FOWLERS GAP ARID ZONE RESEARCH STATION

LANDS OF THE
FOWLERS GAP-CALINDARY AREA
NEW SOUTH WALES

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LANDS OF THE FOWLERS GAP-CALINDARY AREA NEW SOUTH WALES

A Contribution to the Evaluation of Natural Resources in Northwestern New South Wales by Staff of the School of Geography, University of New South Wales, the Soil Conservation Service of New South Wales, and the CSIRO Division of Wildlife Research

Survey Team

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CHAPTER I. INTRODUCTION

By J.A. Mabbutt

I. SELECTION OF AREA

This Report describes land types in an area of approximately 12,000 sq km in northwestern New South Wales. The survey was carried out in answer to several related needs. The CSIRO Division of Wildlife Research had been studying the rabbit problem in this area, partly on an environmental basis (Myers and Parker, 1965), and it was desired to extend this base. The Soil Conservation Service of New South Wales, through its recently established sub-district office in Broken Hill, was engaged in the assessment of lands and pastures in the northwest of the State, partly in relation to soil conservation practice and partly to determine advisable stocking rates and living areas under the existing policy of the Western Lands Commission. The School of Geography, University of New South Wales, had recently carried out a survey of land types on the Field Station at Fowlers Gap, about 100 km north of Broken Hill, and wished to extend this enquiry beyond the borders of the Station, to determine the regional extent of the land types previously defined and hence the relevance of research findings at the Station for the surrounding area. Finally, a study of lands in the area was called for under the programme of the CSIRO Rangelands Research Unit, in its concern with the delimitation and study of rangelands in the southern part of the Australian arid zone.

An area was therefore chosen to comprise the previous Fowlers Gap survey in the southwest and to enclose the main area of rabbit studies in the north. The Bancannia map sheet area to the north of Fowlers Gap was omitted because airphotos of good quality were not then available, and another area was omitted in the southeast because of the lack of a published photomap for Kayrunnera South. The following 1:50,000 photomap sheets are included: Cobham Lake North and South, Fowlers Gap North, Kayrunnera North, Nucha North, Wonominta North and South, Yancannia North and South.

II. SURVEY PROCEDURES

It was agreed that the survey should be carried out by staff of the School of Geography, University of New South Wales, P.L. Milthorpe of The New South Wales Soil Conservation Service as plant ecologist, and J.C. Ngethe, a Range Officer of the Kenya Ministry of Agriculture and Animal Husbandry, at the time a United Nations (F.A.O.) Fellow in the School of Geography. Substantial support was given by the CSIRO units named above, including the supply of airphotos and photomaps, assistance with preliminary mapping, field recording, plant identification, and photography, and through the provision of vehicles and support staff. This help has continued with the drawing of the land system map and assistance with the preparation of this Report.

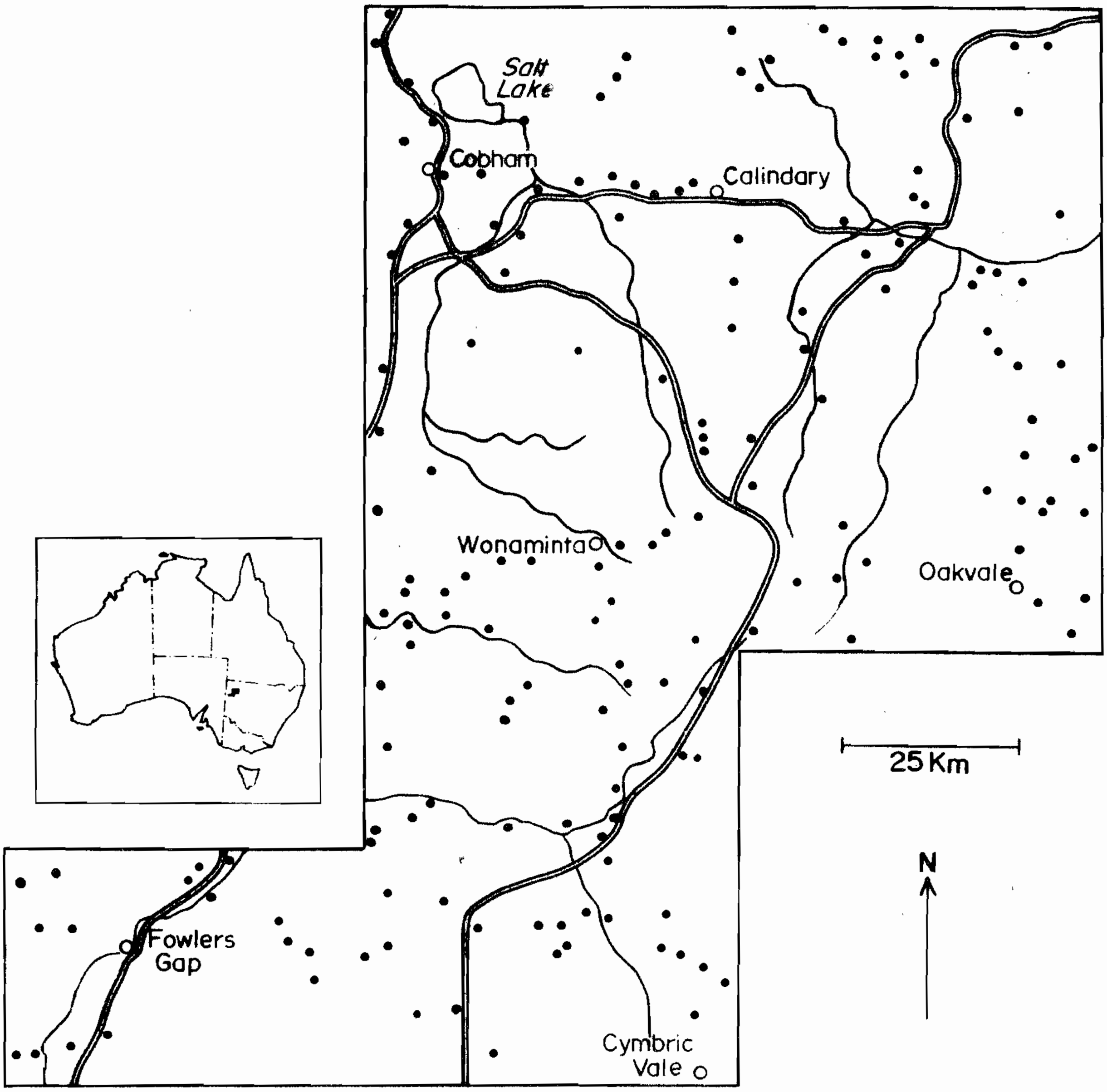


Fig.I-1. - Fowlers Gap-Calindary survey area, showing field sample points and main roads

The survey procedure was similar to that in surveys previously carried out by the CSIRO Division of Land Research. These are made by interdisciplinary teams of scientists with the object of scientifically mapping and describing large areas of country using an integrated approach. The basic descriptive unit is the land system, which has been defined as an area or a group of areas with a recurring pattern of landforms, soils and vegetation. Maps and descriptions of land systems provide a basis for an assessment of the potentiality of an area, for an approach to its land use problems, and for recommendations for further research.

The survey method is based on the concept that each land system or type of country is expressed as a characteristic airphoto pattern. Airphotos of the Fowlers Gap-Calindary area were available at a scale of 1:37,500. Guided by geologic and topographic maps of the area and using the experience of the earlier survey of Fowlers Gap Station, team members carried out preliminary mapping of airphotos in the latter half of 1968, and type areas were then chosen for field sampling. Two periods of field survey, about six weeks in all, followed in the period October-December, 1968, and a soil survey guided by previous work was carried out early in 1969. The distribution of field sample areas is shown in Figure I-1.

During 1969 the boundaries of land types were revised on the airphotos and then transferred to photomaps. Eventually the mapping types were grouped into 31 land systems, the distribution of which is shown on an accompanying coloured map, scale 1:300,000, which also includes brief descriptions of the land systems in its key.

III. THE REPORT

This Report includes tabulated descriptions of the land systems supported by a number of systematic accounts of the survey area, including its climate, geology, geomorphology, soils, vegetation, and fauna. The land systems have also been used to define pastures and pasture lands, so providing a basis for the study of pastoral land use.

The collaborative enterprise has been a complex one with inevitable cumulative delays. Nevertheless it has been instructive for those engaged in it, and it is hoped that this account of a little-known area will justify the exercise, not only as a source of regional data but also as being typical of much of the southern Australian arid zone.

IV. ACKNOWLEDGMENTS

Acknowledgment is made to the Commissioner, Soil Conservation Service, New South Wales, and to the Chiefs of the CSIRO Divisions of Land Research and Wildlife Research for their consent to the undertaking. Mr. R.A. Perry, Leader, Rangelands Research Unit, and Mr. K. Myers, CSIRO Division of Wildlife Research, have organised much of the substantial assistance received from the Organisation. Mr. Perry has also arranged for the map to be drawn by the Division of Land Research, and for the final typing of this Report for offset printing.

Those engaged in the field surveys included -

Dr. Janice Corbett, University of New South Wales, - soils survey
Professor J.A. Mabbutt, University of New South Wales, - geomorphology
P.L. Milthorpe, New South Wales Conservation Service, - survey of vegetation and pastures
J.C. Ngethe, Kenya Ministry of Agriculture and Animal Husbandry, - soils and vegetation survey
B.S. Parker, CSIRO Division of Wildlife Research, - field organisation and photography
Marjorie Sullivan, University of New South Wales, - geology and geomorphology.

Assistance in the field was provided by Messrs. E. Eversons, Division of Land Research, P. Reece, Rangelands Research Unit, and M. Stanger, Division of Wildlife Research, CSIRO.

Visiting scientists who assisted the survey included Dr. J.P. Burrell, and Messrs. P. Martenz, K. Myers and R.A. Perry.

Subsequent to the field surveys, an account of the regional climate was prepared by Mr. F.C. Bell, University of New South Wales, and of the fauna by Messrs. P. Bailey, University of New South Wales, and L.S. Hall, K. Myers and B.S. Parker, Division of Wildlife Research, CSIRO.

The land system map was scribed by Mr. M.J. Woodward of the CSIRO Division of Land Research from base materials made available by the Division of National Mapping, with revised road patterns supplied through the courtesy of Professor T.K. Hogan, Director of the W.S. & L.B. Robinson College, Broken Hill. The compilation of boundaries was carried out by Mr. K. Maynard, and typing and layout by Mrs. V. Threader, School of Geography, University of New South Wales.

In the work of editing and general collation I have been assisted by Miss Marjorie Sullivan and Messrs. J. Ngethe, K. Maynard, and J. Hodge.

The assistance of administrative staff of the W.S. & L.B. Robinson College, University of New South Wales, Broken Hill, and of the Fowlers Gap Research Station is gratefully acknowledged. Help and hospitality were also received from many pastoralists in the area, particularly Mr. F. Clark of Kayrunnera and Mr. G. Green of Tero Creek.

V. REFERENCES

MYERS, K., and PARKER, B.S. (1965). - A study of the biology of the wild rabbit in climatically different regions in eastern Australia. *CSIRO Wildl.Res.*, 10, 1-32.

CHAPTER II. LAND SYSTEMS OF THE FOWLERS GAP-CALINDARY AREA

By J.R. Corbett, J.A. Mabbutt, P.L. Milthorpe,
J.C. Ngethe, and M.E. Sullivan

I. INTRODUCTION

The survey area has been mapped into 31 land systems, defined by Christian and Stewart (1953) as "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation". The land system concept has been used in all reconnaissance land evaluation surveys conducted by the CSIRO Division of Land Research, and the method has been followed in the Fowlers Gap-Calindary survey.

Land systems are distinguished on the basis of airphoto pattern and identified by ground observations at selected sites. Each land system is here described in tabular form, in a sequence based on relief. This ordering follows that used on the accompanying map of land systems, scale 1:250,000, and in the account of landforms in Chapter V.

II. LAND SYSTEM TABLES

Each land system is described in terms of component land units, which are more homogeneous areas too small to be mapped. The relative extent of these units, which are also listed in a relief sequence, has been estimated from airphotos and is indicated in the tables as

VL	very large	more than 50 per cent of land system
L	large	30-50 per cent
M	moderate	15-30 per cent
S	small	5-15 per cent
VS	very small	less than 5 per cent

A block diagram or sketch plan accompanies each land system description and shows the relative positions of the land units, but not necessarily in proportion. Generalised geological sections are shown in the block diagrams.

Each land system table is headed by an overall description of relief, surface drainage, and geology. It also includes a land use statement which relates to the pastures and pasture lands described in Chapter VIII. The stated carrying capacities are based on a method of land assessment employed by the N.S.W. Soil Conservation Service (Condon, 1968).

In the land unit descriptions, soils are described in a profile sequence which can be related through Table VI-1 to the soils as described in Chapter VI. The vegetation of the land units is stated in terms of dominant species, including local common names where possible. Correlation between land units and upper storey communities is given in Table VII-2, and the latter in turn are related to lower storey communities in Table VII-1.

TABLE II-1. SUMMARY OF CHARACTERISTICS OF LAND SYSTEMS

Relief Class	Predominant Lithology	Predominant Soil	Predominant Vegetation	Land System
Ranges	limestone	sandy loam	mulga	Teamsters
	gneiss	sand		Barrier
	phyllite	loamy sand	mulga and bluebush	Wonaminta
	quartzite sandstone		mulga and shrubs	Faraway
				Nundooka
Tablelands			mulga	Kara Hill
	silcrete duricrust		acacias and shrubs	Quarry View
		sandy loam	mulga and shrubs	Pulgamurtie
Hills and plains		loamy sand		Flat Top
	dolerite		dead finish and shrubs	Kayrunnera
	sandstone		mulga	Ravendale
Lowlands and foot-slopes			acacias and shrubs	Pulchra
			mulga	Tekum
			saltbush	Oakvale
	shale		casuarinas and shrubs	Cymbric
		loam	shrubs	Nuntherungie
		loamy sand	shrubs	Katalpa
	shale plus aeolian sand		shrubs and pines	Nundora
	limestone	loam	shrubs	Floods Creek
	gravelly alluvium	loamy sand	saltbush	Sandstone Tank
		sandy loam		Gap Hills
Plains	finer-textured alluvium	loamy sand	Mitchell grass	Caloola
			saltbush and grasses	Conservation
				Fowlers
			mulga, whitewood and shrubs	Yancannia
		sand	mulga, shrubs and grasses	Allandy
				Rodges
	sandy alluvium			Nucha
				Gumpopla
	aeolian sand		white pine and grasses	Marrapina
Pans	evaporites and sand		cane grass, lignum, saltbush	Cobham

Table II-1 serves as a summary of the characteristics of the land systems and indicates the bases of their definition. It also shows relationships within groups of similar land systems, particularly through relief class and lithology.

III. REFERENCES

CHRISTIAN, C.S., and STEWART, G.A. (1953). - General report on survey of Katherine-Darwin region, 1946. *CSIRO Aust. Land Res. Ser.*, 1.

CONDON, R.W. (1968). - Estimation of grazing capacity on arid grazing lands. *In* Stewart, G.A. (Ed.) *Land Evaluation.* Macmillan, Canberra, 112-124.

