac. Unfortunately, higher nitrogen content occurs mainly in the poorer-quality waters of the area and not in those most suitable for irrigation. At Lorna Glen the mean nitrogen content from 7 wells was 23 p.p.m., whilst the Wiluna town wells were found to have a nitrogen content of 25 p.p.m. with 1345 p.p.m. total salts and 572 p.p.m. chlorides (D. G. Wilcox, unpublished data).

(*f*) *Irrigation Prospects*

Ground-water requirements for irrigation will vary with evapotranspiration and irrigation practice and also according to whether water is required merely to ensure survival of crops or to maintain active growth. Evapotranspiration rates have been discussed in Part III. Water needs will also vary with ground-water quality and the need for through drainage. For these reasons it is impossible to lay down minimum recharge for various scales of irrigation enterprises.

Applying the five criteria to the ground waters of the survey area, it is apparent that only the calcreted valley fills of the trunk valleys, with their high rates of yield, recharge, and storage, are likely to satisfy the requirements of even small irrigation schemes, and then only in areas limited by salinity mainly to Cunyu land system.

The tributary alluvial plains have some good-quality water but can rarely provide sufficiently high yields. Localized small plots on Yanganoo and Jundee land systems, as at present, with extension to Belele land system, seem to be the main possibility here.

Sand plain and erosional land systems have few prospects for irrigation, as depth to water and lack of recharge are likely to prevent development.

In attempting to place the catchments in some order of irrigation potential, water requirements only are considered here. A suitable soil would also be necessary, but with the variety available and small areas involved it is not expected to prove a limiting factor.

Only three catchments contain good-quality irrigation water (C3) and all of them are small, with potential recharge less than 4500 ac.ft./yr. Two already support small irrigation plots, and further development would seem to be limited to additional plots of this nature.

Class 2 catchments are more numerous, with generally higher potential recharge, but have only fair-quality water (C4), which will severely limit choice of soil and of crop, as only the more highly salt-tolerant crops on well-drained soils could be attempted. The two largest catchments, Yalgar–Hope River (C I)* and West Creek above Crow well (E I), have a potential recharge of over 25,000 ac.ft./yr and could possibly support small-scale group schemes if these were situated near the outflow points. The remainder could support only relatively small single irrigation areas, probably subsidiary to the pastoral stations as at present.

Class 3 catchments are likely to have little irrigation potential. It might be possible to develop the headward sectors and margins of the trunk valleys, e.g. the Leemans valley, on a modest scale, as water quality tends to be better there, but such developments would be restricted by small recharge. There are also prospects between the areas of saline ground water in the central tracts, e.g. near Belele homestead, provided the waters did not become saline after heavy pumping. The lower sectors of these catchments, where Cunyu land system gives way to Mileura land system and to associated saline alluvial land systems, can generally be ignored.

It is not anticipated that any development will take place in Class 4 catchments.

In conclusion, it is apparent that there is insufficient ground water for large irrigation schemes in the Wiluna–Meekatharra area. Because of the location of the survey area near a main watershed on the plateau of Western Australia, and because of the dismemberment of drainage into numerous interior systems, even the trunk valleys have fairly restricted tributary catchments and recharge is correspondingly

* Designations on map of ground surface types in drainage catchments.

small. For this reason, combined with the regional occurrence of saline ground water, irrigation on the scale of a group scheme is likely to be restricted to the two catchments mentioned above. Elsewhere, it is likely to be confined to localized plots subsidiary to pastoral activities as at present.

It should be emphasized that the calculations on which these conclusions are based are of a reconnaissance nature only, and very careful further study of the ground waters of any area selected for possible development would be necessary before any final assessment of irrigation potential could be made.

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PART X. THE PASTORAL INDUSTRY OF THE WILUNA–MEEKATHARRA AREA

By D. G. WILCOX*

I. ENVIRONMENTAL FACTORS AFFECTING THE PASTORAL INDUSTRY

(a) *Climate*

The major environmental control of land use in the Wiluna–Meekatharra area is climate, in particular a low and unreliable rainfall which precludes the use of sown pastures. Consequently, the industry must depend on a sparse, xerophytic native vegetation which is largely ephemeral or drought-evading, and it must remain essentially extensive in nature. Stocking rates must be adjusted to the uncertain annual rainfall, which is also a major problem opposing the build-up and improvement of flocks.

Recurrent drought affects the pastoral industry by causing periodic widespread death of trees, shrubs, and perennial grasses, and so reducing the amount of available forage as to render the maintenance of the grazing animal difficult and to threaten its survival.

The slight change from somewhat heavier winter rainfall in the west of the area to heavier summer rainfall in the east does not affect the components of the pastures sufficiently to cause regional differences in land use. At any locality, however, the seasonal incidence and effectiveness of the rainfall in any year can significantly influence the pasture response.

Throughout the area, useful and durable pastures follow effective summer rains in undegraded areas; winter rains alone produce an ephemeral growth, and winter rains following effective summer rains serve to maintain valuable perennial grasses. Any controlled grazing policy aimed at preserving the perennial pastures must reflect this seasonal response to rainfall.

High summer temperatures affect pasture response in two ways: in the first place, pasture growth is more rapid in summer; on the other hand there is a higher evapotranspirative loss which reduces the effectiveness of rainfall. By contrast, although evapotranspirative loss is lower in winter and the frequency of effective rainfall thereby increased, pasture response is slower and the herbage produced has smaller value.

In the seven months October to April, 50–60 days with temperatures above 100°F can be expected, about one-third of which have temperatures of 105°F or more. These high temperatures usually occur on single days in October, November, and April, but in December, January, February, and March they occur consecutively in periods usually of a week to a fortnight and occasionally of a month or more. Such summer temperatures affect sheep adversely by imposing stresses which limit their foraging, and also by inducing temporary sterility in breeding animals. Low tempera-

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tures in winter, with occasional frosts, can raise the basal metabolic requirements of recently shorn sheep or young lambs above their foraging ability on poor pastures, and so cause death.

The climatic factors described above apply to the survey area as a whole, although with differing effect on different types of country. Accordingly, there can be no climatic subdivision of the area from a pastoral point of view. Furthermore, the patchy distribution of rainfall may mean that parts of the area are under stress whilst others enjoy favourable conditions.

It should be stressed that although these climatic factors must be accepted as an inevitable background of the pastoral industry, in almost every case their adverse impact can be lessened by proper range management and wise husbandry.

(*b*) *Terrain*

For the most part, the survey area consists of extensive undissected plains which allow free movement of stock and which permit a rational layout of fences and of station roads. Relief exceeds 250 ft only in the whitestone ranges of the Murchison plains and in the Princess Range, and small parts of these ranges may be inaccessible to sheep. Fairly extensive parts in the central and north-eastern uplands would be impracticable for cattle, although accessible to sheep. The only other parts of the survey area which might remain unused because of inaccessibility are the salt-lake floors and the dune fields in the south-east.

The uplands are of restricted pastoral value in that, having little or no soil, they support low-density pastures. Their role as water-shedders may become increasingly important where water-harvesting or artificial recharge is employed. The widespread occurrence of undissected lower slopes and tributary alluvial plains subject to sheet-flow should facilitate water-spreading.

The major contrast between the Murchison and Salinaland plains is expressed in the pattern of pastoral resources and property development. Both provinces have central drainage tracts with extensive saltbush pastures and calcreted valley fills. However, in the Murchison plains these are flanked by extensive wanderrie tracts and stony plains, whereas in Salinaland they are bounded by unattractive sand plain with only a restricted development of tributary alluvial flats. This contrast partly explains the later alienation of much of the eastern part of the area.

(*c*) *Water Supplies*

Early development of the area was guided by the main river plains, where ephemeral surface waters were situated or where soakage supplies could be obtained at extremely shallow depth. These supplies are no longer of significance to the pastoral industry, which is now dependent on ground water from wells and bores.

Fortunately, ground-water supplies adequate for stock or household use are available in most parts of the survey area, particularly beneath the extensive alluvial plains (see Part IX). Some rocky upland areas are lacking in ground water, but since grazing intensity is so low, the paddocks are generally large enough to include alluvial flats where ground water is available.

There are moderately extensive areas of saline ground water in the lower drainage plains and adjacent to salt lakes. These are associated with valuable saltbush pastures on which the salt tolerance of the grazing animal is reduced, and some restriction to development may occur in such areas unless man-made surface storages are employed or supplies piped in.

Irrigation supplies remain almost unexploited and have had no influence upon pastoral land use to date.

(*d*) *Soils*

The soils of the Wiluna–Meekatharra area, as described in Part VI, are mainly infertile, giving rise to sparse pastures of low carrying capacity. The soils affect the pastoral industry mainly through the quality of the pastures they support, but also through their liability to degradation and the problems which they present to regeneration.

Over large areas, only a shallow soil exists above hard-pan or bed-rock. Water storage in such soils is limited and the effects of droughts are accordingly pronounced, resulting in widespread death of vegetation. These shallow soils support ephemeral pastures of low durability, and stocking must accordingly be seasonal and at a low rate. Extensive surface seals prevent water penetration, thus accentuating the ephemeral character of the pastures as well as creating unfavourable establishment conditions. Permanent deterioration of the vegetation cover and trampling caused by uncontrolled stocking result in sheet erosion, rilling near drainage lines, and increased sealing of the soil surface, thus emphasizing the natural deficiencies of the shallow soils. Regeneration of the pastures is hindered by the surface seals, which create unfavourable seed beds. In extreme cases erosion has progressed to the hard-pan, and soil degradation may here be considered complete and irreversible.

Deeper soils on wanderrie banks and in vegetation groves offer better water relationships, and they support more enduring perennial pastures with greater powers of regeneration, despite selective over-grazing. Erosion is restricted to minor wind-piling on wanderrie banks and to some rilling in mulga groves, but is rarely significant. Pasture improvement through water-spreading and clearing will be largely restricted to these areas.