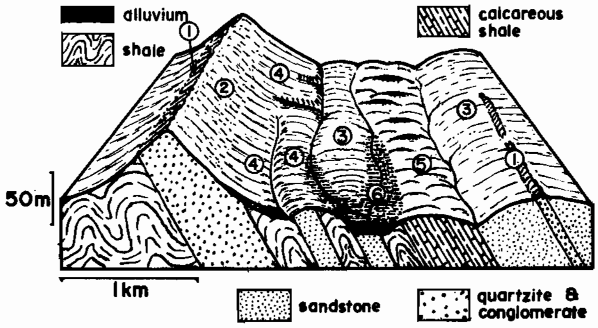
FARAWAY LAND SYSTEM Fw (26,000 ha)

General: High sandstone ranges and low rounded hills, in the south of the area and in the Koonenberry Range

Geomorphology: Strike belts to 10 km wide with prominent ridges of quartzite, sandstone and conglomerate, lower sandstone ridges, and belts of rounded hills in calcareous shale; relief to 150 m; dense trellis pattern of incising drainage; steeply dipping strata of Proterozoic and Palaeozoic age

Land Use: Hilly shrubland country with dense mulga. Units 1 and 2, partly inaccessible, support mulga and pine with limited ephemeral growth after rain; Units 3-6 have moderately dense bladder saltbush or pearl bluebush pastures with high drought resistance and with abundant short grasses and copperburrs after rain. Gullying in Unit 5 and locally in Unit 2

Estimated grazing rates: 4.9 sheep per 100 ha in Units 1 and 2, 11.6 sheep per 100 ha elsewhere



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	S	Rocky crests and faces: slopes commonly above 30%	No soil	Moderate mulga (*Acacia aneura*) with or without white pine (*Callitris columellaris* var. *glauca*), generally without grasses or forbs
2	M	Higher ridges: partly bevelled narrow crests; slopes to 50% and to 300 m long	To 30 cm of yellowish-red massive stony neutral loamy sand on sandstone; locally calcareous	Scattered mulga with or without dead finish (*Acacia tetragonophylla*); abundant pearl and low bluebush (*Kochia sedifolia*, *K. astrotricha*), bladder saltbush (*Atriplex vesicaria*), grasses and forbs
3	M	Lower ridges and strike rises: to 15 m high; flattish crests; slopes to 15% and to 200 m long	Less calcareous sites: red massive loamy sand, pedal with clay skins from 10-30 cm, stony in upper 10 cm, calcareous and weakly saline below 30 cm Calcareous sites: about 40 cm of light-brown stony loose calcareous non-saline loamy sand on rock	Probably scattered pearl bluebush (*K. sedifolia*) with abundant bottlewashers (*Enneapogon avenaceus*) and copperburrs (*Bassia* spp.)
4	S	Footslopes and spurs: local relief to 6 m; slopes to 10% and to 200 m long; some gravel	Red stony loamy sand, calcareous and saline below 30 cm; mainly pedal below 30 cm, locally pedal from 8-30 cm. In southeast of area, light-brown loose calcareous loamy sand	Moderate to sparse *Casuarina* sp. with pearl bluebush, bladder saltbush, grasses and forbs
5	S	Rounded hills: to 15 m high; short slopes to 50%; some leached cappings	To 30 cm of light-brown stony calcareous loamy sand on fresh rock; some soils leached of lime in upper 10 cm	Mallee (*Eucalyptus gillii*), with or without pearl bluebush and/or bladder saltbush, abundant grasses and forbs; mallee absent from leached cappings
6	S	Drainage tracts: flats to 20 m wide, with small tributary fans; channels to 10 m wide and 3 m deep	To 30 cm of red pedal sand with clay skins, overlying 30 cm of gravelly calcareous sandy loam, overlying at least 120 cm of red calcareous saline loamy weathering shale with clay skins	Moderate black bluebush (*K. pyramidata*) and bladder saltbush on flats; casuarinas along minor channels and river red gums (*Eucalyptus camaldulensis*) along larger channels

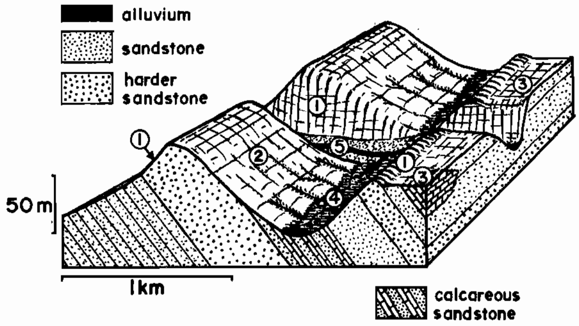
NUNDOOKA LAND SYSTEM   Nk   (2,500 ha)

General: Sandstone ranges with mulga and saltbush, mainly on Fowlers Gap Station

Geomorphology: Strike belts to 6 km wide, with massive cuestas and uplands, broadly rounded or with bevelled crests; relief to 100 m; trellis drainage; moderately to steeply dipping Lower Palaeozoic sandstone

Land Use: Hilly shrubland country with stunted mulga; bladder saltbush and pearl bluebush pastures with abundant short grasses and copperburrs after rain; Units 1 and 2 partly inaccessible. Drought resistance high. Minor gully erosion in Units 2 and 3

Estimated grazing rate: 12.4 - 13.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	S	Rocky crests and faces: short slopes, 25-100%	To 40 cm of red pedal neutral loamy sand on sandstone; commonly with stones only in upper 20 cm; shallower and stonier throughout near outcrops	Sparse to moderate mulga (*Acacia aneura*), abundant bladder saltbush (*Atriplex vesicaria*) and pearl and low bluebush (*Kochia sedifolia*, *K. astrotricha*), grasses and forbs
2	VL	Cuestas of more massive sandstone in west of belt, escarpments to 45%, dip slopes 10-20%, relief to 80 m; rocky foothills, relief to 30 m, slopes mainly to 10%; stony surfaces with gullies		
3	M	Uplands and bevelled ridges on more steeply dipping, thinner-bedded sandstone with some calcareous horizons; planed crests with slopes to 10%; marginal slopes to 45%; relief to 50 m	More calcareous areas: shallow reddish-brown stony loose calcareous weakly saline loamy sand, on calcareous sandstone Less calcareous areas: at stonier sites, about 40 cm of red pedal loamy sand on rock, becoming heavier and weakly calcareous with depth, and with stones only in upper 20 cm; at less stony sites, to 40 cm of red massive stone-free weakly calcareous loamy sand	Sparse to moderate mulga, abundant pearl and low bluebuebush, grasses and forbs Sparse *Casuarina* sp. with abundant bladder saltbush, grasses and forbs
4	VS	Minor drainage tracts: to 20 m wide, with channels to 10 m wide; narrow adjoining flats and small tributary fans	Yellowish-red massive loamy sand on rock; pedal, with strong clay skins from 25-40 cm; calcareous and saline below 40 cm; some soils overlain by red layered sand to 20 cm	Bladder saltbush and copperburrs (*Bassia* spp.), grasses and forbs; fringed by moderate mulga and casuarinas
5	VS	Major drainage tracts: floodplains to 100 m wide, with sandy or rocky channels to 80 m wide	Deep yellowish-red neutral layered sand	Prickly wattle (*A. victoriae*), perennial grass (mainly *Cymbopogon exaltatus*) and forbs; fringing community of river red gums (*Eucalyptus camaldulensis*) or casuarinas

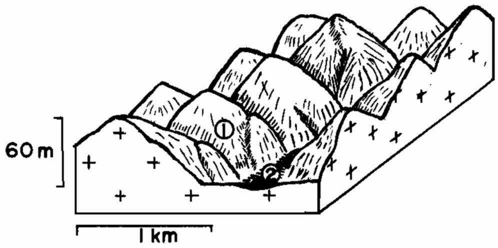
BARRIER LAND SYSTEM Br (500 ha)

General: Rugged hills in the extreme southwest of the area

Geomorphology: Densely dissected ranges, relief to 70 m; Proterozoic Thorndale Gneiss (Willyama Complex)

Land Use: Hill country with moderately dense stunted mulga and scattered bluebush and shrubs, and with ephemerals after rain; partly inaccessible. Moderate drought resistance from leaf fall of mulga

Estimated grazing rate: 9.9 - 11.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Hillslopes: rugged slopes to 35% and to 200 m long; much outcrop and boulders	Pockets of shallow reddish-yellow saline massive loamy sand	Moderate stunted mulga (*Acacia aneura*), black bluebush (*Kochia pyramidata*), and *Ptilotus obovatus*, grasses and forbs
2	L	Valley floors: Stony alluvial surfaces to 100 m wide, with channels to 15 m wide	Yellowish-red sand	Black bluebush and grasses on alluvial surfaces; river red gums (*Eucalyptus camaldulensis*) along channels

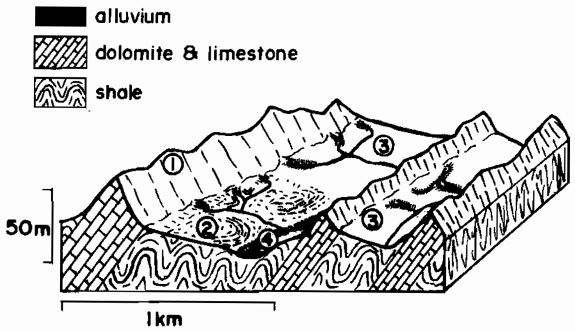
TEAMSTERS LAND SYSTEM   Tm   (7,500 ha)

General: Limestone hills mainly on Floods Creek Station

Geomorphology: Aligned short rocky ridges and footslopes; relief to 50 m; trellis drainage; steeply dipping Proterozoic dolomite, limestone, shale and sandstone (Teamsters Creek Beds)

Land Use: Limestone country with bottlewasher-copperburr pastures in Units 1 - 3 giving quick response after rain, and with scattered bluebush in Unit 1. Drought resistance low except in Unit 3, which has some saltbush. Some sheet and gully erosion, and scalding and saline areas in Unit 4

Estimated grazing rate: 12.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Ridges: rocky slopes to 150 m long; narrow rugged crests	Patches of brownish shallow stony loose calcareous saline loamy sand	Isolated pearl bluebush (*Kochia sedifolia*) with abundant bottle-washers (*Enneapogon avenaceus*) and copperburrs (*Bassia* spp.)
2	S	More stable footslopes: to 10%, with contour patterns of stony risers and less stony steps with minor gilgai	Stony risers: deep red massive sandy loam, pedal with clay skins from 10-80 cm, stony in upper 10 cm, calcareous and saline below 10 cm	Bare
			Less stony steps: deep red massive calcareous saline sandy loam, weakly pedal in upper 100 cm and locally leached to 10 cm	Isolated bladder saltbush (*Atriplex vesicaria*) with abundant grasses
3	M	Less stable footslopes: to 10% and to 100 m long	To 40 cm of brown loose calcareous saline loam on rock, becoming sandier with depth	Abundant bottlewashers, copperburrs and forbs
4	S	Drainage tracts: scalded alluvial surfaces to 150 m wide; shallow sandy channels to 15 m wide	Deep red saline massive sandy loam, stony in upper 5 cm, calcareous and pedal below	Prickly wattle (*Acacia victoriae*), black bluebush (*K. pyramidata*) and berry saltbush (*Rhagodia spinescens*), abundant grasses, forbs and legumes

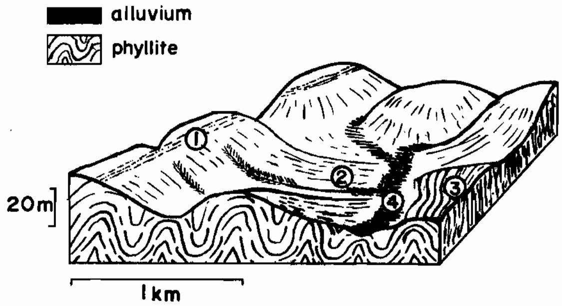
WONAMINTA LAND SYSTEM Wm (19,000 ha)

General: Shale ridges near Wonaminta Homestead

Geomorphology: Strike belt to 8 km wide of rounded and discontinuous ridges on steeply dipping Proterozoic phyllite and schist with minor quartzite and local quartz intrusions (Wonominta Beds); relief mainly to 30 m; incised dense dendritic to pinnate drainage

Land Use: Shale hill country with scattered mulga and black bluebush, and with isolated areas of bladder saltbush mainly in Units 2 and 3. Abundant short grass-forb and bottlewasher-copperburr pastures giving quick response after rain. Drought resistance moderate

Estimated grazing rate: 12.8 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Hillslopes: to 25% and to 30 m long, with much weathering rock exposed	Shallow reddish-yellow loose neutral stony loamy sand	Scattered stunted mulga (*Acacia aneura*) and dead finish (*A. tetragonophylla*); black bluebush (*Kochia pyramidata*) with abundant bottlewashers (*Enneapogon avenaceus*) and forbs
2	L	Footslopes: smooth slopes, generally less than 10% and to 100 m long	To 20 cm of reddish-yellow loose stony loamy sand, locally calcareous and saline	
3	S	Plains: undulating, mainly to 500 m in extent, with slopes to 10%; contour patterns of stony risers and less stony steps	Stony risers: deep brownish-red massive loam, pedal with clay skins from 10-50 cm, calcareous and weakly saline below 50 cm, on weathering rock at about 100 cm	Mainly bare
			Stone-free steps: deep reddish-brown massive loam, weakly pedal with clay skins from 10-40 cm, calcareous and saline below 40 cm, on weathering rock at about 100 cm	Scattered bladder saltbush (*Atriplex vesicaria*) with abundant copperburrs (*Bassia* spp.) and grasses
4	S	Drainage tracts: to 50 m wide; shallow channels to 15 m wide, with sand and gravel beds	Reddish-brown massive calcareous saline loamy sand with stony layers	Black bluebush and perennial grasses along banks; channels generally bare

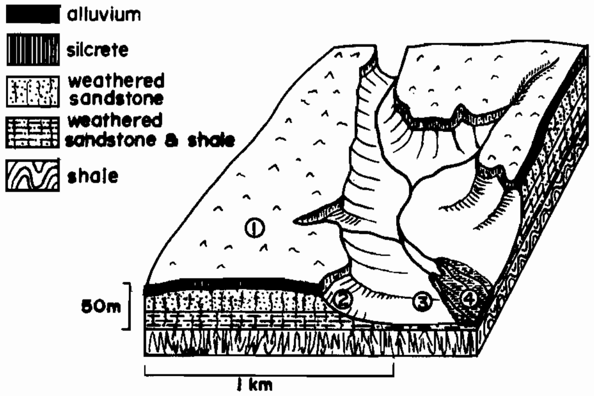
QUARRY VIEW LAND SYSTEM Qv (28,000 ha)

General: Stony tablelands near Quarry View Homestead

Geomorphology: Boulder-strewn, silcrete-capped plateaux with steep fringing escarpments, relief to 60 m, and minor plains with silcrete rises; dense radial drainage; weathered, flat-lying, sandstone, conglomerate, and shale of Cretaceous (Rolling Downs Group) and Tertiary age

Land Use: Hilly shrubland country with mulga and cabbage tree, with sparse bladder saltbush and black bluebush pastures, grasses and copperburrs after rain. Drought resistance moderate. Sheet and gully erosion moderate in Units 2 and 3 and severe in Unit 4

Estimated grazing rate: 17.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Plateau surfaces: slightly dissected, with slopes to 5%; large areas of silcrete boulders to 100 cm	Pockets of red neutral massive loamy sand to 20 cm, on silcrete	Scattered mulga (*Acacia aneura*), and cabbage tree (*A. cana*), bladder saltbush (*Atriplex vesicaria*) and black bluebush (*Kochia pyramidata*), grasses and forbs
2	VS	Escarpments: slopes to 50% and to 150 m long; upper part - discontinuous breakaway of silcrete; lower part - boulder-mantled slopes in pallid rock, with many gullies	To 20 cm of loose yellowish-red loamy sand, on rock	
3	M	Footslopes: stony slopes to 10% and to 500 m long	To 40 cm of reddish-yellow neutral massive loamy sand	Perennial bladder saltbush and black bluebush with abundant grasses and forbs
4	VS	Drainage tracts: to 150 m wide, channels to 50 m wide	Deep red neutral sand, calcareous at depth	

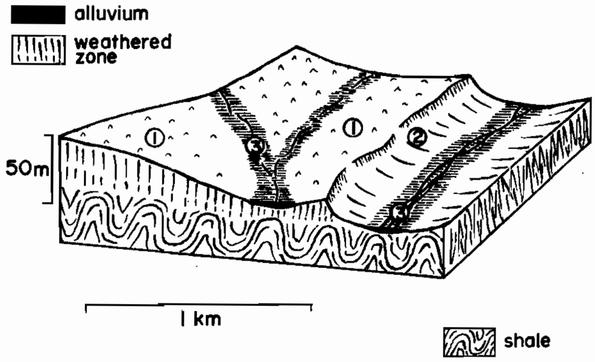
PULGAMURTIE LAND SYSTEM   Pg   (20,500 ha)

General: Rolling stony uplands with breakaways, in the central part of the area

Geomorphology: Silcrete-mantled undulating uplands, relief to 40 m; incised dendritic drainage; weathered, flat-lying sandstone, conglomerate, and shale of Cretaceous (Rolling Downs Group) and Tertiary age over weathered Proterozoic shale (Wonominta Beds)

Land Use: Lowland shrubland country, with degraded bladder saltbush pastures; abundant short grasses and copperburrs after rain. Drought resistance low to moderate. Minor sheet and gully erosion in Units 2 and 3

Estimated grazing rate: 12.1 - 12.8 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Uplands: slopes to 5% and to 500 m long; dense mantle of silcrete boulders	About 20 cm of reddish-yellow stony calcareous loose sandy loam on rock	Bladder Saltbush (*Atriplex vesicaria*) and black bluebush (*Kochia pyramidata*), abundant grasses and forbs
2	L	Minor escarpments and footslopes: discontinuous, to 15% and to 250 m long; minor gravel cover and locally gullied	About 20 cm of red stony neutral loose loamy sand on rock	Scattered mulga (*Acacia aneura*) and cabbage tree (*A. cana*), bladder saltbush and black bluebush, grasses and forbs
3	S	Drainage tracts: stony surfaces to 750 m wide, trench-like channels to 50 m wide	About 30 cm of red massive sand overlying mottled pink and yellow calcareous saline massive loamy sand	Moderate to sparse bladder saltbush and black bluebush with abundant grasses and forbs; scattered prickly wattle (*A. victoriae*) in channels

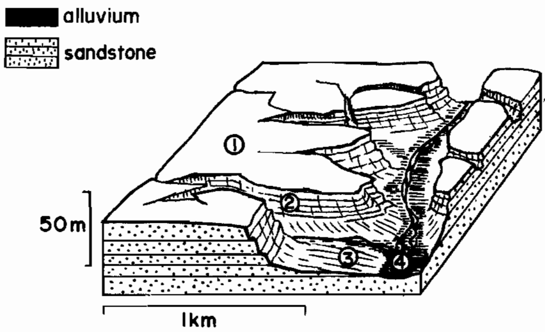
KARA HILL LAND SYSTEM Kh (19,500 ha)

General: Sandstone tablelands near Koonawarra Homestead

Geomorphology: Plateaux to 20 km in extent, relief to 30 m; marginally incised, rectangular drainage; flat-lying Devonian sandstone (Ravendale Formation)

Land Use: Hill country with moderately dense stunted mulga and short grass-forb pastures which respond after rain; partly inaccessible. Moderate drought resistance, mainly due to leaf fall of mulga. Moderate to severe sheet erosion in Units 2 and 3

Estimated grazing rate: 5.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Plateaux: undulating, dissected surfaces, slopes to 10%	About 30 cm of yellowish-red stony calcareous weakly saline weakly pedal loamy sand on rock	Scattered to dense stunted mulga (*Acacia aneura*) with abundant grasses and forbs
2	M	Escarpments and hillslopes: to 60% and to 250 m long, rocky or stony	About 30 cm of yellowish-red stony weakly calcareous weakly saline massive loamy sand on rock	Scattered to dense stunted mulga with abundant grasses and forbs
3	L	Footslopes: to 10% and to 200 m long, with minor outcrop	To 60 cm of yellowish-red massive loamy sand, calcareous saline and weakly pedal below 10 cm	
4	VS	Drainage tracts: to 50 m wide, channels to 15 m wide	At least 100 cm of red calcareous saline massive loamy sand	Scattered black bluebush (*Kochia pyramidata*) and perennial grasses along channels; scattered river red gums (*Eucalyptus camaldulensis*) on channel banks

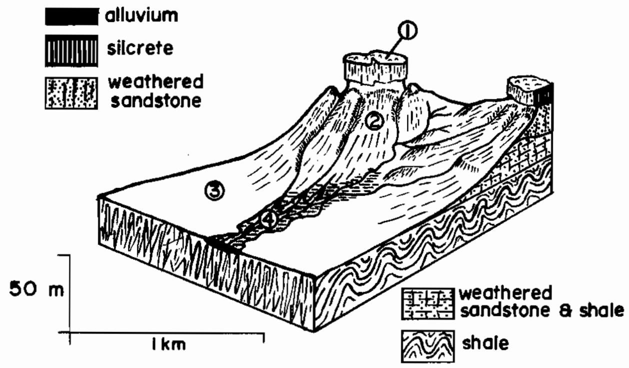
FLAT TOP LAND SYSTEM Ft (10,500 ha)

General: Isolated flat-topped hills and surrounding plains throughout the area

Geomorphology: Silcrete-capped mesas and adjacent plains; relief to 80 m; dense radial drainage; weathered, flat-lying, sandstone, conglomerate, and shale of Cretaceous (Rolling Downs Group) and Tertiary age

Land Use: Lowland and hilly shrubland country with bladder saltbush, pearl bluebush and black bluebush pastures, and with abundant short grasses and copperburrs after rain. Drought resistance moderate, depending on abundance of perennial shrubs. Gullying and minor sheet erosion in Units 2 and 3

Estimated grazing rate: 10.6 - 12.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VS	Mesa tops: silcrete-capped, to 500 m in extent; boulder-strewn surfaces	Patches of red neutral massive loamy sand to 20 cm, on silcrete	Mainly treeless or with scattered mulga (*Acacia aneura*) and cabbage tree (*A. cana*), with sparse black bluebush (*Kochia pyramidata*) and abundant grasses and forbs
2	S	Hillslopes: to 50% and to 150 m long; upper part - discontinuous breakaway of silcrete, lower part - boulder-mantled slopes in weathered rock with structural ledges; many gullies	Patches of yellowish-red loamy sand to 20 cm, on rock	Sparse mulga, scattered to dense pearl and black bluebush (*K. sedifolia*, *K. pyramidata*) and bladder saltbush (*Atriplex vesicaria*), abundant chenopods, grasses and forbs
3	VL	Footslopes and plains: stony slopes steepening to 10% and to 1 km long	Reddish-yellow pedal loamy sand over mottled pink and yellow massive calcareous saline loamy sand	
4	VS	Drainage tracts: to 300 m wide, shallow anastomosing channels	Deep red neutral sand, calcareous at depth	

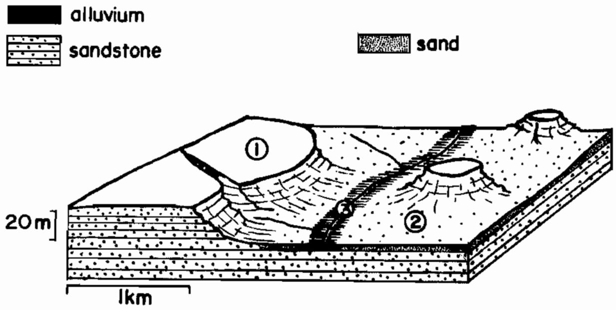
RAVENDALE LAND SYSTEM Rd (8,500 ha)

General: Sandstone hills between Koonawarra and Gnalta

Geomorphology: Mesas and small tablelands of flat-lying Devonian sandstone (Ravendale Formation), relief to 30 m, and minor plains with Quaternary sand cover; radial drainage, restricted to hillslopes

Land Use: Hill country with scattered stunted mulga and short grass-forb pastures giving ephemeral growth after rain. Limited grazing of low drought resistance. Severe sheet erosion in Unit 1 and sand drifting locally in Unit 2

Estimated grazing rate: 7.6 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Uplands: to 2 km in extent; flattish or slightly rounded crests; slopes to 60% and to 100 m long; stony surfaces with outcrop ledges	About 30 cm of yellowish-red stony calcareous weakly saline weakly pedal loamy sand on fresh rock	Scattered to dense stunted mulga (*Acacia aneura*) with abundant grasses and forbs
2	VL	Lowlands: slopes to 10% and to 300 m long	To 60 cm of yellowish-red massive loamy sand, calcareous weakly pedal and saline below 10 cm	Mainly scattered grasses and forbs
3	VS	Drainage tracts: to 50 m wide, with channels to 15 m wide	At least 100 cm of red calcareous saline massive loamy sand	Scattered black bluebush (*Kochia pyramidata*) and perennial grasses along channels, scattered river red gum (*Eucalyptus camaldulensis*) on banks

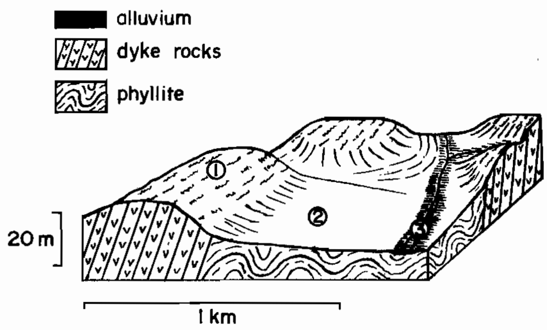
KAYRUNNERA LAND SYSTEM Ka (7,000 ha)

General: Low hills of dark rock near Kayrunnera Homestead

Geomorphology: Aligned hills and ridges of basic dyke rocks, relief to 15 m, traversing plains on steeply dipping Proterozoic phyllite; dense dendritic drainage on footslopes

Land Use: Lowland shrubland country with bladder saltbush and black bluebush pastures, and hill country with scattered dead finish, pearl bluebush, and abundant short grass-forb pastures after rain. Drought resistance moderate. Minor sheet erosion in Units 1 and 2

Estimated grazing rate: 11.6 - 14.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Hills and ridges: flattish crests to 2 km long, and slopes to 20% and to 100 m long; much outcrop and surface stone, minor gullies	Patches of reddish-brown calcareous saline stony loose loamy sand to about 10 cm on rock	Scattered dead finish (*Acacia tetragonophylla*) with sparse caustic bush (*Sarcostemma australe*), pearl bluebush (*Kochia sedifolia*), grasses and forbs
2	VL	Footslopes and plains: smooth slopes to 5% and to 200 m long; cover of fine stone, locally with contour pattern of alternate stony bands and less stony bands with some gilgai	Stony bands: about 50 cm of red massive loamy sand on reddish-yellow calcareous saline loamy sand Less stony bands: deep red calcareous saline massive loamy sand	Bare Bladder saltbush (*Atriplex vesicaria*) and black bluebush (*K. pyramidata*), with abundant grasses and forbs
3	S	Drainage tracts: mainly to 50 m wide, with small shallow channels; to 300 m wide along larger through-going channels	Reddish-brown calcareous saline massive loamy sand, interbedded with pedal loamy sand and irregular stony layers	Bladder saltbush and black bluebush on flats; tobacco tree (*Nicotiana glauca*) and waterbush (*Myoporum* spp.) in channels

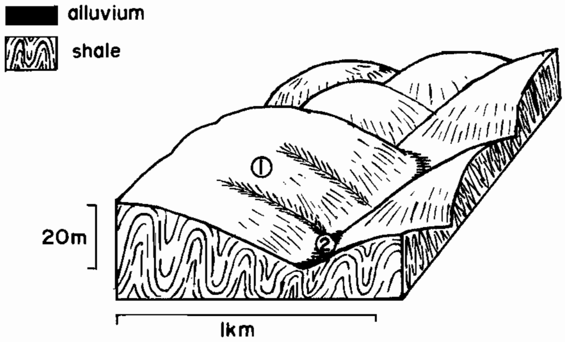
CYMBRIC LAND SYSTEM Cm (9,000 ha)

General: Steeply rolling country and low hills near Cymbric Vale and Floods Creek Homesteads

Geomorphology: Lowlands, low hill belts, and minor escarpments; relief to 30 m; incised dense dendritic drainage; steeply dipping Proterozoic calcereous shale with dolomite (Teamsters Creek and Wonominta Beds)

Land Use: Lowland shrubland country, locally with clumps of casuarinas; abundant short grasses and copperburrs after rain. Moderate drought resistance. Minor sheet and gully erosion

Estimated grazing rate: 15.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Slopes and rounded crests: smooth slopes to 15% and to 200 m long; much outcrop, quartz gravel, and calcareous nodules	To 10 cm of stony reddish-brown calcareous saline sandy loam on rock	Bladder saltbush (*Atriplex vesicaria*) and black bluebush (*Kochia pyramidata*), locally with clumps of *Casuarina cristata* and mulga (*Acacia aneura*); abundant grasses and forbs
2	S	Drainage tracts: to 25 m wide, shallow sandy channels	To 50 cm of reddish-brown calcareous saline weakly pedal loamy sand on rock	Dense bladder saltbush and black bluebush with grasses and forbs

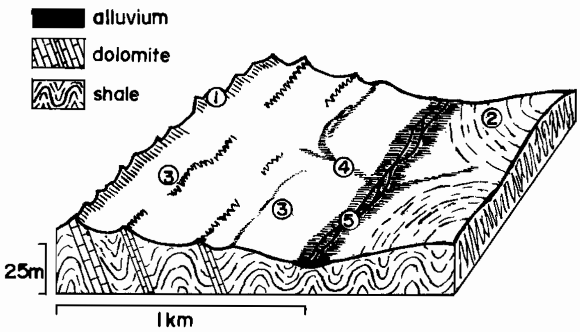
FLOODS CREEK LAND SYSTEM Fc (11,500 ha)

General: Rolling country with dark bands of limestone, mainly on Floods Creek Station

Geomorphology: Undulating lowlands, relief to 30 m, traversed by narrow outcrop ridges; slightly incised, dense dendritic drainage; steeply dipping Proterozoic calcereous shale with outcropping bands of dolomite, fine sandstone and quartz (Teamsters Creek Beds and Floods Creek Formation)

Land Use: Limestone country with bottlewasher-copperburr pastures giving quick response after rain; should be stocked lightly. Low drought resistance, with local areas of bladder saltbush or pearl bluebush pastures providing very limited drought fodder. Soils in Unit 3 powder readily on trampling and are subject to wind erosion; scalding in Unit 4 and local gullying in disturbed areas in Unit 2

Estimated grazing rate: 12.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	M	Strike ridges: rocky, mainly to 5 m high	Patches of shallow stony calcareous saline loose loamy sand	Bare
2	M	More stable surfaces: smooth slopes to 5%, and flattish interfluve crests; contour patterns of stony bands and less stony bands with minor gilgai	Stony bands: about 20 cm of reddish-brown neutral pedal loamy sand, overlying at least 80 cm of reddish-yellow calcareous saline massive silty loam Less stony bands: brown massive silty loam, calcareous and saline below 25 cm	Bare Sparse bladder saltbush (*Atriplex vesicaria*) with copperburrs (*Bassia* spp.); grasses and forbs
3	L	Less stable surfaces: smooth slopes to 10% and to 400 m long; flattish interfluve crests	About 40 cm of brown calcareous saline loose loam, becoming sandier with depth, on rock	Abundant bottlewashers (*Enneapogon avenaceus*) and copperburrs
4	VS	Minor drainage tracts: to 50 m wide, small channels locally	About 100 cm of reddish-brown weakly pedal loam, becoming sandier with depth, on rock; locally calcareous and saline	Prickly wattle (*Acacia victoriae*) and black bluebush (*Kochia pyramidata*), with abundant grasses, forbs and legumes
5	VS	Major drainage tracts: floodplains to 500 m wide; scalded, locally gravelly surfaces with occasional back channels; channel zones with irregular sand and gravel banks; shallow sandy channels to 25 m wide	Deep yellowish-red loamy sand, calcareous below 100 cm, with stony bands	Prickly wattle and black bluebush, with grasses and forbs; fringing community of river red gums (*Eucalyptus camaldulensis*) in channels

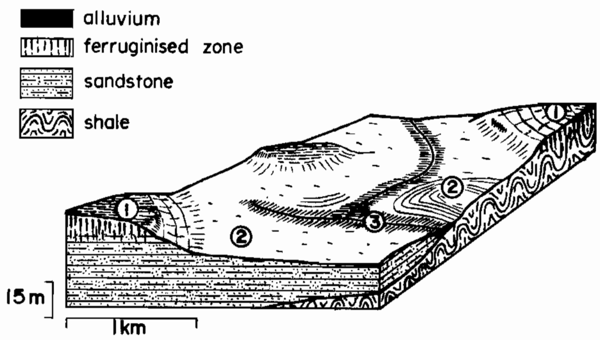
PULCHRA LAND SYSTEM P1 (47,000 ha)

General: Stony plains with low rocky rises scattered throughout the area

Geomorphology: Broadly undulating stony plains to 15 km in extent, with rocky rises of silicified and ferruginised rock; relief to 20 m; dendritic, shallowly incised drainage; flat-lying, partly-weathered Cretaceous sandstone (Rolling Downs Group) on steeply dipping partly-weathered Proterozoic sandstone and shale (Wonominta Beds)

Land Use: Lowland shrubland country with generally sparse bladder saltbush and black bluebush pastures and local areas of cabbage tree. Low drought resistance. Large areas subject to severe sheet erosion, particularly in Unit 2, and supporting little vegetation

Estimated grazing rate: 10.4 - 12.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Rocky rises and breakaways: rises to 500 m across and 20 m high; flattish stony crests with rock outcrop; breakaways and slopes to 15%	No soil; local sand cover	Scattered stunted mulga (*Acacia aneura*) and cabbage tree (*A. cana*) with sparse black bluebush (*Kochia pyramidata*) and grasses and forbs
2	VL	Plains: stony surfaces to 1 km in extent, slopes mainly 1-2%, some to 5%; locally with alternate stonier contour bands and less stony bands with some gilgai; minor gullies	Stonier bands: to 20 cm of red neutral pedal loamy sand, overlying to 40 cm of red calcareous massive silty loam Less stony bands: deep yellowish-red calcareous saline massive loamy sand	Bare Moderate to sparse bladder saltbush (*Atriplex vesicaria*) and black bluebush, with abundant grasses and forbs
3	VS	Drainage tracts: to 75 m wide, gradients to 2%; discontinuous small channels in upper sectors and channels to 2 m wide downslope	Deep yellowish-red loamy sand, calcareous and saline below about 50 cm	Moderate *Casuarina cristata* and cabbage tree with dense black bluebush and abundant grasses and forbs