Texture-contrast soils on saline alluvial plains are prone to superficial wind erosion aggravated by flooding. The subsoil pan is extensively bared to form scalded surfaces, and the topsoil sand collects in hummocks. These soils generally support valuable halophytic shrubland pastures, and have been subject to heavy stocking over long periods. Erosion has commonly reached an almost irreversible condition, rendering regeneration difficult or impossible.

The sand plain soils are subject to intermittent wind erosion, particularly after burning, but are essentially stable surfaces subject to little grazing pressure.

II. Historical

Demands for additional grazing land within the Colony of Western Australia led the Colonial Secretary in 1846 to organize expeditions into the unknown interior of the continent. These expeditions were charged with the task of exploring and reporting on the pastoral potential of the new lands.

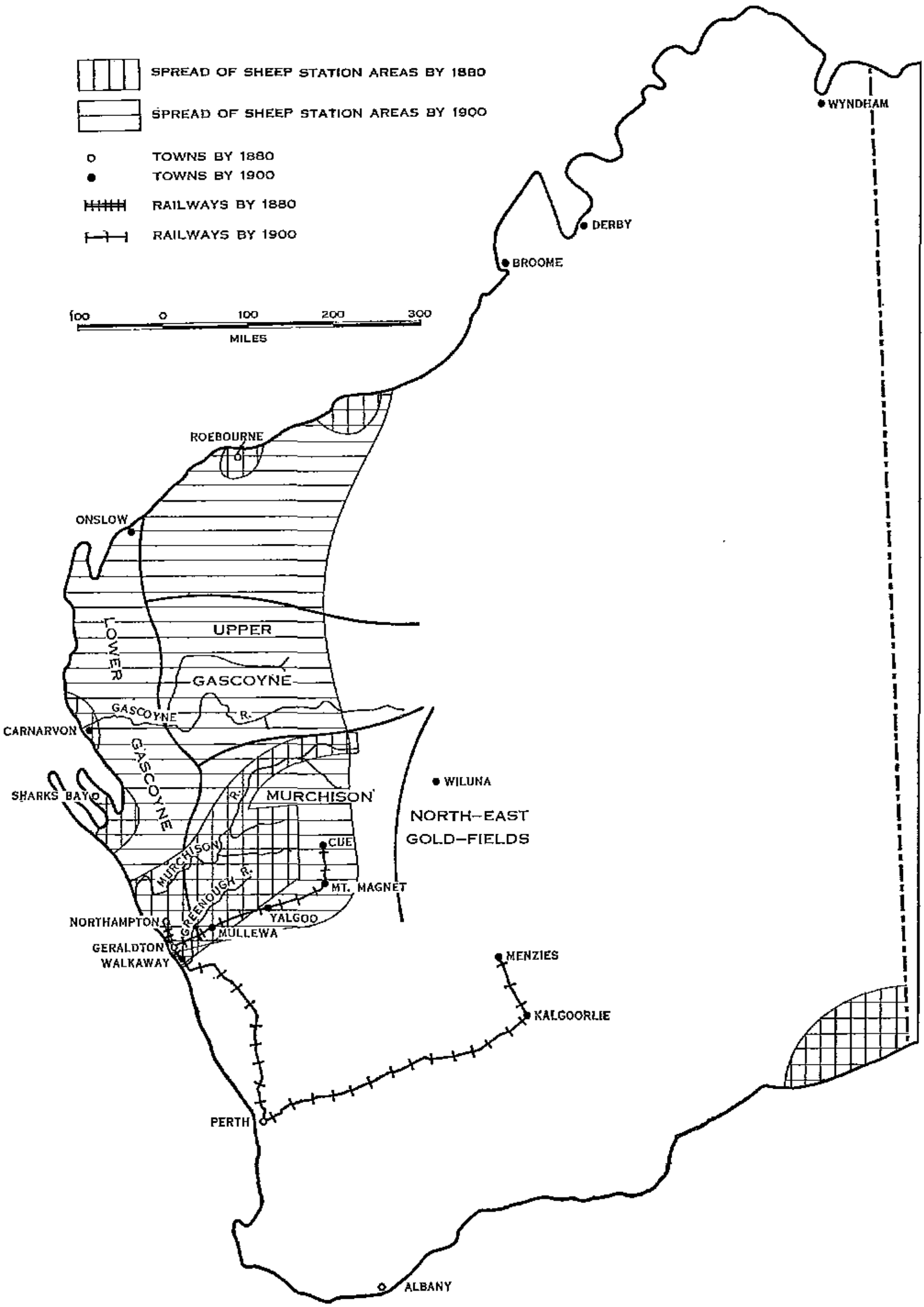

Fig. 6.—Spread of sheep station areas, towns, and railways, 1880–1900. Pastoral divisions of the mulga zone are after Melville and Rowley (1940).

The lower course of the Murchison River was rapidly reported on in the area near the coast, and in 1854 Robert Austin explored the lower parts of the Murchison and its tributaries and the country near Mt. Magnet. He underwent severe trials during this journey and reported unfavourably on the pastoral resources of the area, but did predict the occurrence of the gold-bearing ores of the Murchison Goldfield.

F. T. Gregory explored the Murchison and Gascoyne Rivers through most of their length in 1857 and gave a favourable report, but this did not encourage settlement, although his expeditions of 1861 and 1862 were followed by fairly rapid settlement to the north-west of the survey area.

The development of the area is shown in Figures 6 and 7. Initial settlement in the Murchison* region occurred about 1871, when W. Burges sent 2000 ewes to be shepherded for some months on the upper Greenough River. The success of this speculation encouraged others to take up leases, and by 1880 as many as 12 stations had been established along the Greenough and Murchison Rivers as far inland as Meekatharra.

In the early stages sheep husbandry was haphazard, and consisted of shepherding along the pools and springs of the main river systems, a grazing practice which probably accounts for the extreme degradation of the halophytic pastures of the Murchison River plains. The change to paddocking in the latter part of the nineteenth century enabled the early pastoralists to consolidate their position and by 1910 the Murchison was largely taken up. Expeditions sent by pastoralists in South Australia in the 1890s found that the only available land was further east near Wiluna and to the south.

The discovery of gold at Cue and Nannine in the 1880s was of immense value to the pastoral industry, which alone would not have caused the creation of towns and railways. Gold-mining was undoubtedly the prime cause of settlement in an otherwise remote area. In fact, the first settlers in Wiluna were almost certainly miners who came from Cue and Coolgardie in 1892. Some cattle stations were established near Wiluna in subsequent years, as well as horse stations to supply the coaching trade, cattle stations, and the mines, but it was not until the 1920s that sheep stations were established here. Even now, the area east of Wiluna is devoted to cattle-raising rather than to wool production.

In the 1890s and the early years of this century, the stock routes which traverse the survey area were established by the State. The last of these, the Canning Stock Route, was put through from Wiluna to Halls Creek, an almost incredible undertaking through uninhabited and unknown country. The stock routes were equipped with wells and troughs at intervals approximating to a day's droving, and they usually followed the best pastures. They aided the exploitation of the eastern part of the area by providing dependable routes to markets.

With the introduction of motor trucks and stock trains, these routes are now very seldom used and are no longer maintained by any Government instrumentality. They merely serve as a reminder of a not-very-distant pioneering stage.

* F. N. Melville (Melville and Rowley 1940) defines two pastoral regions in the mulga zone, the Murchison and the North Eastern Goldfields. Both are characterized by a vegetation dominated by mulga, the Murchison being all that region in the catchments of the Greenough and Murchison Rivers west of the No. 1 rabbit-proof fence. The survey area comprises part of both pastoral regions.