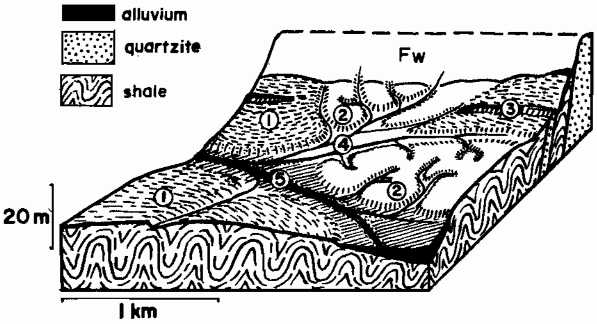
NUNTHERUNGIE LAND SYSTEM Nn (126,500 ha)

General: Undulating stony country with bands of saltbush and bare areas of bulldust soils, mainly in the south of the area

Geomorphology: Undulating lowlands with prominent contour pattern of stonier and less stony bands; relief to 15 m; minor low strike ridges; dense dendritic drainage; steeply dipping Proterozoic shale partly calcareous, with bands of quartzite and dolomite (Teamsters Creek and Wonominta Beds)

Land Use: Lowland shrubland country with bladder saltbush and black bluebush and pearl bluebush pastures, commonly with moderately dense casuarinas and leopardwood and with abundant short grasses and copperburrs after rain. Mitchell grass commonly replaces saltbush after heavy stocking. Drought resistance high due to dense shrubs and trees. Severe gullying in Unit 4, local gullying in disturbed areas in Unit 1, and wind erosion following trampling in Unit 2

Estimated grazing rate: 12.8 - 16.8 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	More stable interfluves: to 600 m in extent; flat to rounded crests; slopes mainly less than 5% and to 300 m long; contour pattern of stony risers and mainly stone-free steps with minor gilgai, becoming more pronounced downslope	Stony risers: deep brownish-red massive loam; pedal with clay skins from 10-50 cm, calcareous and weakly saline below 50 cm, on weathering shale at 100-250 cm Stone-free steps: deep reddish-brown massive loam, weakly pedal with clay skins from 10-40 cm, calcareous and saline below 40 cm, on weathering shale at 100-250 cm	Bare Dense black and pearl bluebush (*Kochia pyramidata, K. sedifolia*) and bladder saltbush (*Atriplex vesicaria*); saltbush often replaced by Mitchell grass (*Astrebla lappacea, A. pectinata*); areas of moderate to dense *Casuarina* sp. and isolated leopardwood (*Flindersia maculosa*) confined mainly to the east of the area; abundant grasses and forbs
2	M	Less stable interfluves: more narrowly dissected than Unit 1 and lacking contour patterns	Deep light-brown loose calcareous saline loam with lime hardpan from 40-100 cm	Grasses and forbs, locally with tobacco tree (*Nicotiana glauca*) on disturbed areas such as rabbit warrens
3	VS	Low rocky ridges and outcrops	Shallow reddish-yellow neutral loamy sand on rock	Bladder saltbush and black and pearl bluebush with abundant grasses and forbs
4	S	Minor drainage tracts: alluvial flats to 50 m wide, commonly severely gullied; narrowly entrenched small channels	Reddish-brown calcareous saline massive loamy sand interbedded with pedal loamy sand and irregular stony layers	Black bluebush on banks, with isolated water bush (*Myoporum montanum*) and tobacco tree
5	S	Major drainage tracts: alluvial flats to 200 m wide; trench-like channels to 3 m deep and 6-8 wide, cut into bedrock or alluvium, with gravel and sand bed loads	To 20 cm of yellowish-red layered saline sand overlying deep reddish-brown calcareous saline massive loamy sand; weakly pedal from 30-60 cm, with irregular stony layers	Black bluebush with grasses and forbs on plains; fringing community of river red gums (*Eucalyptus camaldulensis*) on channel banks

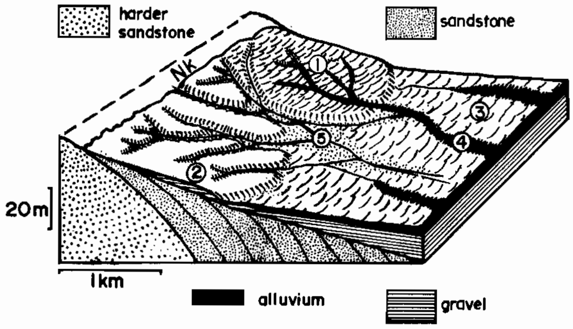
GAP HILLS LAND SYSTEM Gh (8,500 ha)

General: Slopes with bands of saltbush and Mitchell grass and stony ground, mainly on Fowlers Gap Station

Geomorphology: Footslopes to 6 km long; upper slopes planed across steeply dipping Devonian sandstone and conglomerate, locally calcareous with extensive gravel capping and dissected to 15 m by dense dendritic drainage; lower slopes, smooth lobes of Quaternary gravelly alluvium with shallow drainage depressions between larger drainage outlets; well-developed contour pattern of stonier and less stony bands

Land Use: Lowland shrubland country with dense bladder saltbush pastures in which shrub cover should be maintained by careful management. High drought resistance. Severe scalding and minor gullying in Unit 5 and local gullying in disturbed areas in Units 1 and 2

Estimated grazing rate: 16.5 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	M	Stable spur crests: planed smooth crests to 400 m wide, slopes to 1%; contour pattern of stonier risers and less stony steps	Stonier risers: deep red massive loamy sand with pedal sandy loam from 10-35 cm; calcareous below 10 cm, saline below 100 cm, stony below 180 cm Less stony steps: yellowish-red massive neutral loamy sand on stones at 100 cm	Bare Abundant bladder saltbush (*Atriplex vesicaria*), isolated caustic bush (*Sarcostemma australe*), grasses and forbs
2	M	Stripped spur crests and slopes: narrower crests than Unit 1, with steeper slopes and minor outcrop; marginal slopes to 15%; relief to 15 m	Shallow light-brown calcareous loose fine sand	Sparse *Casuarina* sp. and pearl bluebush (*Kochia sedifolia*), grasses and forbs
3	L	Alluvial lobes: to 5 km long and to 2.5 km wide, slopes to 1%; contour pattern of flatter, partly stone-covered steps and narrower risers with gilgai	Stone-free steps: deep yellowish massive loamy sand, with pedal sandy loam from 10-30 cm; calcareous below 40 cm, saline below 10 cm Stony steps: deep red massive silty loam, pedal from 10-45 cm, calcareous and saline below 45 cm Risers: deep red massive calcareous sandy loam, saline below 15 cm	Abundant bottlewashers (*Enneapogon avenaceus*) grading to areas of no perennial vegetation Bare Abundant bladder saltbush and Mitchell grass (*Astrebla pectinata*) with grasses and forbs
4	S	Shallow drainage tracts: to 100 m wide, with well-developed gilgai; discontinuous small trench-like channels	About 15 cm of yellowish-red layered sand overlying deep red massive loamy sand which is pedal for 30 cm and saline below	Sparse bladder saltbush and copperburrs (*Bassia* spp.) with or without perennial grasses
5	VS	Incised drainage tracts: alluvial flats to 50 m wide, with sandy channels to 20 m wide	Deep yellowish-red massive loamy sand, becoming heavier with depth; pedal from 15-40 cm, calcareous below 40 cm, saline below 15 cm in some areas, stones below 100 cm	Bladder saltbush and Mitchell grass on flats; black bluebush (*K. pyramidata*) and perennial grass (*Cymbopogon exaltatus*) in drainage tracts; smaller tracts fringed by sparse mulga (*Acacia aneura*), casuarinas or tobacco tree (*Nicotiana glauca*); larger tracts fringed by river red gums (*Eucalyptus camaldulensis*) and prickly wattle (*A. victoriae*)

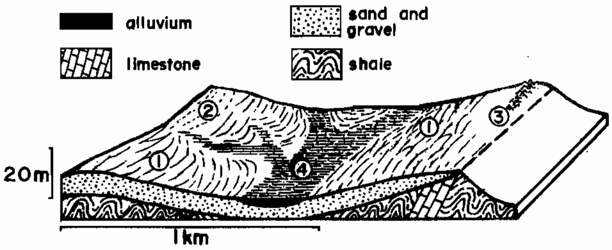
SANDSTONE TANK LAND SYSTEM St (1,500 ha)

General: Broadly undulating stony country with bands of saltbush north of Fowlers Gap Homestead

Geomorphology: Broadly undulating perched plains with prominent contour pattern of stonier and less stony bands; relief to 15 m; shallowly incised dendritic drainage; Tertiary and Quaternary gravels over weathered Proterozoic shale (Teamsters Creek Beds)

Land Use: Lowland shrubland country with dense saltbush pastures with local areas of short grasses and copperburrs. Drought resistance high. Gullying in Unit 4, and locally in disturbed areas in Units 1 and 2

Estimated grazing rate: 18.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	More stable interfluves: rounded, with slopes to 10% and to 400 m long; contour pattern of stonier risers and less stony steps with some gilgai	Stonier risers: red loamy sand, pedal from 10-50 cm, calcareous below 10 cm, saline below 50 cm Less stony steps: red massive loamy sand, weakly pedal from 10-30 cm, calcareous and saline below 30 cm, rock at 140 cm	Generally bare Abundant bladder saltbush (*Atriplex vesicaria*), grasses and forbs
2	M	Less stable interfluves: as Unit 1, but locally higher, with less marked steps, and commonly stonier	Stonier risers: red loose calcareous loamy sand, weakly pedal from 10-25 cm, saline below 10 cm Less stony steps: as for stonier risers, but less saline and with minimal ped development	Generally bare Abundant bladder saltbush, grasses and forbs
3	VS	Minor outcrops: rocky and stony rises	No soils	Isolated bluebush (*Kochia* spp.)
4	S	Drainage tracts: flats to 200 m wide, gradients 1 in 50 to 1 in 100; discontinuous small head-channels and sandy shallow main channels to 20 m wide, locally braiding	To 30 cm of red layered sand overlying deep red massive sand; weakly pedal from 50-100 cm, with stony layers	Abundant bladder saltbush, copperburrs (*Bassia* spp.) and grasses on flats; channels bare

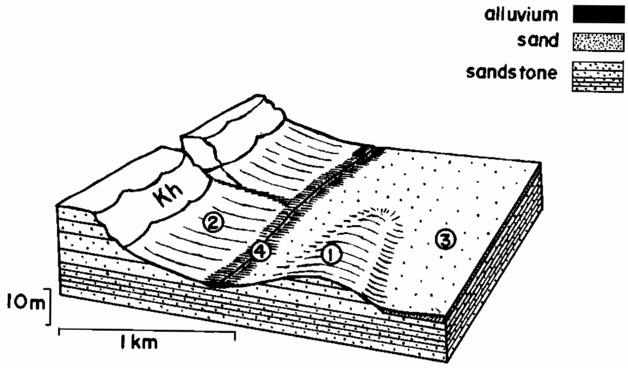
TEKUM LAND SYSTEM Tk (9,000 ha)

General: Sandy areas below sandstone hills near Koonawarra Homestead

Geomorphology: Footslopes and low rises, relief to 15 m; sparse through-going drainage; flat-lying Devonian sandstone (Ravendale Formation), extensively overlain by Quaternary sand

Land Use: Sandy country with open mulga and areas of inedible shrubs, with short grass-forb pastures yielding ephemerals after rain; should be lightly stocked. Low drought resistance. Susceptible to sand drifting, especially in Units 2 and 3, and to minor sheet erosion in Unit 2

Estimated grazing rate: 10.6 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	S	Rises: broadly rounded crests; slopes to 10% and to 200 m long; much outcrop	Red massive loamy sand, calcareous below 10 cm	Scattered stunted mulga (*Acacia aneura*), isolated native poplar (*Codonocarpus cotinifolius*), with abundant grasses and forbs
2	L	Footslopes: to 5% and to 300 m long; stony with outcrop locally and with sand cover	About 30 cm of red weakly calcareous pedal loamy sand, overlying at least 70 cm of yellowish-red calcareous massive loamy sand	As for Unit 1, locally with inedible turpentine (*Eremophila sturtii*) and hopbush (*Dodonaea attenuata*)
3	VL	Sandplain: to 500 m in extent; slopes about 1%	Deep red massive loamy sand, calcareous below 20 cm	Abundant speargrass (*Stipa variabilis*), copperburrs (*Bassia* spp.) and other grasses and forbs
4	VS	Drainage tracts: to 10 m wide, shallow sandy channels to 5 m wide	Deep yellowish-red calcareous saline massive loamy sand	Generally bare

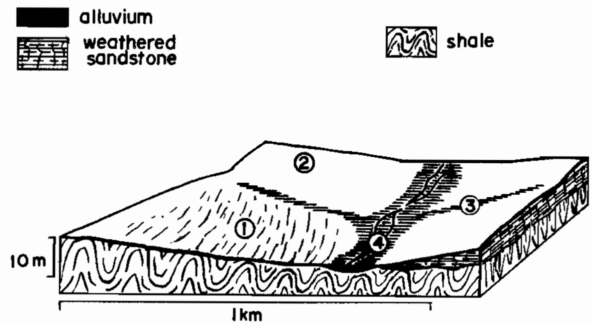
KATALPA LAND SYSTEM Kt (224,000 ha)

General: Stony plains throughout the area

Geomorphology: Extensive, very broadly undulating stony plains, relief to 10 m; sparse dendritic drainage; steeply dipping Proterozoic shale, calcareous in part (Teamsters Creek and Wonominta Beds), overlain in the east by flat-lying Cretaceous sandstone (Rolling Downs Group), both partly weathered

Land Use: Lowland shrubland country with bladder saltbush and black bluebush pastures, with abundant short grasses and copperburrs after rain. Mitchell grass commonly replaces saltbush after heavy stocking. High drought resistance. Calcareous soils in Unit 2 subject to powdering and wind erosion if heavily stocked; severe scalding and gullying in Units 3 and 4; local gullying in disturbed areas

Estimated grazing rate: 11.4 - 15.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	More stable interfluves: to 1 km wide, slopes to 3%; stony surfaces and less stony bands with gilgai, locally as contour pattern	Stony surfaces: red massive loamy sand, pedal from 10-50 cm, calcareous and saline below 50 cm Less stony bands: red massive loamy sand, weakly pedal from 10-40 cm, saline below 10 cm, calcareous below 50 cm	Bare Sparse *Casuarina cristata* with abundant bladder saltbush (*Atriplex vesicaria*); saltbush commonly replaced by Mitchell grass (*Astrebla lappacea*, *A. pectinata*); grasses and forbs
2	L	Less stable surfaces: slopes to 3%, with calcareous nodules	Deep light-brown loose sand, calcareous and saline throughout	Bladder saltbush and black bluebush (*Kochia pyramidata*), with grasses and forbs
3	VS	Minor drainage tracts: to 60 m wide, with minor gullies and locally with gilgai	Reddish-brown calcareous saline massive loamy sand with gravelly lenses	Bladder saltbush and black bluebush, with grasses and forbs
4	VS	Major drainage tracts: severely eroded surfaces to 500 m wide; channels to 50 m wide; locally unchannelled	Oeep yellowish-red calcareous saline layered loamy sand with gravelly lenses	Black bluebush and berry saltbush (*Rhagodia spinescens*), with abundant grasses and forbs on flats; fringing community of river red gums (*Eucalyptus camaldulensis*) on channel banks

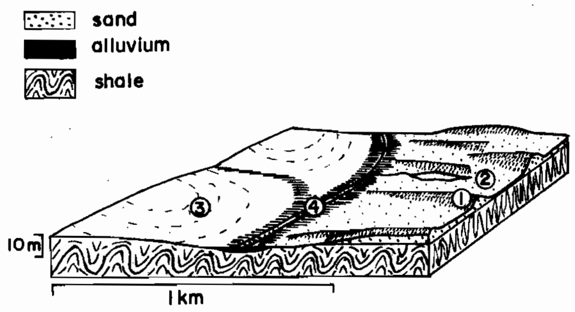
NUNDORA LAND SYSTEM Nd (8,000 ha)

General: Stony plains with areas of low dunes, north of Nundora Homestead

Geomorphology: Gently undulating stony plains to 10 km in extent, relief to 10 m, sparse dendritic drainage, on steeply dipping Proterozoic shale (Wonominta Beds); partly overlain by parallel dune ridges of unconsolidated Quaternary sand, trending ENE

Land Use: Sandy country with open mulga in Unit 1, with short grass-forb pastures yielding ephemerals after rain; sparse bladder saltbush pastures on heavier soils of Units 2 and 3. Difficult country to manage. Low drought resistance. Loose sand in Unit 1 liable to drifting in drought

Estimated grazing rate: 10.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	M	Dunes: irregular ridges to 3 m high and 1 km long, spaced at 250 m; mainly vegetated, with small eroded areas and patches of loose sand	Red neutral sand	Scattered mulga (*Acacia aneura*), isolated white pine (*Callitris columellaris* var. *glauca*) and whitewood (*Atalaya hemiglauca*); locally with cover of moderate inedible shrubs such as turpentine (*Eremophila sturtii*) and hopbush (*Dodonaea attenuata*); abundant grasses and forbs
2	M	Swales: flats to 100 m wide with small pans	Yellowish-red massive neutral loamy sand	Grasses and forbs
3	L	Plains: stony surfaces, slopes to 2% and to 2 km long; contour patterns of stony and less stony bands	Stony bands: red massive loamy sand, pedal from 10-50 cm, calcareous and saline below 50 cm Less stony bands: red massive loamy sand, weakly pedal from 10-40 cm, saline from 10 cm, calcareous below 50 cm	Bare Isolated bladder saltbush (*Atriplex vesicaria*), grasses and forbs
4	VS	Drainage tracts: to 60 m wide, with minor gullies and locally with gilgai	Reddish-brown calcareous saline massive loamy sand with gravelly lenses	Scattered bladder saltbush and black bluebush (*Kochia pyramidata*), abundant grasses and forbs

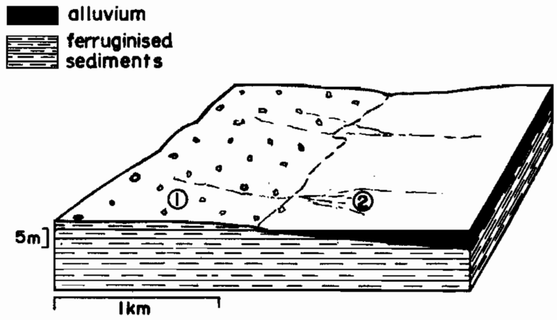
OAKVALE LAND SYSTEM Ok (16,000 ha)

General: Stony plains, locally with Mitchell grass, near Oakvale Homestead

Geomorphology: Very gently sloping plains, more stony in upper parts, with well-developed gilgai in flatter lower parts, relief to 3 m locally; sparse dendritic pattern of ill-defined drainage; flat-lying ferruginised Cretaceous sandstone (Rolling Downs Group), with increasing cover of Quaternary alluvium downslope

Land Use: Mitchell grass country with areas of cottonbush pastures, with abundant short grasses and copperburrs after rain; responds quickly to summer storms. Drought resistance moderate. Minor wind erosion in Unit 2

Estimated grazing rate: 13.8 - 20.8 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Stony plains: slopes to 1% and to 500 m long; much fine gravel; partly with contour patterns of stonier bands and less stony bands	Deep red massive sand or loamy sand, neutral to 50 cm, calcareous below	Scattered *Casuarina* sp. with edible and inedible copperburrs (*Bassia longicuspis*, *B. divaricata*), grasses and forbs
2	VL	Alluvial plains: to 3 km in extent, with some gilgai; locally with discontinuous channels to 25 m wide, but generally unchannelled	Yellowish-red loose sand on red massive sand or loamy sand	Sparse cottonbush (*Kochia aphylla*) and bluebush (*K. pyramidata*) and abundant edible and inedible copperburrs (*Bassia* spp.), Mitchell grass (*Astrebla pectinata*), other grasses and forbs

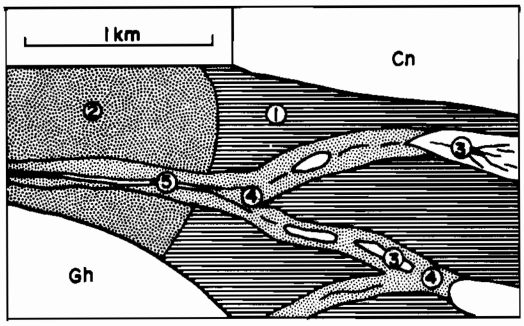
CALOOLA LAND SYSTEM C1 (44,500 ha)

General: Mitchell grass flats with crabholes, about the floodouts of main creeks throughout the area

Geomorphology: Terminal floodplains to 5 km wide, with many gilgai; braiding channels in upper sectors, distributary channels, typically anastomosing and very sinuous, in lower sectors; Quaternary alluvium

Land Use: Mitchell grass country, and lowland shrubland country with bladder saltbush pastures; abundant ephemerals after floods allow heavy stocking. Well-suited to cattle grazing. Subject to scalding in Units 2, 3 and 4, and to gullying in Unit 2

Estimated grazing rate: variable depending on frequency of flooding, but generally above 18.3 sheep equivalents per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Plain tracts: to 2 km wide; lower areas with pronounced gilgai, locally as linear gilgai	Deep reddish-yellow saline massive loamy sand, becoming heavier and more saline with depth, weakly pedal in upper 15 cm, calcareous below 60 cm	Scattered cottonbush (*Kochia aphylla*) and bladder saltbush (*Atriplex vesicaria*); mainly Mitchell grass (*Astrebla pectinata*) and other perennial grasses, copperburrs (*Bassia* spp.) and forbs
2	M	Feeder floodplains: scalded surfaces to 2 km wide; patches of gravel, and sand hummocks about shrubs	Scalds: deep yellowish-red massive sandy loam, with prominent clay skins in upper 30 cm; calcareous and saline below 30 cm	Generally bare
			Sand hummocks: about 45 cm of yellowish-red layered neutral sand overlying deep massive sandy loam, weakly calcareous throughout and saline below about 100 cm	Scattered bladder saltbush, abundant copperburrs, grasses and forbs
3	L	Pans: to 500 m wide and 1 km long, slightly below Unit 1; bare,sealed or cracked surfaces with minor gravel	Deep reddish-yellow sandy loam, calcareous and saline below 60 cm, weakly pedal in upper 60 cm	Scattered bladder saltbush, Mitchell grass locally, perennial grasses and forbs
4	VS	Levees: discontinuous and to 200 m wide, sloping gently away from channels; scalded surfaces with sand and gravel patches	Deep light-brown undifferentiated fine sand with lime lenses throughout	Scalds: generally bare Crests: isolated bladder saltbush and copperburrs with grasses and forbs
5	S	Channels: active and abandoned; variable, to 30 m wide and 3 m deep; braiding and locally meandering	Deep light-brown layered massive loamy sand, locally calcareous and saline	Scattered black bluebush (*K. pyramidata*) and berry saltbush (*Rhagodia spinescens*), with areas of Mitchell grass and tobacco tree (*Nicotiana glauca*); fringing community of river red gums (*Eucalyptus camaldulensis*) on larger channel banks

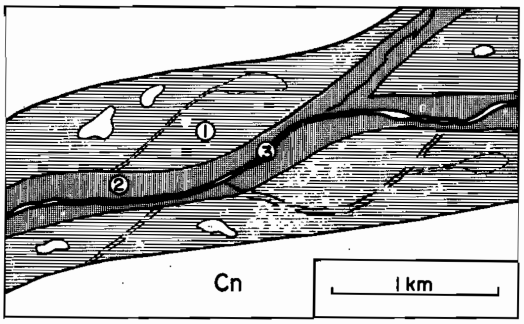
FOWLERS LAND SYSTEM F1 (38,000 ha)

General: Main river frontages throughout the area

Geomorphology: Floodplains along middle sectors of larger creeks, to 3 km wide, with scalded backplains and uneven channel tracts; sinuous, commonly braiding sandy channels; Quaternary alluvium

Land Use: Frontage country and minor areas of lowland shrubland country, with black bluebush and Mitchell grass pastures in Unit 1 and bladder saltbush pastures in Unit 2; with short grasses and copperburrs after rain or floods. Drought resistance low. Unit 2 subject to severe scalding

Estimated grazing rate: 10.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Backplains: to 400 m wide, with flood channels and terminal depressions; moderately scalded, with some sand patches	Deep undifferentiated yellowish-red loose neutral loamy sand	Isolated areas of prickly wattle (*Acacia victoriae*) and river red gums (*Eucalyptus camaldulensis*); scattered black bluebush (*Kochia pyramidata*) with abundant Mitchell grass (*Astrebla pectinata*), other grasses and copperburrs (*Bassia* spp.)
2	L	Levees: discontinuous, to 200 m wide; sloping gently away from channels	Deep reddish-brown sand with gravelly bands; calcareous and weakly saline below about 100 cm	Isolated bladder saltbush (*Atriplex vesicaria*) and black bluebush, grasses and forbs
3	S	Channel: trench-like, to 10 m wide and to 5 m deep, with some waterholes; bed material unsorted sand to cobbles	Deep undifferentiated yellowish-brown sand	River red gums in channel, with perennial grasses and forbs

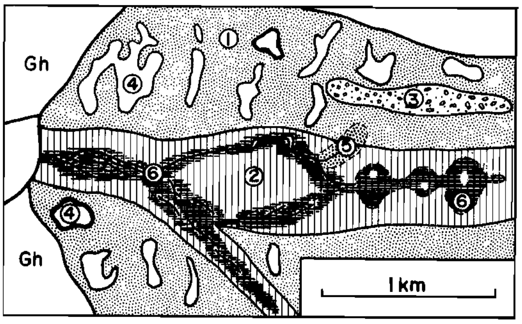
CONSERVATION LAND SYSTEM Cn (39,500 ha)

General: Scalded flats between major river floodouts, mainly in the south of the area

Geomorphology: Stable alluvial plains to 8 km wide between active floodplains; extensively scalded surfaces traversed by sub-parallel ill-defined depressed drainage zones; Quaternary alluvium

Land Use: Frontage country with short grass-forb and bottlewasher-copperburr pastures, with minor perennial shrubs; abundant ephemerals after rain. Low drought resistance. Units 1 and 4 subject to scalding and development of sand hummocks if overgrazed

Estimated grazing rate: 10.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Higher-lying tracts: scalded plain tracts to 200 m wide and 800 m long, with many transverse scalds to 200 m in extent; uneven surfaces, particularly hummocky about margins of scalds	Deep yellowish-red massive loamy sand; calcareous below 60 cm, saline below 20 cm	Isolated punty bush (*Cassia* spp.) on sand hummocks; copperburrs (*Bassia* spp.), grasses and forbs
2	S	Lower-lying tracts: to 800 m wide; uneven surfaces with weak gilgai	Deep yellowish-red massive loamy sand, becoming heavier with depth; calcareous below 30 cm; weakly saline at surface, becoming more saline with depth	Scattered shrubs [bladder saltbush (*Atriplex vesicaria*), berry saltbush (*Rhagodia spinescens*) and cottonbush (*Kochia aphylla*)], with abundant perennial grasses [*Astrebla*, *Sporobolus* and *Eragrostis* spp.]
3	VS	Gravelly rises: elongate, to 100 m wide and 400 m long, and to 1 m above Unit 1; stony surfaces	No observations; probably red pedal loamy sand, calcareous and saline at depth	Generally bare
4	L	Scalds and claypans: hard, bare surfaces to 500 m in extent, with some gravel	Claypans: deep yellowish-red massive sand, strongly pedal from 10-40 cm, calcareous below 40 cm, saline below 10 cm Scalds: as above, but calcareous below 10 cm	
5	VS	Sand splays: marginal to drainage lines, with elongate low mounds of loose sand to 50 cm high	To 30 cm of yellowish-red layered neutral sand overlying deep yellowish-red massive loamy sand, becoming heavier with depth; calcareous below 40 cm, weakly saline below 100 cm	Copperburrs, grasses and forbs
6	S	Drainage zones: to 200 m wide, with discontinuous small channels in upper sectors and aligned circular depressions to 200 m across in lower sectors; some gilgai	About 30 cm of yellowish-red layered neutral sand overlying deep yellowish-red massive loamy sand; calcareous and saline below 100 cm	Isolated prickly wattle (*Acacia victoriae*), scattered bladder saltbush, berry saltbush and cottonbush, abundant perennial grasses

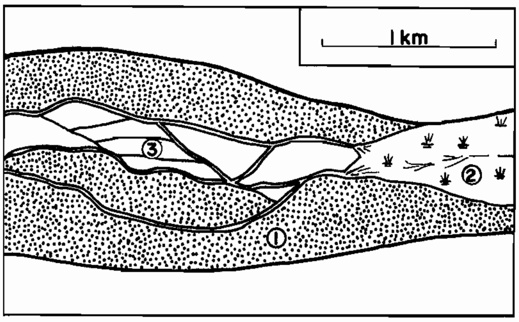
YANCANNIA LAND SYSTEM Yn (19,500 ha)

General: Sandy floodplains, mainly along Yancannia Creek

Geomorphology: Floodplains to 3 km wide, mainly with anastomosing channels, locally unchannelled, and with floodouts in lowest sectors; Quaternary alluvium

Land Use: Sandy country with open mulga; Warrego summer grass-native millet pastures and shrubs where frequent floodings produce abundant growth in Unit 2; dense timber in Unit 3; suited to cattle grazing. Drought resistance high. Unit 1 subject to scalding and sand drifting

Estimated grazing rate: 26.2 sheep equivalents per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Backplains: uneven scalded surfaces with bare patches to 100 m wide and sheets and hummocks of loose sand; relief to 1 m	Deep yellowish-red massive neutral loamy sand	Scattered mulga (*Acacia aneura*) and whitewood (*Atalaya hemiglauca*) with chenopods, grasses and forbs
2	M	Floodouts: elongate tracts to 150 m wide and 1 km long, locally with gilgai		Canegrass (*Eragrostis australasica*), with grasses and forbs; locally areas of black box (*Eucalyptus largiflorens*)
3	S	Channel zones: to 750 m wide; uneven, with banks of sand and gravel; trench-like channels to 30 m wide and 3 m deep	Deep yellowish-red loose neutral sand or loamy sand, calcareous below about 100 cm	Dense river red gum (*Eucalyptus camaldulensis*), black box, coolibah (*E. microtheca*), acacias [*Acacia salicina*, *A. victoriae*] and *Eremophila bignoniiflora*, with abundant perennial grasses

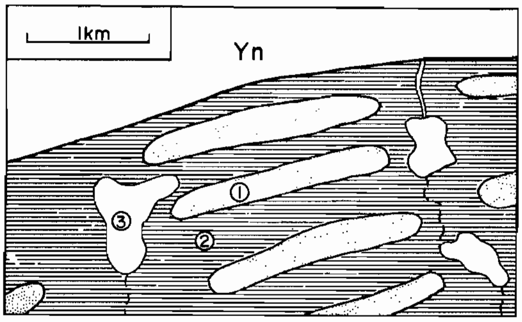
ALLANDY LAND SYSTEM   Al   (65,500 ha)

General: Alluvial flats with low dunes, in the north of the area

Geomorphology: Alluvial plains to 20 km in extent, with parallel sand ridges trending ENE; pans aligned along swales fed by drainage floodouts at upper margin; Quaternary alluvium and aeolian sand

Land Use: Sandy country with open mulga; short grass-forb pastures with ephemerals after rain in Units 1 and 2; mainly chenopods and composites in Unit 3. Drought resistance low. Severe scalding in Unit 2 and minor sand drifting in Unit 1

Estimated grazing rate: 9.4 - 11.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Dunes: ridges to 3 m high and commonly 500 m apart, slopes to 10%; vegetated rounded crests; locally eroded flanks	Red neutral sand to at least 100 cm	Open mulga (*Acacia aneura*) and sparse whitewood (*Atalaya hemiglauca*) with scattered inedible shrubs [*Eremophila sturtii*, *Dodonaea attenuata*], grasses and forbs
2	VL	Alluvial plains: scalded cracked surfaces	Scalds: about 40 cm of reddish-yellow sandy loam, overlying at least 40 cm of brown loamy sand; massive and neutral throughout Non-scalded areas: reddish-yellow massive loamy sand	Bare Open mulga and sparse whitewood with scattered inedible shrubs, grasses and forbs
3	VS	Pans: cracking surfaces with minor gilgai; mainly to 750 m in extent	About 30 cm of yellowish-red sandy loam, overlying at least 100 cm of brown loamy sand or sand; massive and neutral throughout	Canegrass (*Eragrostis australasica*) and other grasses and forbs; fringing community of black box (*Eucalyptus largiflorens*)

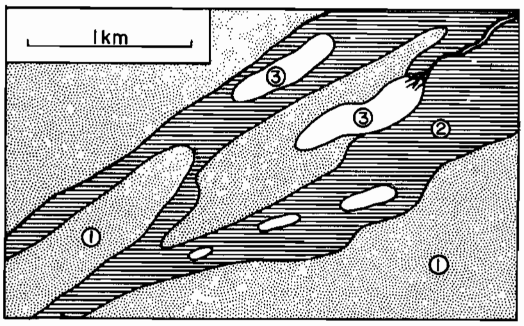
RODGES LAND SYSTEM Rg (68,500 ha)

General: Sandy flats, mainly in the north of the area

Geomorphology: Extensive plain tracts about 30 km in extent, with sandy rises and many small pans; dense, ill-defined, sub-parallel drainage; Quaternary sand and alluvium