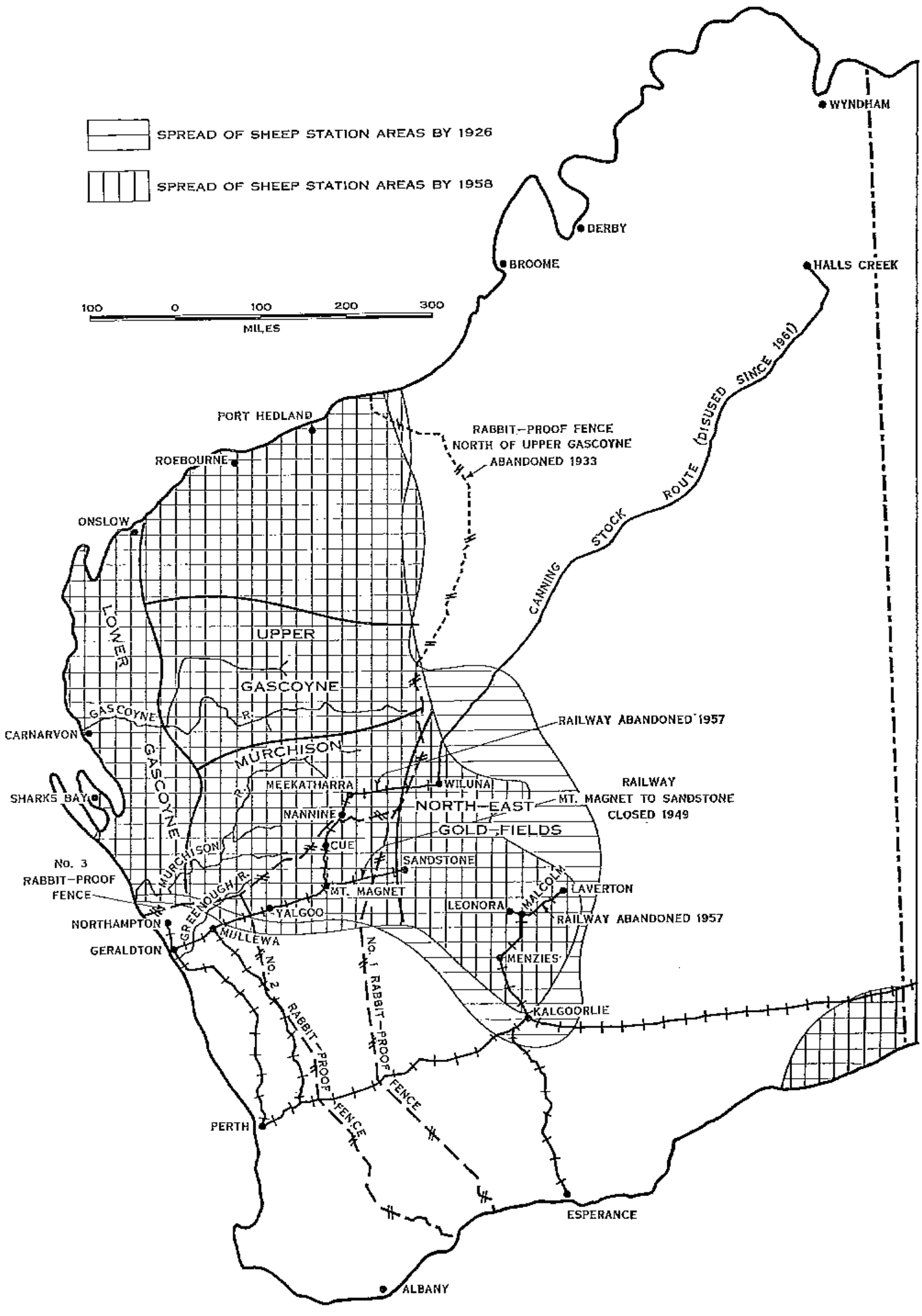

Fig. 7.—Spread of sheep station areas, towns, and railways, 1926–58. Pastoral divisions of the mulga zone are after Melville and Rowley (1940).

By the 1930s the Murchison and the North Eastern Goldfields region was almost entirely taken up, and apart from isolated pockets of unsuitable country the area was extensively developed. But the gold industry had meanwhile almost disappeared. Within the survey area only one or two very small mines, employing less than 10 men, are now being worked. The large Wiluna Gold Mine ceased operation in 1948 and Wiluna became, like Cue and Meekatharra, a small town dependent upon the pastoral industry. In 1957 services on the railway line from Meekatharra to Wiluna were discontinued owing to the small demands made upon it by the pastoral industry.

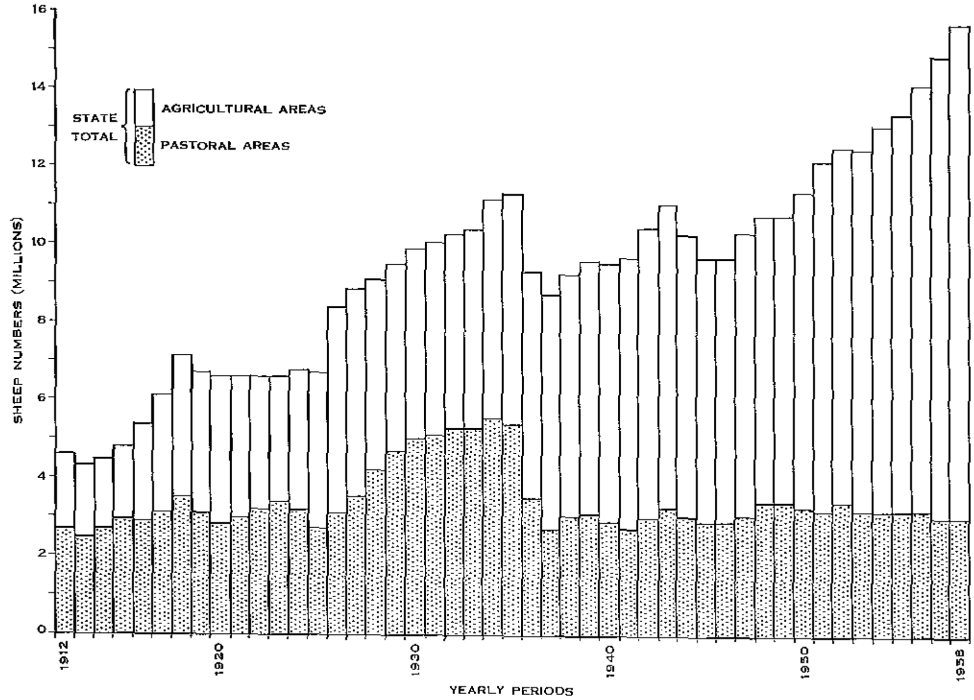

Fig. 8.—Sheep distribution in Western Australia, 1912–58.

Sheep numbers (Fig. 8) in the pastoral areas of Western Australia totalled over 5,500,000 in 1934—about half the State total. A prolonged drought in 1936–41 reduced this population to less than 3,000,000. Better seasons have seen a subsequent recovery to approximately 3,500,000, but there has since been no approach to the high numbers of the pre-drought period. It is apparent that sheep in the pastoral areas now form a very small proportion of the State total.

Comparable fluctuations in sheep numbers occurred in the Wiluna–Meekatharra area, as shown by figures for two of the earliest-established properties in the Murchison plains (Figs. 9 and 10).

III. Present Station Structure and Practice

Sheep and cattle stations throughout the survey area are held under pastoral lease from the Crown under the Land Act of 1933–56. The maximum area which may be held by a lessee is 1,000,000 ac, whilst the minimum area, which varies from one land division to another, can range from 3000 to 50,000 ac. The leases are all due for renewal in 1982.

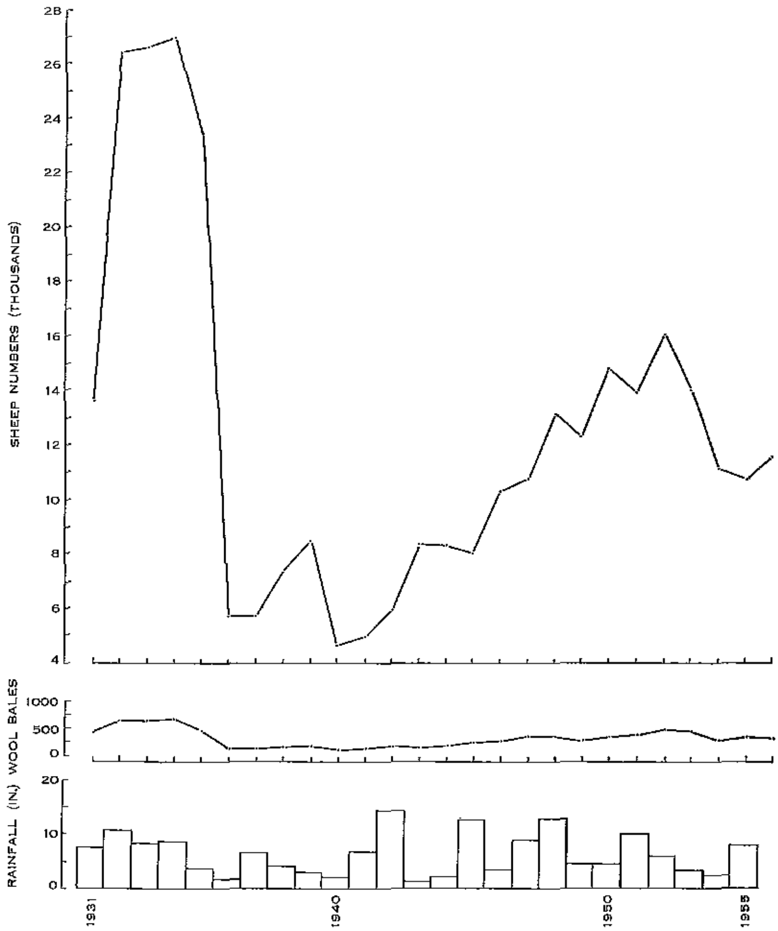

Fig. 9.—Fluctuations of sheep numbers and production of wool bales and annual rainfall, 1931–56, at a station in the Wiluna–Meekatharra area.

Under the Land Act, the lessees are required to effect improvements to the value of £10 per 1000 ac within 10 yr and to stock the lease at the rate of 30 sheep or 6 cattle to each 1000 ac within 8 yr.

The annual rental charges vary regionally depending on the appraisement of a pastoral inspector appointed under the Act, and may vary between 5*s*. and 35*s*. per annum for each thousand acres. During drought periods or other crises, lessees may request relief from rents.

(*a*) *Sheep Stations*

Sheep stations within the survey area range from just over 100,000 to 1,000,000 ac. They are boundary fenced, and within the boundary are subdivided into paddocks which are usually 5 miles square but can be as large as 12 miles square.

Each paddock is watered by wells or bores equipped with wind pumps which lift water either to tanks and troughs or to small dams. Ephemeral soaks and clay pans are now used only after rains, whilst permanent waters are almost non-existent.

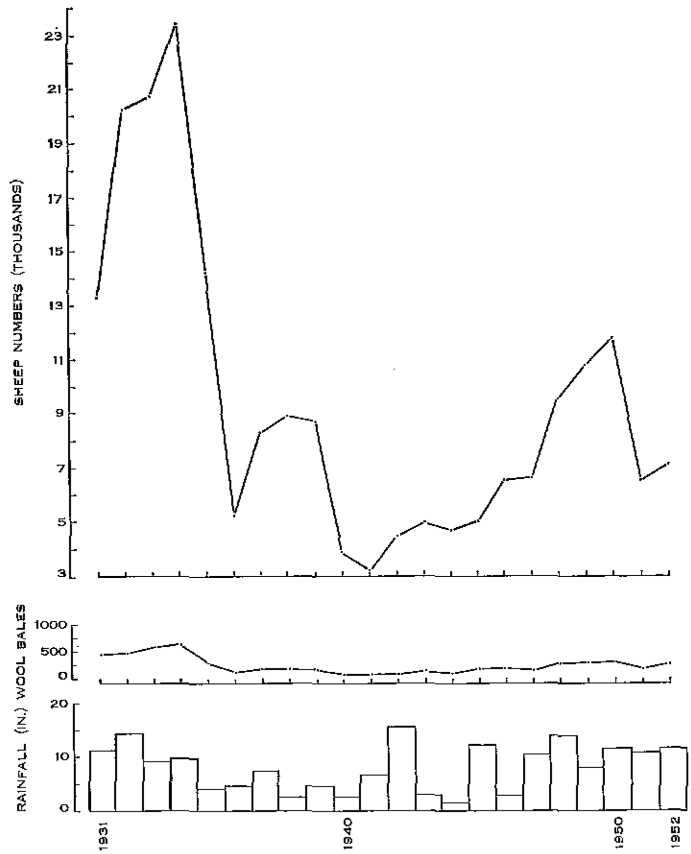

Fig. 10.—Fluctuations of sheep numbers and production of wool bales and annual rainfall, 1931–52, at another station in the Wiluna–Meekatharra area.