Land Use: Sandy country, with open mulga in Unit 1 and close timber in Unit 2; short grass-forb pastures and ephemerals after rain. Drought resistance low in Unit 1, moderate in Unit 2. Unit 1 subject to sand drifting during drought; some scalding in Unit 2

Estimated grazing rate: 13.2 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Sandplain: locally with dunes to 3 m high	Sandplain: to 100 cm of red neutral massive sand over red calcareous saline massive loamy sand Dunes: red neutral sand	Very open mulga (*Acacia aneura*), with or without scattered inedible shrubs [*Eremophila* spp., *Dodonaea* spp.]; grasses and forbs
2	L	Alluvial plains: scalded surfaces; sandy hummocks around vegetation	Scalds: to 100 cm of reddish-yellow neutral massive loamy sand over calcareous saline massive loamy sand; some scalds calcareous and saline throughout Non-scalded areas: yellowish-red calcareous saline loose loamy sand with gravelly layers	Generally bare Dense to moderate *Casuarina cristata*, cabbage tree (*A. cana*), mulga; isolated leopardwood (*Flindersia maculosa*) and inedible shrubs including turpentine (*Eremophila sturtii*); grasses and forbs
3	VS	Pans and terminal floodouts: slightly cracking surfaces to 500 m in extent, with minor gilgai	To 80 cm of red loose neutral sand over red calcareous sand	Lignum (*Muehlenbeckia cunninghamii*) and canegrass (*Eragrostis australasica*) with abundant grasses and forbs; fringing community of black box (*Eucalyptus largiflorens*)

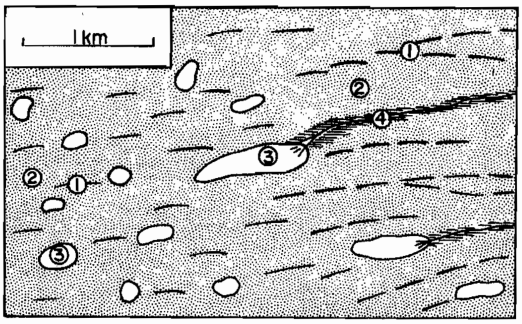
NUCHA LAND SYSTEM   Nu   (101,500 ha)

General: Sandplain with many small pans, mainly in the south of the area

Geomorphology: Sandplain with low sand rises having a general ENE trend, occupying lowlands to 40 km in extent; receiving much run-on, with trains of small pans and with marginal floodouts; Quaternary aeolian sand

Land Use: Sandy country with open mulga and areas of dense mulga, mostly dead in Unit 1 and mainly living in Unit 3; short grass-forb pastures and copperburrs in Units 1 and 3, with abundant emphemerals after rain; spear grass and bottlewasher-copperburr pastures of low drought resistance in Unit 2. Unit 1 subject to slight sand drifting

Estimated grazing rate: 11.6 - 12.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	Sand rises: irregular rounded ridges to 5 m high and to 1 km long; minor areas of loose sand to 100 m in extent	To 50 cm of red neutral sand overlying red calcareous sand	Sparse to moderate mulga (*Acacia aneura*), isolated clumps of rosewood (*Heterodendrum oleaefolium*) with or without inedible shrubs [*Eremophila sturtii*, *Dodonaea attenuata*], abundant grasses and forbs
2	L	Flats: elongate and to 100 m wide, locally with lime nodules on surface	Red sand, calcareous from about 15 cm and becoming loamy sand with depth	Clumps of dense mulga with neverfail (*Eragrostis setifolia*); surrounding areas of copperburrs (*Bassia* spp.), spear grass (*Stipa variabilis*) and other grasses and forbs
3	S	Pans: cracking surfaces to 300 m in extent, locally with gilgai	Red weakly pedal loamy sand, calcareous and saline below about 40 cm	Perennial grasses and forbs; fringing community of black box (*Eucalyptus largiflorens*)
4	S	Drainage tracts: linear depressions and floodouts to 500 m wide; minor channels	Red neutral sand, calcareous below about 60 cm	Clumps of dense mulga with neverfail; surrounding areas of copperburrs, spear grass and other grasses and forbs

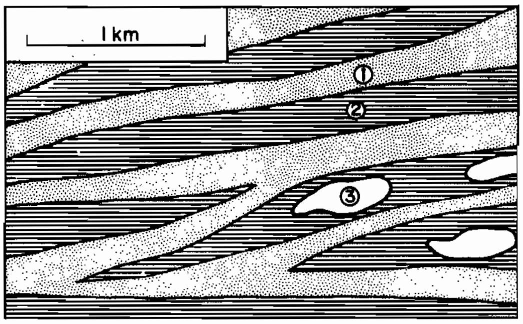
GUMPOPLA LAND SYSTEM Gp (123,000 ha)

General: Sand hills alternating with flats and pans, mainly in the north of the area

Geomorphology: Plains with parallel sand ridges spaced at about 500 m and trending ENE, and alluvial corridors with small pans subject to flooding from adjacent land systems; Quaternary alluvium and aeolian sand

Land Use: Sandy country with open mulga, but inedible shrubs locally; short grass-forb pastures with abundant ephemerals after rain; some canegrass in Unit 3. Drought resistance low. Sand drifting in Unit 1 during drought, and scalding in Unit 2

Estimated grazing rate: 8.4 - 12.3 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Dunes: parallel ridges to 3 km long and to 10 m high, and small areas of irregular smaller dunes; smooth, mainly vegetated slopes to 15%, locally scalded near the base; rounded crests with mounds of loose sand	At least 120 cm of red neutral sand; calcareous below 120 cm	Open mulga (*Acacia aneura*) and scattered whitewood (*Atalaya hemiglauca*) with areas of inedible shrubs [*Eremophila sturtii* and *Dodonaea attenuata*], abundant grasses and forms
2	L	Alluvial corridors: to 400 m wide; extensively scalded surfaces with minor sand hummocks	Scalds: about 50 cm of yellowish-red calcareous massive sand, weakly pedal in upper 10 cm, overlying yellowish-red calcareous saline loamy sand	Bare
			Non-scalded areas: yellowish-red loose sand, with subsoil as in scalds	Open mulga and scattered whitewood with areas of inedible shrubs, abundant grasses and forbs
3	S	Pans: to 1 km in extent; locally with cracking surfaces and minor gilgai	Deep light-brown neutral massive loamy sand	Canegrass (*Eragrostis australasica*), rarely with black bluebush (*Kochia pyramidata*); abundant chenopods, grasses and forbs; fringing community of black box (*Eucalyptus largiflorens*)

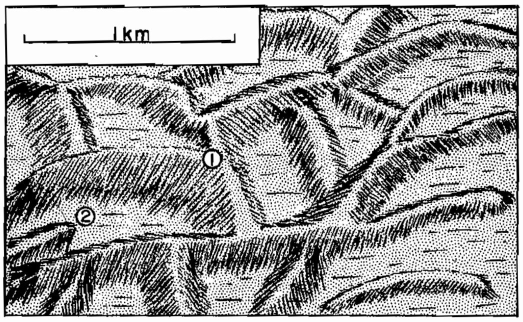
MARRAPINA LAND SYSTEM Mp (11,000 ha)

General: Dunes with stands of pine, mainly near Marrapina and Kara Homesteads

Geomorphology: Areas of low sand dunes locally aligned ENE; no surface drainage; Quaternary aeolian sand

Land Use: Sandy country with pine; short grass-forb pastures with abundant ephemerals after rain. Drought resistance low. Should be lightly stocked as subject to sand drifting during drought

Estimated grazing rate: 9.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	VL	Dunes: to 6 m high, slopes to 10%; mainly as small hills, locally as parallel ridges; mainly stable, with some loose sand on rounded crests	At least 100 cm of yellowish-red neutral sand	Dense white pine (*Callitris columellaris* var. *glauca*) with sparse mulga (*Acacia aneura*), grasses and forbs
2	L	Swales: flat floors 50-100 m wide		Scattered white pine and mulga, locally with cane grass (*Eragrostis australasica*); abundant grasses and forbs

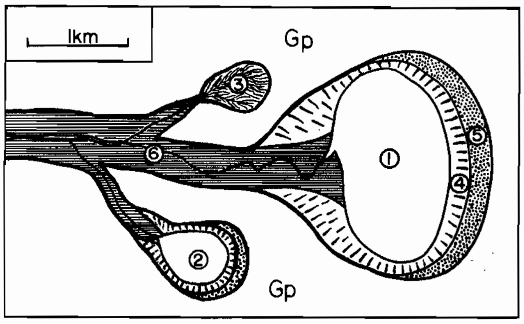
COBHAM LAND SYSTEM Cb (31,000 ha)

General: Salt lakes with fringing dunes and flats in sand country, mainly in the northwest of the area

Geomorphology: Playas, including salinas, claypans and swamp basins, forming terminal or subterminal basins of major rivers in sand country; lunettes, best developed on eastern margins; feeder channels and adjoining alluvial plains; Quaternary alluvium, mainly saline, and aeolian sand

Land Use: Desert lake country, with extensive areas subject to flooding by saline or fresh water. Unit 1 is of little grazing value; Units 2 and 3 support dense grasses, chenopods and unpalatable shrubs and are suited to cattle grazing; Unit 4 supports unpalatable shrubs; Unit 5 supports open mulga and ephemerals. Drought resistance high in Unit 3, moderate in Unit 2, low elsewhere. Rilling and scalding in Units 4 and 5, and wind erosion in Unit 4

Estimated grazing rates: extremely variable depending on local extent of units and frequency and type of flooding



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	M	Saline floors: level, salt-crusted surfaces to 10 km in extent	Very thin salt crust overlying saturated brown massive loamy sand or sand; abundant salt crystals; strong mottling below 20 cm; very sharp layer boundaries	Bare
2	M	Claypans: to 3 km in extent; sealed surfaces with gilgai, commonly puffy and salt-encrusted, and with some stones	Deep brown calcareous saline loose loamy sand or silty loam	Canegrass (*Eragrostis australasica*) in centre; copperburrs (*Bassia* spp.), grasses and forbs on margins
3	M	Swamp basins: surfaces to 7 km in extent, seamed with linear and network gilgai; locally marginal to Unit 2	Deep reddish-yellow massive loamy sand, leached to about 50 cm, calcareous and saline below	Lignum (*Muehlenbeckia cunninghamii*) and prickly wattle (*Acacia victoriae*) with grasses and forbs; local areas of black box (*Eucalyptus largiflorens*)
4	S	Pan margins: smooth slopes, about 1%, locally scalded and with sand hummocks; scattered lime nodules	Reddish-yellow loose sand or loamy sand, generally calcareous and saline but in some areas, such as Salt Lake margins, neutral to more than 100 cm	Old man saltbush (*Atriplex nummularia*) and berry saltbush (*Rhagodia spinescens*) with abundant grasses and forbs
5	M	Lunettes: slopes to 10% and to 500 m long; hummocky, locally scalded surfaces rising to 10 m above pan floors	Brown calcareous loose loamy sand; generally neutral to 100 cm	Very open mulga (*A. aneura*), locally with turpentine (*Eremophila sturtii*) or pearl bluebush (*Kochia sedifolia*), grasses and forbs
6	S	Alluvial plains: to 500 m in extent; winding, locally anastomosing channels to 20 m wide; irregular, puffy surfaces	Deep yellowish-red massive calcareous saline sand or loamy sand	Canegrass, lignum and berry saltbush with grasses and forbs; fringing areas of black box

CHAPTER III. CLIMATE OF THE FOWLERS GAP-CALINDARY AREA

By F.C. Bell

I. INTRODUCTION

According to the recognised systems of climate classification the Fowlers Gap-Calindary area is well within the arid zone. In the system proposed by Meigs (1953), as adopted in several UNESCO studies, the area is described as arid with mild temperatures and no distinct season of precipitation, the symbolic representation being Aa23. In the Thornthwaite (1948) scheme it is arid mesothermal (EB'); in the Köppen (1936) it is warm arid (BWh), and in the more recent Budyko (1956) scheme it is classified as desert. De Beuzeville (1943) has suggested that there are homoclimes of the area at Blythe in California, Buckeye in Arizona, and Sfax in Tunisia, but the degree of similarity of climates at these places is rather questionable.

Other Australian studies with some relevance to the climate of the area include those reported by Slatyer (1962), Foley (1956), White (1955), McIllwraith (1953), and Prescott and Thomas (1949). Some of these have been directed towards specific applications of climatic data, being concerned chiefly with conditions critical for plant growth, or for engineering and architectural purposes. Where appropriate, such directly useful information will be presented in this chapter, which will aim to identify the principle climatic features of the area with some regard to man's occupation of it. Because of the general inadequacy of data from within the survey area, it is necessary to refer to data from a larger surrounding area that includes the long-established climatic stations at Broken Hill, Tibooburra and Wilcannia. Simple interpolations between these stations seem permissible in the absence of more detailed data as there are no topographic or other features likely to cause abrupt changes in climatic variables.

II. GENERAL CLIMATIC INFLUENCES

The survey area is near the centre of the belt of prevailing anti-cyclones or high pressure systems that circulate from west to east around the southern hemisphere. The general paths of these anticyclones shift seasonally from their most northerly locations in winter, centred at approximately 28°S, to their most southerly locations in summer, centred at approximately 37°S (Karelsky, 1956). Thus the survey area at 31°S remains within their influence throughout the year.

Each high pressure cell is a zone of gradually subsiding air which becomes warmer and relatively drier as it approaches the surface of the earth. This subsiding air is responsible for the maintenance of the so-called Tropical Continental air mass over inland Australia, with its associated dry sunny weather that is characteristic of such latitudes for much of the year. Other factors contributing to the aridity of the area are its remoteness from ocean influences with their moisture-bearing air masses, and the absence of high mountains causing orographic precipitation. It should be noted, however, that there appear to be small orographic effects on the rainfall pattern due to the relatively low Barrier Range to the southwest of the area (see Section III (a) below).

Remoteness from the moderating influences of the oceans is chiefly responsible for moderate to large diurnal ranges of temperature in both summer and winter. Another factor contributing to these typically continental temperature ranges is the prevailing dry, cloudless atmosphere which favours high rates of incoming solar radiation during the day and high rates of outgoing terrestrial radiation at night. The subtropical latitude, relatively low altitude, and lack of moisture for latent heat transfer by evaporation ensure that average daily temperatures remain fairly high, even in winter months.

III. RAINFALL

The predominantly dry weather is interrupted occasionally by invasions of relatively moist air, either from Tropical Maritime sources to the north and east or from Southern Maritime sources to the south and southwest. If there is sufficient moisture in these air masses by the time they reach the area, and if other conditions are favourable for localised or general uplift, then rain may fall, usually either in spasmodic local convective storms or as more prolonged drizzle. In summer months such rain occurs mainly under the influence of tropical depressions and intense inland "heat lows" to the north or east. On rare occasions in summer, tropical cyclones passing over eastern Australia, or degenerated tropical cyclones travelling further inland may bring heavier downpours. In winter months the invasions of moist air are usually associated with extra-tropical cyclones and accompanying frontal activity. Relatively prolonged rain of moderate intensities may also occur in any season due to strongly developed low pressure systems that sometimes form in the upper atmosphere over inland Australia (Foley, 1956).

(a) *Annual, Seasonal, and Monthly Rainfall*

Over the survey area the mean annual rainfall varies from 180 mm on the western boundary to 228 mm in the northeastern corner at Bootra Homestead. This part of New South Wales has the most variable and unreliable rainfall in the state, the coefficient of variability * of annual values being 44 per cent. The distribution of annual values is skewed, the highest and lowest deciles being approximately 400 mm and 100 mm respectively at all stations in the area (i.e. one year in ten may be expected to have more than 400 mm while one year in ten may be expected to have less than 100 mm.) At Yancannia, which has the

* The coefficient of variability quoted here is calculated by expressing the standard deviation as a percentage of the mean.