Stocking rates within the survey area vary with the pasture lands within the station boundary, and are even more strongly influenced by seasonal conditions. Most properties maintain 1 sheep to 40–50 ac, though this may be reduced to 1 sheep to 100 ac or be as high as 1 sheep to 30 ac. There would appear to be little immediate prospect of a return to the early 1930 rates of 1 sheep to 15–20 ac.

In general, equal numbers of ewes and wethers are held on the property. If seasonal conditions permit, most sheep should be disposed of at 5 or 6 years. However, this ideal situation is seldom realized, only wethers being sold at this age; the ewes generally reach advanced years before being sold or finally expiring on the property under conditions of severe stress which must periodically occur in this environment. Ewes are usually pastured in the best paddocks and wethers left to the less productive areas.

Rams are almost universally imported from studs outside the area. While some stations were founded with first-quality females, most have been built up from culled ewes from other properties. Initially, and almost up to the 1936 drought, lambing percentages are reported to have been high. Since that time they have declined so far that 50% is considered normal. Beyond putting breeding ewes into the best paddocks, there is little conscious management of the flock at this critical time.

The sheep on each property are commonly mustered at least twice each year, for shearing and for lamb tailing. At shearing, which occurs between March and October, sheep, particularly ewes, are visually classed for wool production, and if the season permits they are sold either to the metropolitan markets or more probably to other pastoral districts, one of which is almost certainly recovering from a drought or other crisis.

Shearing facilities on all stations are of a high standard. Quarters, shearing sheds, and yards are usually well built and well designed. This is to be expected, for the end product of the year's labour is gathered within a few days, and the quality of the wool clip and its presentation depend upon an efficiently run shearing period. Contracting teams commonly shear the sheep at a set price per head, class the wool, and deliver it in pressed and labelled bales at the shearing shed door. The wool is transported to the metropolitan area by motor truck and train, displayed on an agent's floor, and sold by open auction.

A feature of the pastoral industry is the low labour charge per head of stock. On most properties, a ratio of 2000 sheep or more to 1 man would be standard. Even though the region experiences more droughts than good seasons, there has been no attempt until very recently to limit the marked fluctuations in the stocking rate. The unfortunate animals are left to survive as best they can on sub-maintenance pastures, and sheep numbers have fluctuated widely.

In the post-war period, low running costs and high returns per head enabled these fluctuating stocking rates to remain economically feasible. Under these conditions, it was possible to buy sheep to replace the ones which had died and to pay for their purchase price within a year or two from the wool received. Within recent years, a narrowing of the gap between costs and returns has altered this attitude to management to some extent, but generally not sufficiently for there to be any attempt to keep sheep alive during droughts, even though a few properties have amply demonstrated the wisdom of additional feeding at these times.

Most sheep stations have been developed to take advantage of any chance surplus provided by the environment. There has been little effort to come to terms with the environment or to conserve its more desirable and enduring features.

(*b*) *Cattle Stations*

If the sheep stations are poorly equipped to compete with what must be considered normal environmental hazards, the cattle properties in the east of the survey area are even more vulnerable. Beyond providing water, there is little attempt at control of the animals. Some properties do boast bullock paddocks into which sale beasts are mustered before shipment, but most allow free range at all times. Under these conditions it is difficult to control breeding periods and almost impossible to avoid the build-up in the number of scrub bulls which prevents improvement in the quality of the herd. It is difficult to see how this cattle country can be effectively managed without some further subdivision. The control of breeding periods and the maintenance and improvement of the pastures are dependent upon such measures.

In good seasons, and when cattle are strong enough to travel, they are mustered together, and on nearly every property salable beasts are transported by motorized road train to the railhead at Meekatharra. The beasts are there transferred to rail trucks and sent to market in the metropolitan area of Perth. Here, depending upon their condition, they may be sold immediately for slaughter or alternatively sold as store cattle for fattening.

When cattle were driven by stock route to the railhead, only robust beasts at least 5 or 6 years old could be included for sale. Road trains now allow cattle owners to sell beasts at a much younger age, with a consequent increase in annual turn-off.

At present prices there is little to choose between the two pastoral enterprises, both sheep and cattle country showing an approximate gross return of 1*s.* 6*d.* per ac.

Since the investment per acre on cattle stations is so much lower than that on sheep stations in the area, the return on capital on cattle stations is much higher than on sheep stations. Labour charges, however, are comparable. Because of the nature of the animals carried, cattle stations are not able to take advantage of the isolated good seasons which allow sheep stations to build up their flocks again and to sell old sheep. Even in drought, there is income from wool on a sheep station when there will be no income on a cattle station. Improved facilities for handling stock and controlling pastures will increase the capital outlay on the cattle station so that it will approach that of the sheep station, and the immediate net return will be less. The potential for continued improvement will be enhanced, however. Improved management practices in both types of enterprise will accordingly bring increased returns.

IV. Present Condition of the Pastures

To some degree the condition of the pastures within the area reflects the sequence of settlement. Settlement prior to 1890 was along the watercourses of the Murchison plains. These early stations depended upon the saltbush country of the river plains and their shallow ground waters to support their sheep. The wanderrie country marginal to the main river plains was also rapidly and early exploited, even though its use quite often entailed the inclusion within the leases of large areas of short grass–forb country. The hill country and stony pastures were almost always taken up and utilized later. Both Mileura and Belele stations, which were taken up before 1880, show this pattern of development. Belele, situated on the Hope and Yalgar Rivers, and Mileura on Pindabarn and Whela Creeks, have long narrow tracts of saltbush country throughout their length, flanked on each side by wanderrie pastures. Only minor amounts of hill country and stony pastures exist in either property, whereas they are important elements on adjacent and later-settled stations.

The spinifex sand plain of the Salinaland plains is comparable to the hill country and stony pastures of the Murchison plains, in that only recently-developed stations have large tracts of these unpalatable pastures within their boundaries.

Accordingly, the saltbush country in the west of the area, and to a lesser degree the wanderrie country adjoining it, show the maximum deterioration from overstocking and mismanagement, whilst similar pastures in the later-settled areas further east are somewhat less degraded. The less resistant short grass–forb country, which has its fullest extent on the Murchison plains, is also severely degraded. The least desirable hill country and spinifex country have suffered less deterioration.

But although the date of first settlement has had its effect on the condition of the pastures of particular areas, similar trends are visible in all pasture lands of the survey area. This trend is towards deterioration and degradation, illustrated in some cases by subclimax vegetation and in others by removal of perennial vegetation and by soil erosion or by sealing of the soil surface. There has been a general increase in the density of unpalatable shrubs and herbs in almost every environment.

The deterioration in productivity of the pasture lands need not necessarily be ascribed solely to overgrazing; rather, it could be the combination of a number of factors, including both droughts and animals, and in particular the current practice of grazing all pastures continuously even when these pastures are recovering from drought condition. The inability to return to former stocking rates in the survey area is a consequence of this deterioration in range condition, and is a situation which has to be accepted in planning a new approach to management.

Recurrent drought, a very wide range in the palatability of pasture species, and uncontrolled access to all components of pasture combine in this environment to cause range degradation. For increased production and for improvement in range condition to occur, a change in management must take place and practices must be adopted which involve the recognition of the requirements of the pasture species for survival and propagation.

V. Rehabilitation of Types of Country through Improved Range Management

The methods adopted for rehabilitation of the related groups of pasture lands must be varied to allow for differences in the behaviour of the pasture plants as well as in associated environmental problems. Many of these involve the use of the deferred grazing technique originally outlined by Hyder and Sawyer (1951) and developed in north-west Australia by Nunn and Suijdendorp (1954).

(a) *Saltbush Country*

Rehabilitation and improvement of the halophytic shrubland pastures of these pasture lands depend upon the rate of return of the perennial parts of the pasture. Wilcox (1960*a*) has indicated that young perennial saltbushes are extremely vulnerable during the first two seasons of their life and need complete protection from grazing during this period. The native shrubs also need protection for shorter periods at intervals to produce seed and to recover after periods of stress. Complete protection for extended periods (more than 10 yr) does not increase production from established bushes, but rather diminishes it. It does, however, allow the number of perennial bushes to increase.

Where wind and water erosion have wrought an irreversible change in soils, revegetation is difficult and slow, because of unsuitable surfaces for establishment and the lack of nurse plants to maintain seed supplies. In some localities chequerboard furrowing with disk ploughs materially aids regeneration of perennials on extensive scalds, provided that the area is protected from grazing during the recovery period. Seeding of halophytes may be necessary in severely degraded areas.

The large-scale flooding to which the alluvial flats are subject renders the construction of check banks or other erosion control measures impracticable.

In the short grass–forb pastures with minor halophytic shrubland, notably in Ero land system, isolated small patches of halophytic pastures may occur. Except where these exceed about 3000 ac, it would not be feasible to manage them separately from the adjoining range.

The shrub component of the ephemeral short grass pastures of this pasture land will be as difficult to reclaim as the halophytes of the saline alluvial plains. Shallow and often sealed soils are a constant barrier to the establishment and perseverance of such shrubs as *Rhagodia* and *Kochia* species. Ploughing to break the surface seal and to increase soil water supplies may aid the process locally, but it is doubtful whether this method would be profitable for the small return possible.