TABLE III-1. ANNUAL AND SEASONAL RAINFALL DATA

Station	First Year of Available Records	Means etc. for 60-Year Period 1909-68 Incl.					
		Oct-Mar (incl.)		April-Sept (incl.)		Annual	
		Mean (mm)	Mean Wet Days	Mean (mm)	Mean Wet Days	Mean (mm)	Mean Wet Days
Bootra	1890	135	14	90	11	224	25
Broken Hill	1889	127	19	107	27	234	38
Corona	1882	109	12	91	15	201	27
Culpaulin	1887	132	16	99	18	231	34
Glen Lyon	1884	125	14	81	16	206	30
Gnalta	1895	107	11	79	13	185	24
Langawirra	1887	112	11	86	13	198	24
Milparinka	1883	119	13	74	13	193	26
Mt. Arrowsmith	1895	102	11	69	10	170	21
Mundi Mundi	1908	109	12	92	15	201	28
Nuntherungie	1880	109	13	76	11	185	24
Olive Downs	1896	112	9	71	8	183	17
Onepah	1891	119	11	71	8	191	19
Quinyambie	1888	92	10	63	9	155	19
Silverton	1884	127	14	102	18	229	32
Stephens Creek	1891	120	17	96	22	216	40
Sturts Meadow	1895	107	9	86	10	193	19
Tarella	1877	124	12	86	15	211	27
Tibooburra	1886	124	14	79	13	203	26
Tongo	1878	140	15	92	14	231	29
Topar	1896	117	12	81	14	198	26
Umberumberka	1911	107	14	86	18	193	32
Urisino	1881	137	15	92	13	229	28
White Cliffs	1901	134	14	91	16	226	30
Wilcannia	1879	135	18	101	21	236	39
Wonaminta	1882	112	13	76	11	188	34
Yalpunga	1911	112	14	71	14	183	28
Yancannia	1877	130	16	89	15	218	30
Yandama Downs	1888	94	8	58	8	152	16

N.B. Missing records at some stations were estimated from isohyetal patterns for individual years longest rainfall record in the district (since 1877), the highest annual rainfall was 577 mm in 1956 and the lowest 79 mm in 1888. Most other stations in the district have recorded annual values exceeding 500 mm and several have recorded values less than 50 mm.

The mean summer rainfall (October to March inclusive) varies from 105 mm in the western section to 135 mm in the east, as shown in Figure III-1, and the mean winter rainfall (April to September inclusive) varies from 74 mm in the northwest to 91 mm in the southwest, as shown in Figure III-2. The highest mean winter values are in an area of locally higher rainfall extending from Broken Hill to Corona, and this is probably due to small orographic effects of the Barrier Range. Similar effects are not apparent to a significant extent for summer rainfall.

As listed in Table III-1, the data from 29 official rainfall stations were used to establish the isohyetal patterns of Figures III-1 and III-2. A common 60-year period, from 1909 to 1968, was adopted for all stations because considerable irregularity was found if different periods of records were used for different stations. Part of this irregularity may be associated with an apparent trend towards wetter summers and drier winters throughout the district during the past 70 or 80 years, and which may be shown by the progressive increase in the percentage of rain falling in summer, averaged over 30-year periods. Typical increases in the percentages are from 46 per cent (1889-1918) to 58 per cent (1939-68) at Corona, and from 59 per cent (1889-1918) to 67 per cent (1939-68) at Tibooburra. Thus in the early part of this century the survey area tended to have approximately equal summer and winter rainfalls, but at the present time mean summer rainfalls are considerably higher than mean winter rainfalls. However, the significance of this trend is less than may appear at first glance because of the high variabilities of both summer and winter values. The respective coefficients of variability are 59 per cent and 51 per cent, so winter rainfalls are somewhat more reliable than summer rainfalls.

The patterns of monthly rainfall differ slightly from station to station, the highest mean values being in February and June, and the lowest mean values in April and August. A reasonably typical monthly pattern, that for Yancannia, is shown in Figure III-3. All months have high degrees of variability, the highest deciles varying from about 25 mm in August to about 80 mm in February. The lowest deciles are zero for all months for all stations in the area.

(b) *Wet Spells and High-intensity Rainfall*

A sequence of consecutive days with measured rain is regarded here as a "wet spell", and the durations of these range from one to six days in the survey area. Estimates of the probabilities of occurrence of wet spells with various amounts of rainfall for the area are

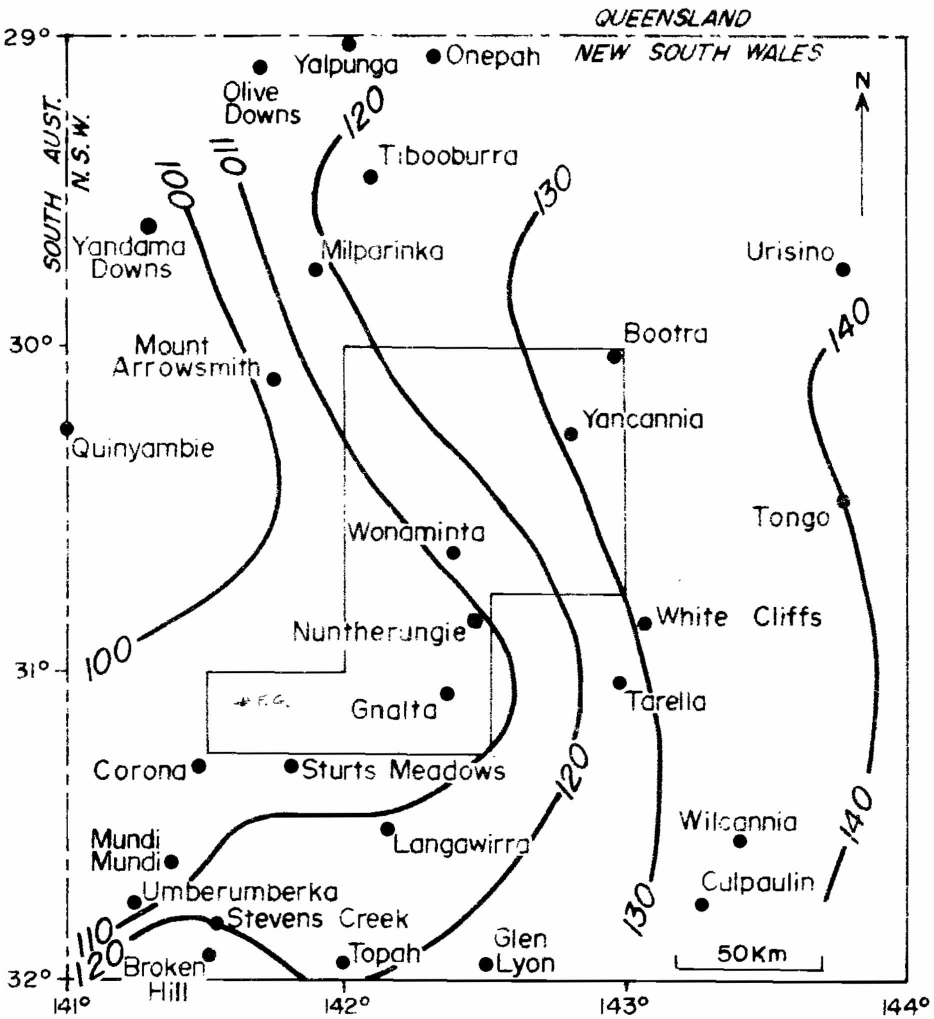


Fig.III-1. - Mean summer rainfall in mm. (October to March inclusive, 1909-1968)

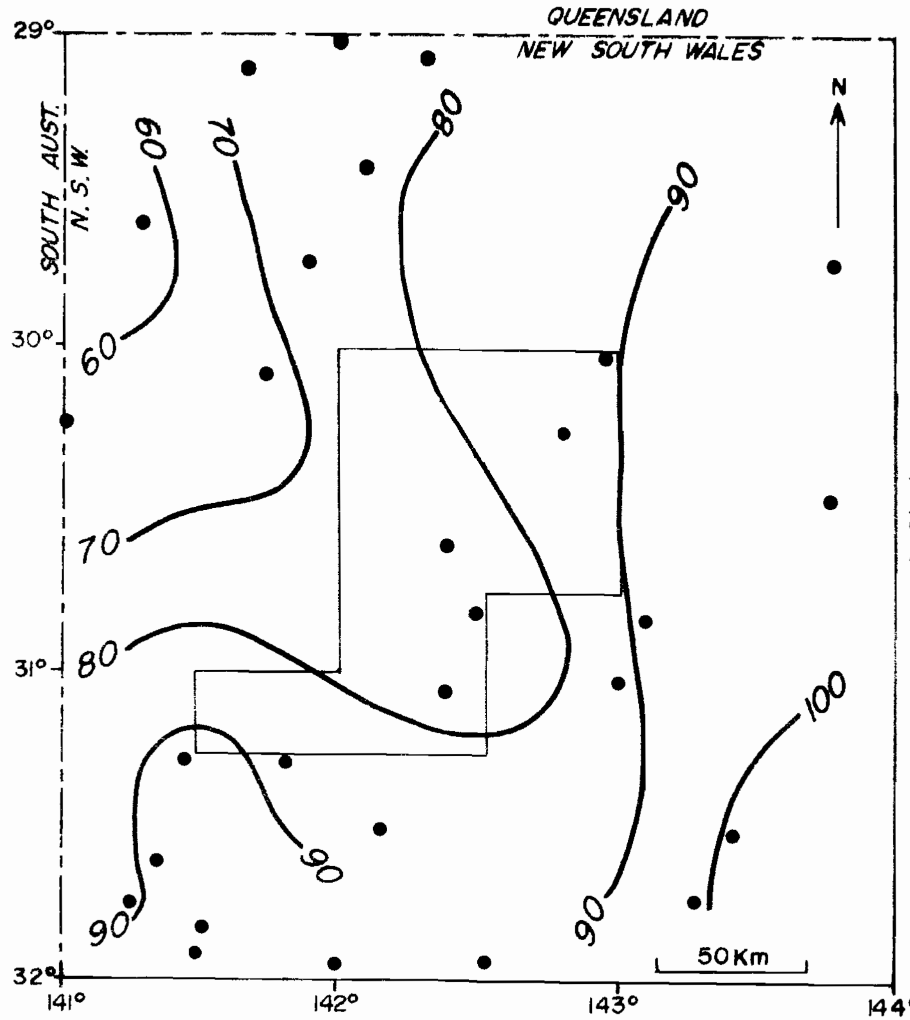


Fig.III-2. - Mean winter rainfall in mm. (April to September inclusive, 1909-1968)

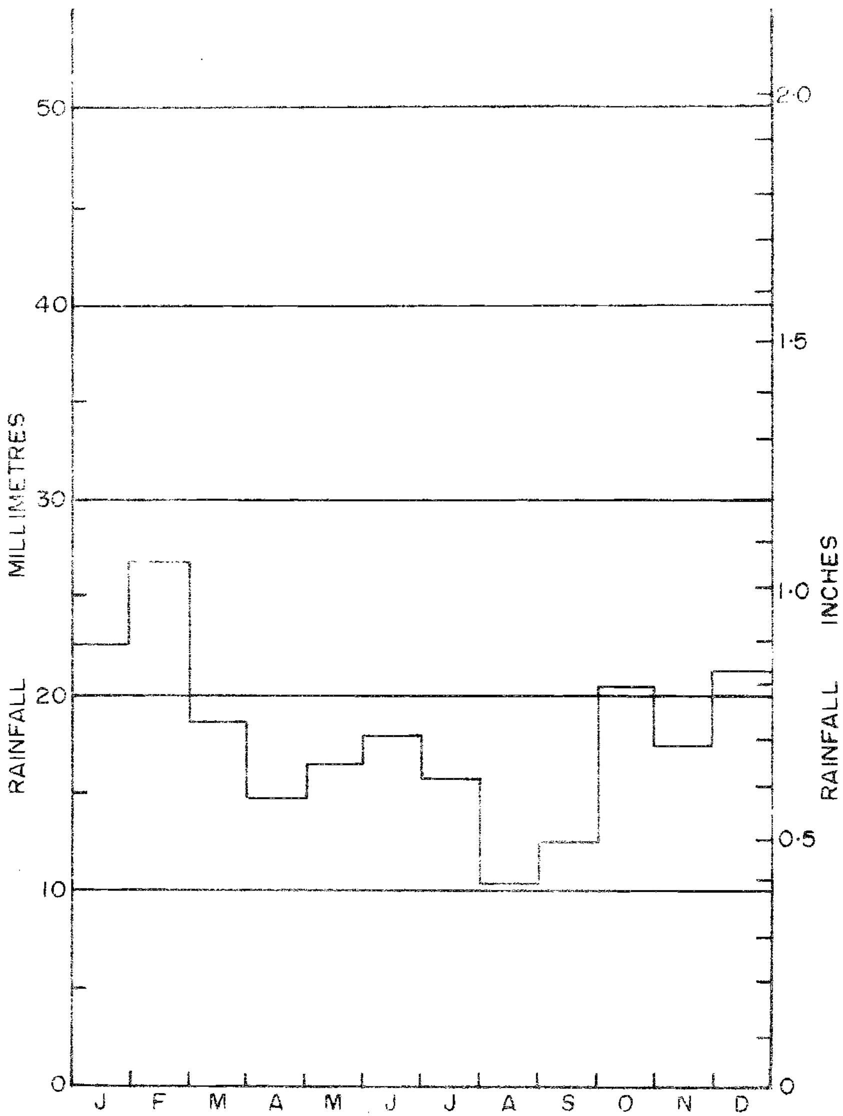


Fig. III-3. - Mean monthly rainfall at Yancannia

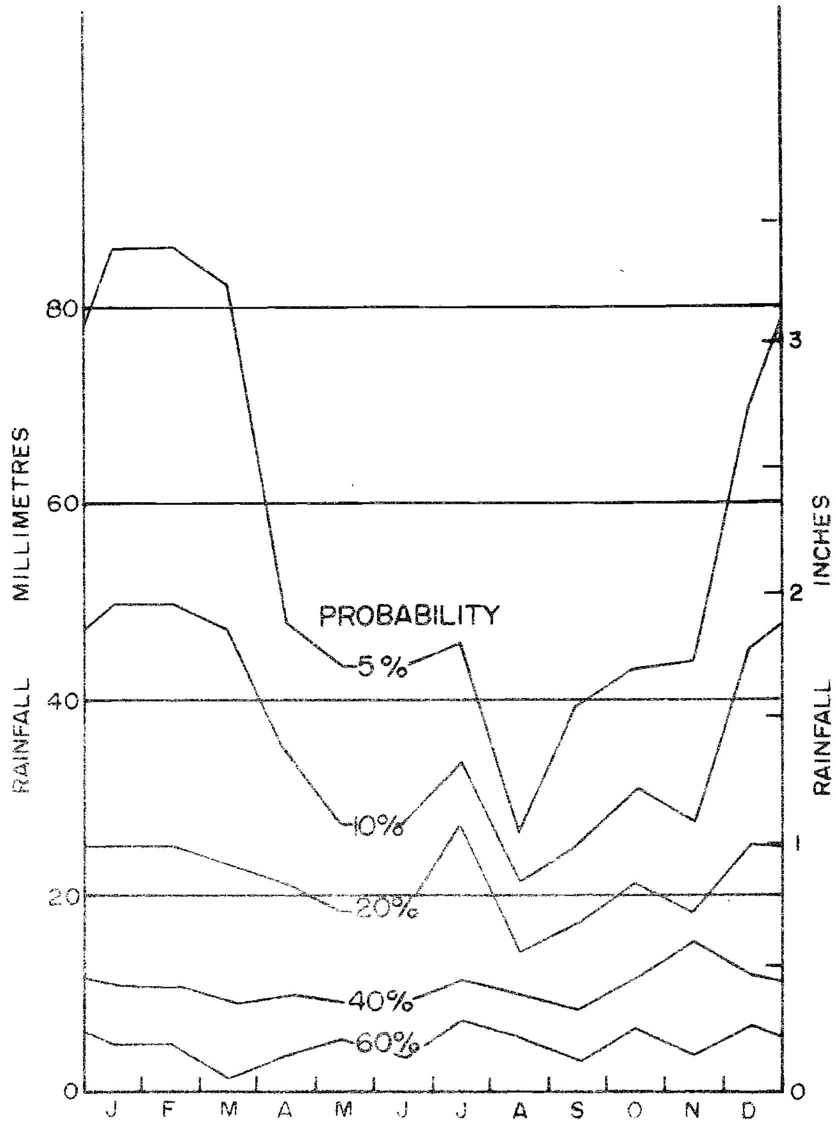


Fig.III-4. - Probability of occurrence of wet spell with rainfall exceeding indicated value given in Figure III-4, which is based on the results of a State-wide study by Fitzpatrick (1953). These estimates show that heavy falls of 50 mm or greater are most likely in the period December to March inclusive, and least likely from August to November inclusive.

Short wet spells of one day or less are responsible for a large proportion of the rainfall, averaging about 45 per cent of the total in the summer half of the year and 65 per cent in the winter half. Their mean frequencies of occurrence are 9 times per year in the summer months and 11 times per year in winter, and their average rainfall intensities are therefore about the same in each season. Longer wet spells of 3 days or more are usually responsible for the heavier summer falls, although their contributions average only 22 per cent and 13 per cent to the summer and winter seasonal totals respectively. They occur much less frequently than the shorter wet spells, i.e. only about once every two years, with equal likelihood in each season and therefore with higher intensities in summer. (These findings are based on analyses of wet spells at Sturts Meadow and Corona for the period 1909 - 1968).