With controlled grazing to allow establishment, the wanderrie banks and groves are capable of a return to climax conditions within a short time. Ploughing would not aid rehabilitation in these situations.

(*b*) *Wanderrie Country*

Return to the climax vegetation of the perennial pastures of wanderrie banks and mulga groves depends upon the adoption of a controlled grazing programme. In general, recovery will be aided by the relatively deep soils, which have fairly high water-storage capacity. The occurrence of favourable seasons can influence the rate of this recovery.

Wilcox (1960*b*) has shown that a protection period of up to 6 months is necessary for the regeneration and establishment of the better perennial grass species such as *Danthonia bipartita* and *Eragrostis lanipes*. Later work has indicated that at least a summer and winter growing period with protection are essential for survival if a period of moisture stress follows initial establishment. Return of the perennial grasses will increase the carrying capacity and drought resistance of an otherwise vulnerable pasture.

Wanderrie pastures are multi-storied, however, and shrubs and trees are important. Without them the association loses its nutritive balance during droughts, since most shrubs then maintain a high crude protein content. In most parts of the area the palatable shrubs have already disappeared. It appears that regeneration of the shrub components will be as slow and difficult as in saltbush country and will require long periods of protection from grazing.

(c) *Short Grass–Forb Country*

These pasture lands produce abundant growth only in good seasons, and this should be removed when it is available so that better pastures can meanwhile be allowed to recover.

The shrub components of these pastures have deteriorated considerably. Regeneration of the upper storeys will be a prolonged process, rendered even more difficult in the extensive plains where sealing and erosion of the soil have taken place. Erosion to hard-pan is an irreversible process, and it is unlikely that any return to a climax vegetation can take place under such conditions. It is doubtful whether ploughing to aid re-establishment would be worth while, since the soils are uniformly shallow and could not store more than an inch of rainfall, which is probably insufficient to support a summer-growing perennial grass in this environment.

In areas with considerable run-on the shrub population can still be high and the pasture is worth some consideration. It should be protected for extended periods along the lines recommended for saltbush country.

Rehabilitation of the minor perennial pastures of the wanderrie banks and mulga groves is possible with controlled grazing, but it is doubtful whether these more valuable pastures could be preserved under extensive grazing because of their small area and localized occurrence.

Parts of this country could be used as the source of water for water-spreading in more favoured locations, or even within the pasture land where suitable areas of deeper soils are large enough.

(d) *Hill Country*

The hill pastures have an inherently low carrying capacity. The trees are sparse and the ground flora patchy, but the shrubs are fairly frequent and extremely varied. While some are unpalatable, the majority are relished by sheep and at low stock densities are capable of supporting stock through periods of stress. This country therefore constitutes a useful drought reserve. Continuous stocking must deplete the reserves, and the country should be allowed to recuperate occasionally after prolonged drought.

Regeneration of the shrub components will be a slow process, aided by protection from grazing in good seasons. Recovery of the small areas of perennial grasses is possible provided that controlled grazing is adhered to.

Locally, the pasture land may be used to catch water and to direct it upon other more suitable areas.

While the hill country within the survey area is by no means inaccessible to sheep, some parts would not be visited by cattle, so that sheep are preferred for most effective use of the country.

(e) *Spinifex Country*

The concepts of range management, involving protection at susceptible times and the ensurance of seed supplies, do not seem to be applicable to spinifex country. These pastures are unpalatable and are only useful when the sclerophyllous spinifex is removed and when other short-lived plants take its place. It would appear that the spinifex pastures should be burnt to encourage these volunteer species and then utilized at as high a rate as possible before the dominant low-value species can compete successfully again. There is no advantage in deferring the grazing of these volunteer species, since their term is so short in the face of competition from the spinifex.

It is, however, possible that too continuous a cycle of burning and grazing might deplete the seed supplies of the more desirable volunteer species as in veld burning (Theron 1946). A return to climax conditions, should degradation occur, would be effected more easily than in other pasture lands, for the ability of the deep soils to store large amounts of water will aid re-establishment of the perennials provided that proper management is concurrently adopted.

(*f*) *General Considerations*

To summarize, proper range management depends upon the recognition of the useful species in each pasture land and of their requirements for survival under grazing. Most of the species encountered on the range are vulnerable if grazed at particular stages of their growth, but if animals are excluded during these periods the plants are able to advance to maturity and provide an adequate diet. Neglect of the requirements of the desirable plants will result in minimal productivity from the pastures and may hasten their further degradation. A programme of rehabilitation put into effect on a property may take 50 yr before the pastures have returned to optimum production. On the other hand, if deterioration continues at its present rate, it is possible that degradation could be almost complete and irreversible within the next 50 yr. It should not be difficult for the pastoralist to make a choice.

Experiments now in progress show that wanderrie country is capable of supporting at least 1 sheep to 20 ac and even better, while grazing trials on saltbush country have included treatments using 1 sheep to 4 ac with no detrimental effects, provided that proper grazing practices are adhered to.

Where dense mulga occurs, on the deeper soils and in areas of localized run-off, it is usually associated with a poor ground flora. Removal of the trees results in an improved cover of perennial grasses and shrubs which are fully accessible to sheep. It has been shown by Wilcox (1960*c*) that the production in terms of available forage from such cleared areas is in excess of that from an uncleared area. In any case, the leaf and seed fall from the trees is at very low levels during the periods of stress when the trees are relied upon to keep sheep alive. It is likely that the value of the mulga scrub resided formerly in the wealth of high-protein bushes beneath the tree canopy, and that the loss of these through unwise grazing practices has resulted in decreased durability of these pastures and in a dependence upon rainfall at least every year to maintain flocks.

Since fences are due for renewal at intervals, pastoralists should consider their relocation so that pasture lands may be more coherently fenced. In this way, management policies can be adopted which will be applicable to the entire paddock.

VI. Improved Water Use

Development of the pastoral industry was facilitated by the readily available water at shallow depths throughout the area. But beyond equipping these shallow waters with pumps adequate for the low stocking rates, there has been little attempt to exploit available ground-water supplies.

(*a*) *Improved Stock Water Supplies*

As shown in Table 19, there are few tracts of unwatered country in the west of the area, those areas which are unwatered being on properties still under development. The centre and east of the area tend to be underwatered for maximum exploitation.

In some cases these unwatered areas are mainly hill and spinifex pastures which it does not pay to develop fully, since their carrying capacities are so low. However, there is scope for development in other pasture lands. Many pastoralists do not fully develop their properties because they regard unwatered areas as drought reserves, but it is highly doubtful if sheep can reach these parts in times of stress. Productivity could be increased by providing additional waters in the better pasture lands in the central and eastern parts of the area. In saltbush country in other parts of Australia pipelines have locally been used with good effect to bring high-carrying country into production where water supplies are too saline for sheep.

(*b*) *Water-harvesting and Water-spreading*

There have been no attempts in the survey area at improving production by water-harvesting and water-spreading as practised in arid parts of the U.S.A. However, many of the land systems would lend themselves to small water-spreading schemes.

The most obvious sites for water-spreading are the localized areas of deeper soil on wanderrie banks and in mulga groves, where check banks, leaders, and contour banks could be used to transport water from zones of concentrated flow. These are essentially simple schemes requiring little surveying and needing only small banks.

In dense mulga groves, water-spreading could be combined with tree removal to increase pasture production.

The aim of water-spreading would be the preservation and increase of perennial species. This could be aided by the introduction of suitable perennial species such as buffel and Birdwood grasses (*Cenchrus ciliaris* and *C. setigerus*), associated with a properly orientated management programme.

(*c*) *Irrigation and the Pastoral Industry*

As described in Part IX, ground water sufficient for irrigation occurs extensively in the area, in Cunyu land system in particular, but is as yet scarcely developed. These supplies have been used by four pastoralists to grow supplementary feed for sheep, a practice which is still not considered feasible in this environment by the majority of pastoralists, although fodder crops can be readily grown in the area.

Lucerne is the most commonly grown fodder crop, and it produces between 8 and 10 tons of dry baled hay per acre. It is high in crude protein (*c.* 22%) and is most suitable for the short-duration drought where protein, but not energy foods, becomes limiting. High-energy supplements such as oaten hay are easily grown and can commonly produce between 4 and 5 tons of dry baled hay per acre with a crude protein content of 8%. It is not likely that this form of supplementation will greatly improve utilization of the available energy foods in short-duration droughts, but it will be more suitable for use in major droughts when fodder is almost completely lacking.

Lucerne requires approximately 90 in. of irrigation water per acre each year, while an oaten hay crop can be produced on about 20 ac.in. in the growing period. In terms of water use oats produce twice as much as lucerne, but are a fodder not suited to every type of drought emergency.

Ideally, a station irrigation scheme should be based on lucerne production, even though it requires more attention and is more subject to insect damage. It is clear from Part III that short-duration droughts, when protein but not energy becomes limiting, are more likely than droughts of long duration. In this situation, lucerne is the most suitable form of supplementation. When the water demand of lucerne is at its lowest level in winter, crops of oats could be grown for hay in order that the pumping capacity of the irrigation scheme might be maintained. These oaten hay crops could be used to form a stockpile for the major drought which must occur.

The price of locally-grown fodder is competitive with feeds bought elsewhere. Lucerne hay can be produced for between £15 and £20 per ton and oaten hay for less than half this amount, inclusive of all charges including interest and depreciation. If adequate roughage is available, sheep could be supplemented with lucerne hay at a cost of £2 per head per year if allowed about 5 lb of hay per week. Oats bought in farming areas could not cost less than £25–£30 per ton landed on a station in the survey area, and the cost of supplementation will be correspondingly higher.

The high capital cost of an irrigation enterprise is often sufficient to prevent a pastoralist from undertaking a scheme, but where the additional financial burden can be borne the scheme should be undertaken to give complete insurance against drought.

Although most of the research into supplementary feeding of stock in pastoral areas has been directed towards maintenance during drought, there is evidence to suggest that supplements for short periods could increase lambing percentages and weaner survival. This would result in heavier stocking rates, but provided the numbers can be contained within the management programme, pastures should not deteriorate, since the supplement will be used in conjunction with dried and mature pastures and not with the vulnerable growing components.

Smaller-scale irrigation projects can be erected at low cost to feed valuable stock such as rams and horses. These are usually watered by wind-pumps using automatic siphons from large-capacity tanks. Projects of this size cannot attempt to supply the needs of the breeding flock on the property.

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APPENDIX I

LIST OF SOME PLANTS OF THE AREA WITH THEIR COMMON NAMES

	Botanical Name	Local Common Name
Trees	*Acacia adsurgens*	Sugar brother
	Acacia aneura	Mulga
	Acacia burkittii	Jam
	Acacia craspedocarpa	Hopbush mulga
	Acacia grasbyi	Minnie-ritchi
	Acacia linophylla	Bowgada
	Acacia sclerosperma	Bowgada
	Acacia tetragonophylla	Curara
	Acacia victoriae	Acacia
	Callitris hugelii	Cypress pine
	Codonocarpus continifolius	Desert poplar
	Eucalyptus camaldulensis	River gum
	Eucalyptus dichromophloia	Spinifex gum
	Eucalyptus kingsmillii	Mallee
	Eucalyptus microtheca	River gum
	Eucalyptus oleosa	Mallee
	Eucalyptus striaticalyx	Cue York gum
	Hakea lorea	Corkwood
	Melaleuca microphylla	Tea-tree
	Melaleuca uncinata	Tea-tree
	Pittosporum phillyraeoides	Weeping willow
Shrubs	*Cassia desolata*	Grey cassia
	Duboisia hopwoodii	Pituri
	Eremophila fraseri	Turpentine bush
	Eremophila hastieana	Grey poverty bush
	Eremophila leucophylla	Grey poverty bush
	Eremophila macmillaniana	Grey turpentine bush
	Eremophila maculata	Fuchsia bush
	Eremophila platycalyx	Granite poverty bush
	Eremophila spathulata	Grey turpentine bush
	Eremophila xanthotricha	Grey poverty bush
	Frankenia spp.	Frankenia
	Santalum spp.	Sandalwood, quondong
	Tribulus platypterum	Hop-bush
Herbaceous shrubs	*Aizoon quadrifidum*	Sweet samphire
	Arthrocnemum spp.	Samphire
	Atriplex paludosa	Silver saltbush
	Atriplex rhagodioides	River saltbush
	Atriplex vesicaria	Silver saltbush
	Cratystylis subspinescens	Sage bush
	Enchylaena tomentosa	Berry saltbush
	Kochia georgei	Bluebush
	Kochia pyramidata	Bluebush
	Kochia triptera	Bluebush
	Lachnostachys sp.	Lambs tails
	Lycium australe	Water bush

	Botanical Name	Local Common Name
Herbaceous shrubs	*Pachycornia* spp.	Samphire
	Ptilotus obovatus	Cotton-bush
	Ptilotus rotundifolius	Perennial pink mulla mulla
	Rhagodia spp.	Tall saltbush
	Solanum ellipticum	Flannel bush
Grasses and forbs	*Aristida arenaria*	Wind grass
	Atriplex inflata	Annual saltbush
	Atriplex semilunaris	Annual saltbush
	Atriplex spongiosa	Annual saltbush
	Bassia eurotioides	Bindy-eye
	Bassia paradoxa	Gee
	Calandrinia spp.	Parakeelya
	Carpobrotus spp.	"Junga"
	Cheilanthes spp.	Ferns
	Chenopodium spp.	Goosefoot
	Cymbopogon exaltatus	Lemon-scented grass
	Danthonia bipartita	Broad-leafed wanderrie grass
	Dichanthium humilius	Blue bundle bundle
	Enneapogon spp.	Niggerheads
	Eragrostis dielsii	Murchison grass
	Eragrostis eriopoda	Woollybutt wanderrie grass
	Eragrostis lanipes	Creeping wanderrie grass
	Eragrostis setifolia	Wire wanderrie grass
	Eragrostis xerophila	Neverfail grass
	Eriachne flaccida	Swamp or claypan grass
	Eriachne helmsii	Buck wanderrie grass
	Eriachne mucronata	Gravel wanderrie grass
	Euphorbia boophthona	Balsam
	Euphorbia drummondii	Creeping balsam
	Helipterum battii	Mustard
	Helipterum humboldtianum	Mustard
	Helipterum splendidum	White daisy
	Helipterum sterilescens	Limestone daisy
	Hibiscus spp.	Hibiscus
	Kennedia spp.	Scarlet runner
	Neurachne mitchelliana	Soft wanderrie grass
	Plectrachne melvillei	Feathertop spinifex
	Ptilotus alopecuroides	Green mulla mulla
	Ptilotus exaltatus	Pink mulla mulla
	Ptilotus macrocephalus	White mulla mulla
	Salsola kali	Roly-poly
	Setaria carnei	Chinterbee
	Swainsona spp.	Vetch
	Themeda australis	Kangaroo grass
	Tragus australianus	Burr grass
	Triodia basedowii	Spinifex
	Triodia concinna	Spinifex
	Triodia plurinervata	Spinifex
	Triodia pungens	Soft spinifex

INDEX TO LAND SYSTEMS

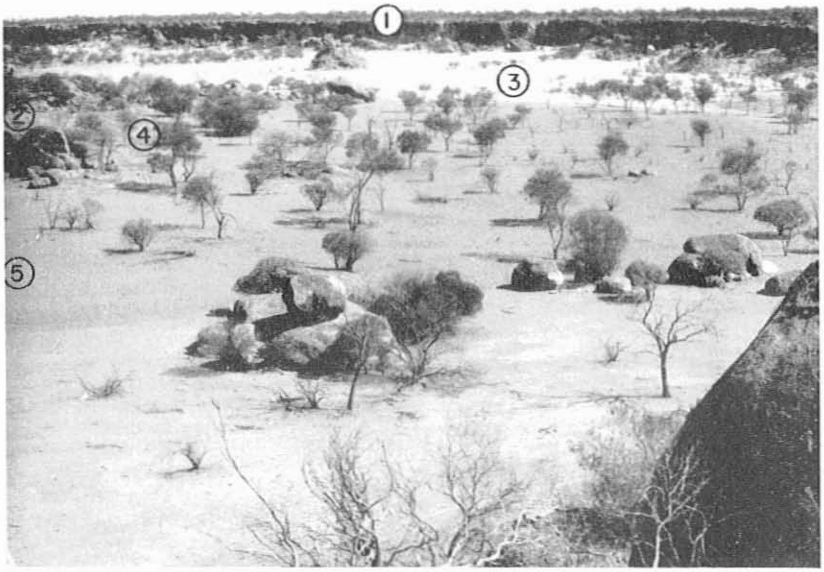

Fig. 1.—The basic descriptive unit is the land system, which has been defined as an area or group of areas with a recurring pattern of land forms, soils, and vegetation. Sherwood land system (No. 18) is a stripped granitic plain backed by laterite breakaways and carrying sparse mulga and short grass–chenopod pastures. The numbered land units are described in the text.

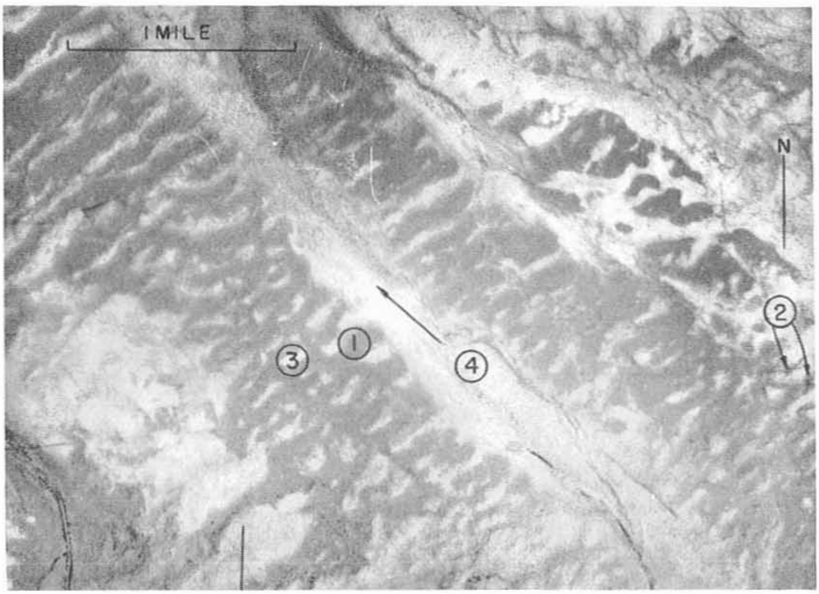

Fig. 2.—The method of survey is based on the concept that each land system is expressed on air photographs by a distinctive pattern. This aerial view of Belele land system (No. 41) shows alternating low sandy banks (dark grey) and alluvial flats (light grey) traversed by lightly channelled flood-plains, with minor mulga groves (black). These 4 elements form distinct land units as numbered. In all, 48 land systems have been mapped and described in the survey area.

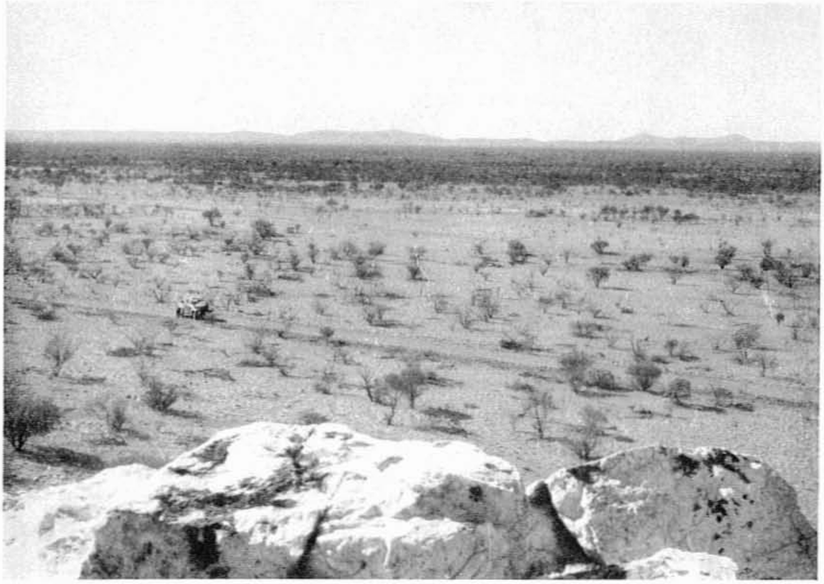

Fig. 1.—The survey area consists mostly of extensive plains with low hill ranges and plateaux of minor extent. This terrain allows free movement of stock and permits a rational layout of fences and station roads. The only parts which might remain unused pastorally because of inaccessibility are salt-lake floors and dune fields.

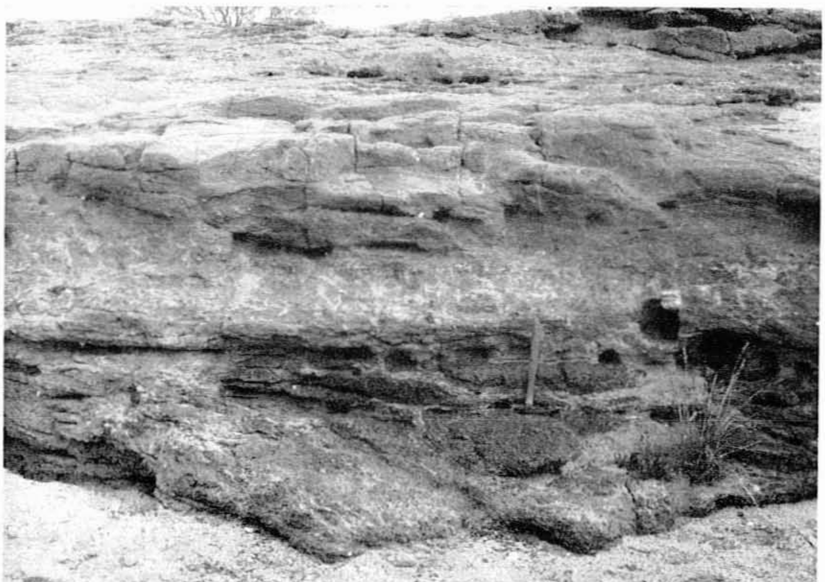

Fig. 2.—One of the outstanding features of the soils of the area is the widespread siliceous hard-pan or cement, which results in shallow soils with little drought resistance. The hard-pan is reddish brown and massive or coarsely laminar, as shown in this creek bank near Meekatharra.

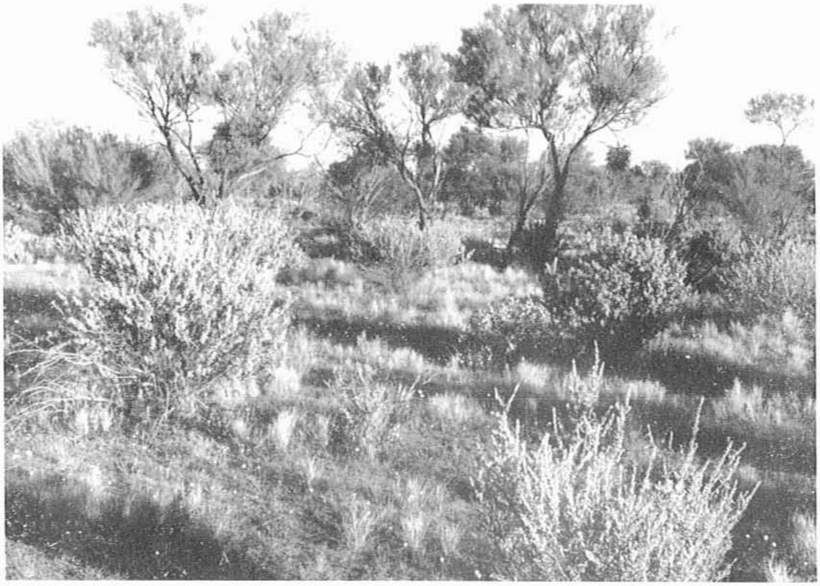

Fig. 1.—The 75 vegetation communities recognized embrace woodlands, shrublands, and spinifex grasslands. Woodland is widespread, with upper layers mainly dominated by mulga (*Acacia aneura*) and with well-developed shrub layers. *Eremophila* species are prominent shrubs and form useful indicator plants which have been employed to designate many of the mulga communities.

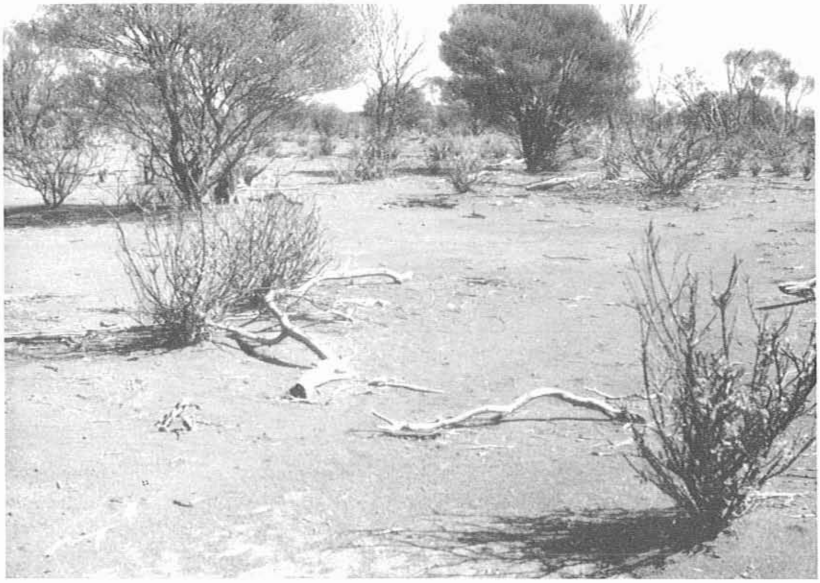

Fig. 2.—The pastoral industry depends on the sparse, xerophytic vegetation. In dry seasons, when ground cover may be impoverished or lacking, the shrub and tree layers provide nutritious top feed, which is a valuable carry-over element in the pastures. All layers of the vegetation must therefore be included in any description of native pastures. This illustration shows evidence of heavy grazing of grey poverty bush (*Eremophila leucophylla*) and mulga (*Acacia aneura*) under dry conditions.

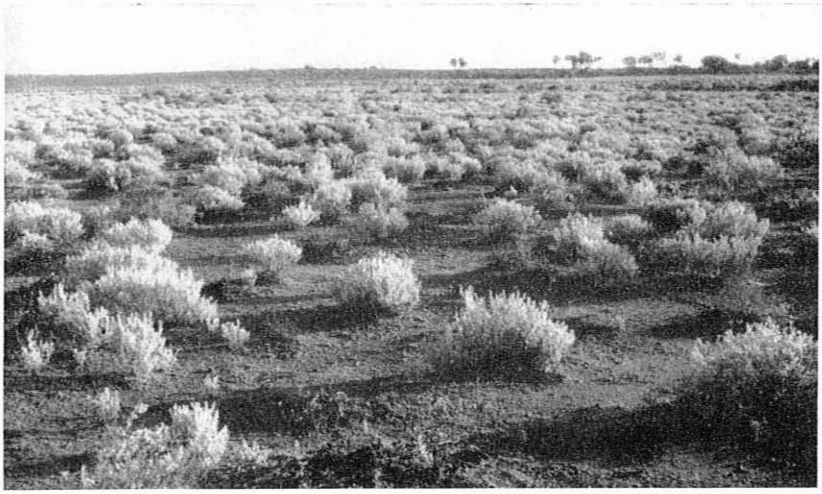

Fig. 1.—By grouping land systems with similar patterns of pastures, 9 pasture lands have been established. These are further grouped into 5 types of country on the basis of broad similarity of pastoral environment. Saltbush country (3500 sq. miles) is characterized by drought-resistant halophytic shrubs on saline alluvial plains. These are the most valuable pastures in the area but have been extensively degraded by uncontrolled heavy grazing, with loss of perennial species. Rehabilitation will depend on protection from grazing during re-establishment and at subsequent intervals to allow seed production and recovery.

Fig. 2.—Wanderrie country (7000 sq. miles) comprises mulga with wanderrie shrubland and combines valuable perennial grass pastures with useful top feed. The most important constituent is Belele land system (No. 41), where deep sandy soils on wanderrie banks carry broad-leafed and creeping wanderrie pastures, whilst the intervening alluvial flats have shallow soils with ephemeral short grass–forb pastures. These pasture lands have high carrying capacity but heavy selective grazing has caused serious reduction in perennial grasses and edible shrubs. Protection for at least 6 months is required for regeneration of perennial species.

Fig. 1.—Short grass–forb country (5300 sq. miles) comprises alluvial and stony plains with shallow soils. These yield ephemeral short annual grasses and forbs, mainly after winter rains. Top feed is scanty throughout. These pasture lands have been extensively degraded and there has been widespread sealing of the shallow soils, hindering regeneration of the shrubs.

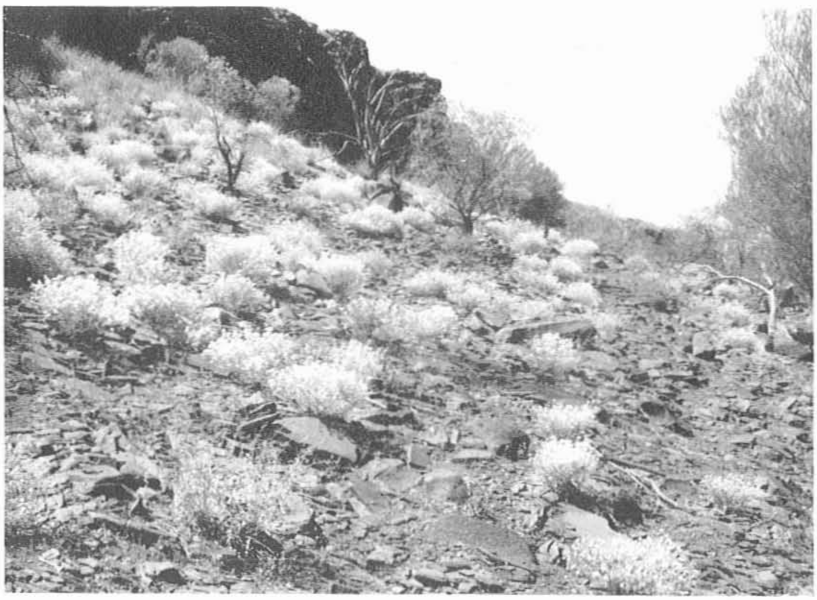

Fig. 2.—Hill country (4000 sq. miles) consists mainly of short grass–mixed forb pastures with stunted mulga shrubland. This country should be grazed for ephemeral growth after rain, but the dense shrub layer can also provide a useful grazing reserve during drought. Few parts of the area are too rugged for sheep, although certain hill tracts may be inaccessible to cattle. Hill country may be useful as catchments for water-harvesting in better country down-slope.

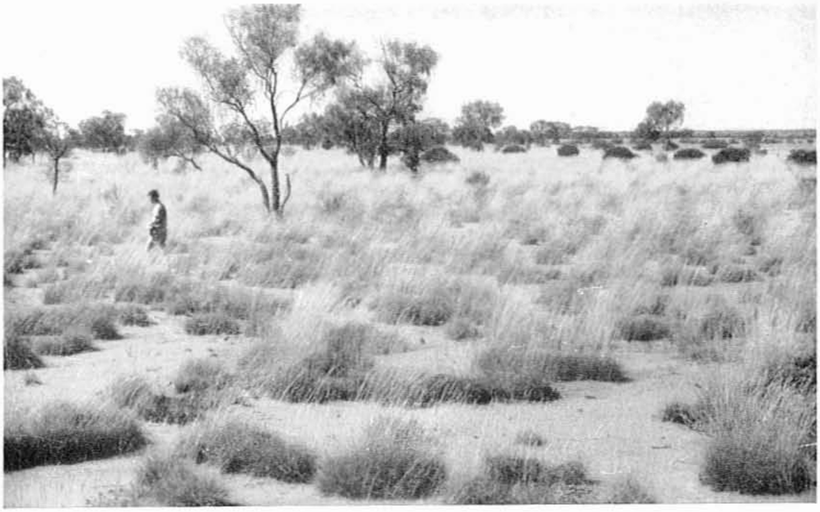

Fig. 1.—Spinifex country (5800 sq. miles) consists mainly of hard spinifex (*Triodia basedowii*) pastures on sand plain. There are variable tree and shrub layers, and small areas of more valuable pastures occur in localities receiving run-on. These pastures are unpalatable and the carrying capacity of the country is low, so that it remains little developed pastorally. Its chief value is in the transitory growth of more palatable species following burning.

Fig. 2.—Uncontrolled grazing has resulted in severe degradation, particularly the loss of more palatable grasses and shrubs. Increased wind and water erosion have caused loss of topsoil in some areas and widespread sealing of soils elsewhere, resulting in widespread death of mulga on shallow soils, and removal of shrub and ground layers. Rehabilitation involves recognizing the requirements of pasture species for survival and propagation. There may be need for checkerboard ploughing and seeding to aid regeneration in severely degraded areas.

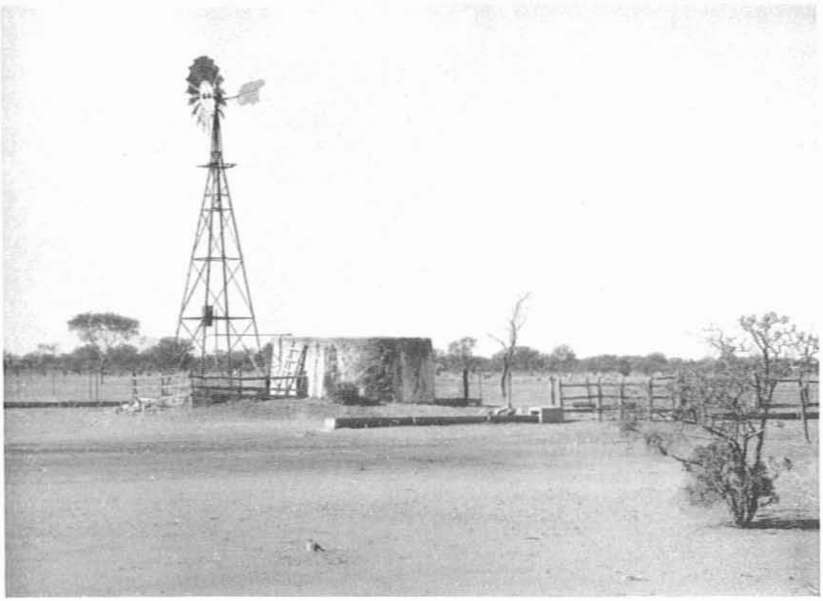

Fig. 1.—In the absence of surface water, the pastoral industry is dependent on abundant groundwater supplies at shallow depth. There are more than 1000 stock-water points as shown here, mainly producing between 1000 and 5000 gal/day.

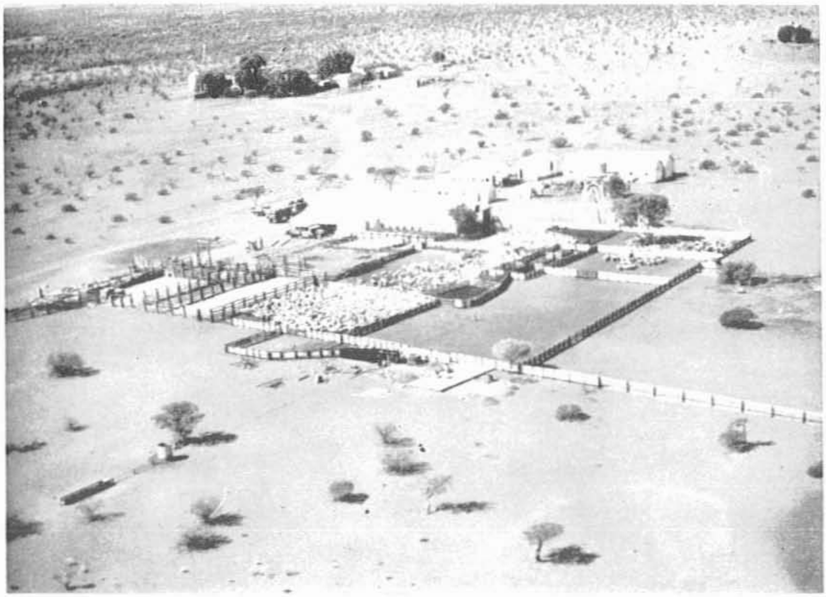

Fig. 2.—Sheep stations within the survey area range from just over 100,000 to 1,000,000 ac. They are boundary-fenced and subdivided into paddocks. Quarters, shearing shed, and yards are usually well built and well designed.

Fig. 1.—Ground water sufficient for irrigation occurs in some localities, particularly in Cunyu land system (No. 31), and could be more widely used to grow supplementary feed. Lucerne, in combination with winter oats, can be produced cheaply in the area for flock maintenance during drought and as a supplement to improve lambing percentages and weaner survival. Winter oats are here shown growing on a 5-ac plot east of Wiluna using a border-check system.

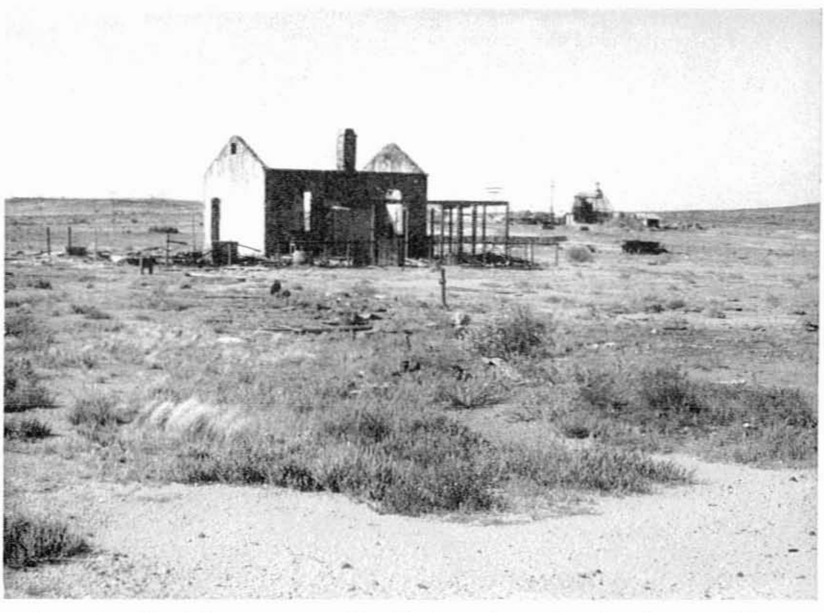

Fig. 2.—Although gold-mining was a considerable factor in the initial settlement of the area and in the development of its communications, it has now virtually ceased and many former mining settlements such as Nannine, illustrated here, have been abandoned.