The relative importance of wet spells of one day or less is partly, although not entirely, reflective of the influence of local convective storms which characteristically consist of brief bursts of high-intensity rainfall lasting from a few minutes to one or two hours, and which are of major interest in hydrologic and erosion studies. Textbooks sometimes suggest that this type of rainfall is more intense in arid than in humid areas but actual data usually indicate the reverse. However, various studies of depth-duration-frequency data for New South Wales and South Australia show that the probabilities of extreme high-intensity rainfalls (exceeding 20 mm per hour), are essentially the same for the survey area as for Adelaide, where the mean annual value is nearly three times as great (Institution of Engineers, Australia, 1958; Stewart, 1960; Bell, 1964). These probabilities are given in Figure III-5 for durations from 5 minutes to 3 days.

(c) *Dry Spells and Droughts*

Typical of the arid zone, the area experiences some very low seasonal and annual rainfalls. The lowest annual rainfalls recorded in New South Wales have been in or close to the area, including 32 mm at Mena Murtee, near White Cliffs, in 1902, and 43 mm at both Wonaminta and Nuntherungie in 1888 (Commonwealth Bureau of Meteorology, 1958). During the period 1909 to 1968 the annual rainfall was below 100 mm throughout the area in the years 1913, 1919, 1927, 1929, 1938, 1940, and 1965. As previously mentioned, a value of 100 mm corresponds at most stations with the lowest decile of annual rainfall, and this has been suggested as a convenient drought index by Gibbs and Maher (1967).

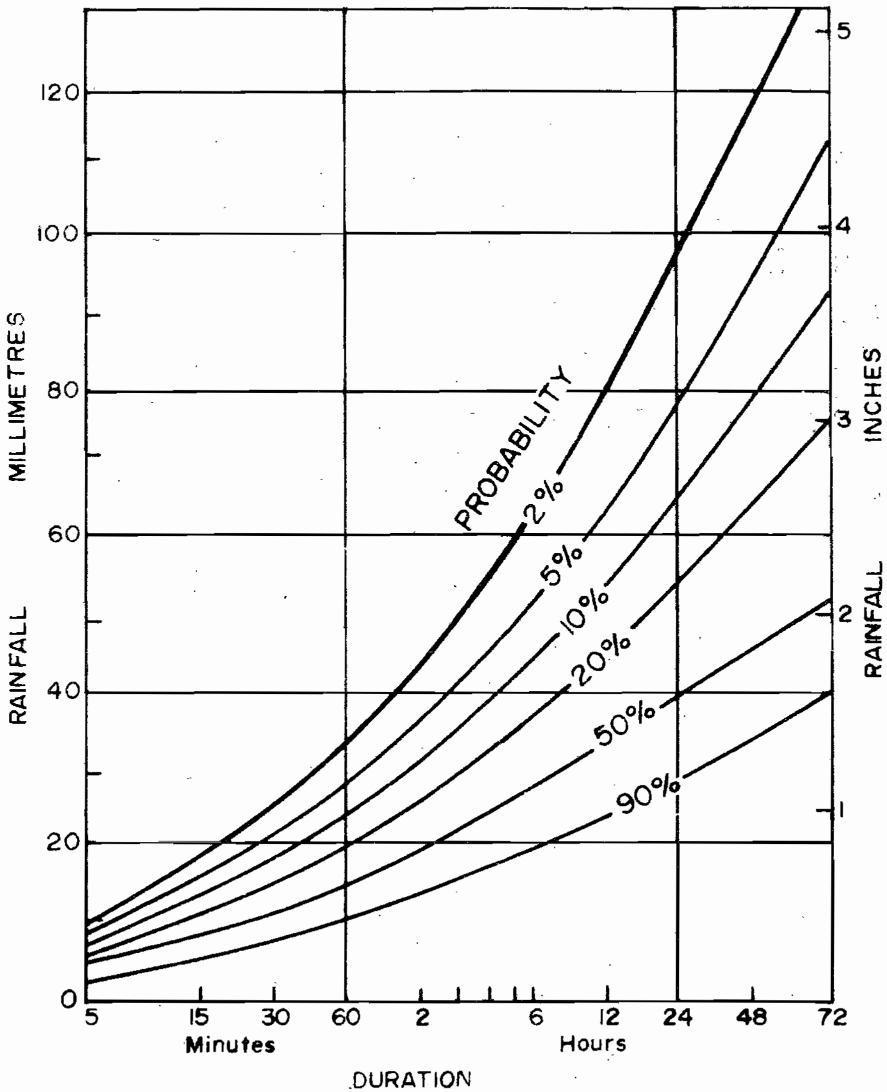


Fig.III-5. - Probability of occurrence in any year of rainfall exceeding indicated value in given duration

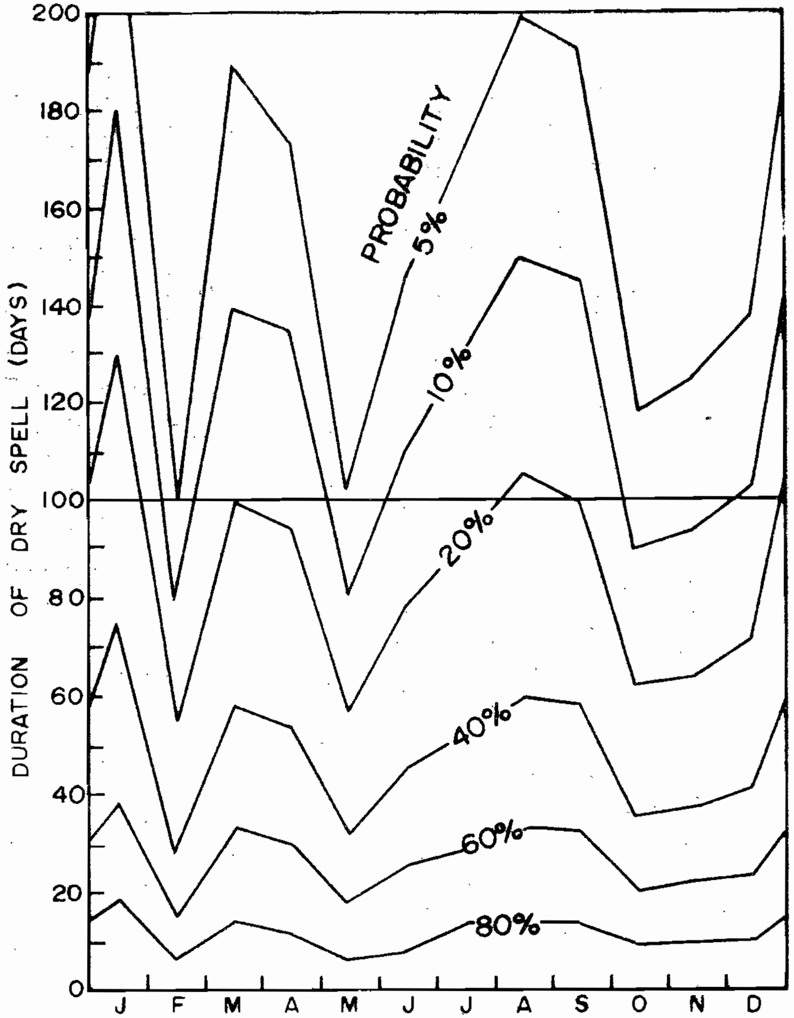


Fig.III-6. - Probability of occurrence in any year of dry spell exceeding indicated duration commencing in given month

More detailed information on droughts is often required in terms of the probabilities of occurrence of dry spells of various durations. Defining a dry spell as a period of consecutive days terminated by at least 6.4 mm of rainfall in 48 hours, Fitzpatrick (1953) estimated such probabilities for New South Wales, and his values for the Fowlers Gap - Calindary area are presented in Figure III-6. The peaks in the curves show that dry spells commencing in January, March, August and September are more likely to develop into long severe droughts than those commencing in other months. The least favourable month is January, and a dry spell commencing in this month has a 10 per cent probability of persisting for 180 days or longer. February, May, and October are the most favourable months, with 10 per cent probabilities corresponding with periods of persistence of 80 days or longer.

IV. TEMPERATURE

Although no official long-term temperature records are available from the survey area itself, the Bureau of Meteorology has published data for nearby stations at White Cliffs, Tibooburra, Broken Hill, Wilcannia, and Umberumberka (Commonwealth Bureau of Meteorology, 1960, 1969). Of these, White Cliffs should be the most typical, and its mean daily values should not differ by more than one degree from places with standard exposures in any part of the survey area. Unlike the rainfall data, the temperature data showed no significant trends or erratic variations with different periods of record, and accordingly the published values have been accepted without adjustment.

The general temperature characteristics result mainly from the gains and losses of solar radiation within the area, there being close relationships between the temporal patterns of these phenomena on both daily and seasonal bases. It is therefore advantageous to examine the available information on solar radiation and sunshine prior to the treatment of temperature itself.

(a) *Sunshine and Solar Radiation*

The mean cloudiness, expressed as a percentage of sky cover, does not vary greatly from month to month, the minimum being about 20 per cent in August and the maximum about 25 per cent in February (Berry, Bollay and Beers, 1945). The mean number of sunshine hours per year is approximately 3270, representing 75 per cent of the maximum possible total of 4380 hours per year, (Department of National Development, 1953).

Of some importance for engineering, architectural and other purposes are the angles and directions of incidence of sunlight at various times of the day throughout the year, as calculated by Phillips (1950). Data for the latitude of the survey area are given in graphical form in Figure III-7, which shows some aspects of the climate

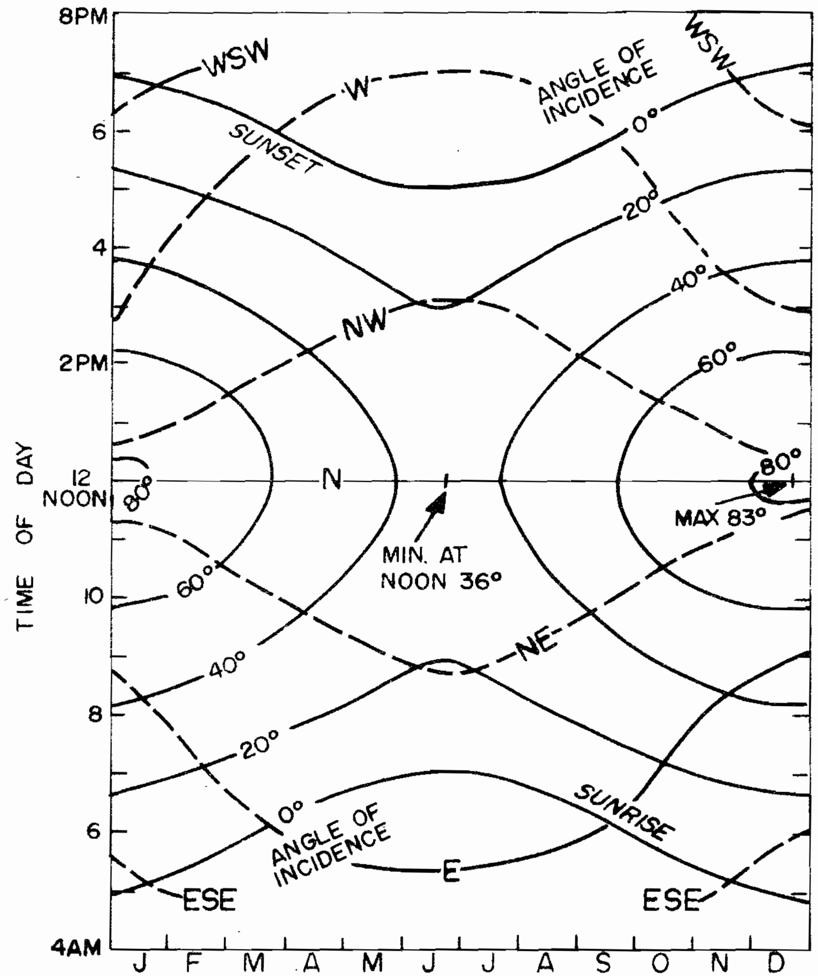


Fig.III-7. - Directions and angles of incidence to horizon of solar beam at given times throughout the year

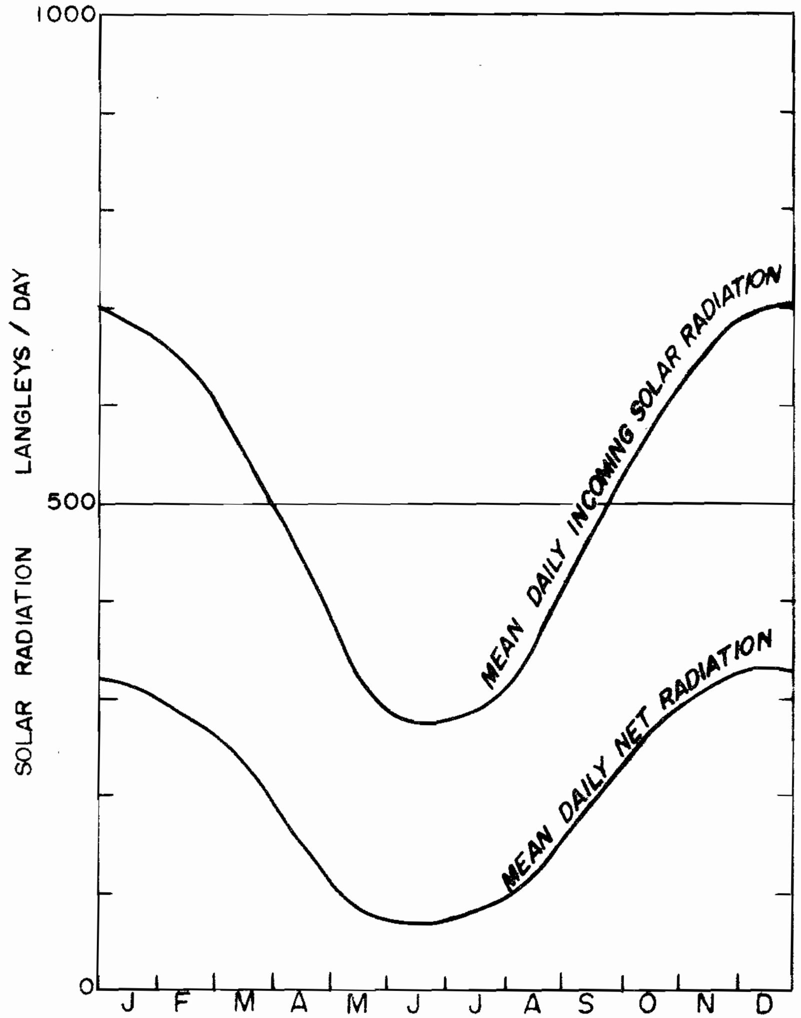


Fig.III-8. - Variations in mean rates of solar radiation throughout the year that should be considered in the design of buildings, particularly as human comfort in the area may be stressed by the high temperatures. During the relatively warm month of March at critical times of the day, the angles of incidence of sunlight are as low as 40^o to the horizon, indicating the desirability of wide roof overhangs on northern and western sides to prevent excessive heating and sun penetration. Figure III-7 also shows the effective hours of daylight, which vary from 10 hours in June to 14 hours in December. This photoperiodicity has significant implications for plant growth and livestock behaviour, for example in influencing the times of germination and fertilization in certain species (Black, 1958; Macfarlane, 1958).

Adequate direct measurements of solar radiation are not yet available in the vicinity of the survey area, but generalised estimates on a monthly basis have been made for the whole of Australia by Hounam (1963), from correlations of sunshine data with measurements in the capital cities and elsewhere. Interpolated from the maps of this study, the mean monthly values of incoming solar radiation for the Fowlers Gap-Calindary area vary from 260 langleys per day in June to 680 langleys per day in December and January, as shown in Figure III-8. Also shown in the same figure are Hounam's estimates of net ratiation, i.e. the difference between incoming and outgoing radiation. In these estimates average ground reflective properties are assumed with the adoption of a value of 0.23 for the albedo.

The maximum rates of incoming solar radiation for short periods at various times of the day may be obtained from tables prepared by Loewe (1962). These are the rates occurring with clear skies and a dry atmosphere, the highest being in December when they reach 1.39 langleys per minute at noon, and the lowest in June when the noon rate is as low as 0.72 langleys per minute. The noon rate in December is close to the highest reached anywhere in the world, according to Loewe's estimates. It is equivalent to an energy input of 10,000 kilowatts per hectare, which represents a power potential worthy of investigation for possible exploitation.

The similarity between seasonal patterns of solar radiation and temperature may be seen by comparing Figures III-8 and III-9, the latter showing mean daily values throughout the year at White Cliffs based on data published by the Commonwealth Bureau of Meteorology (1969). Although they have comparable geometrical forms, the temperature curves lag behind the radiation curves by a period varying from 4 weeks in summer to 2 weeks in winter. These typically continental lags are shorter than those at coastal locations influenced by the greater heat storage in the ocean.

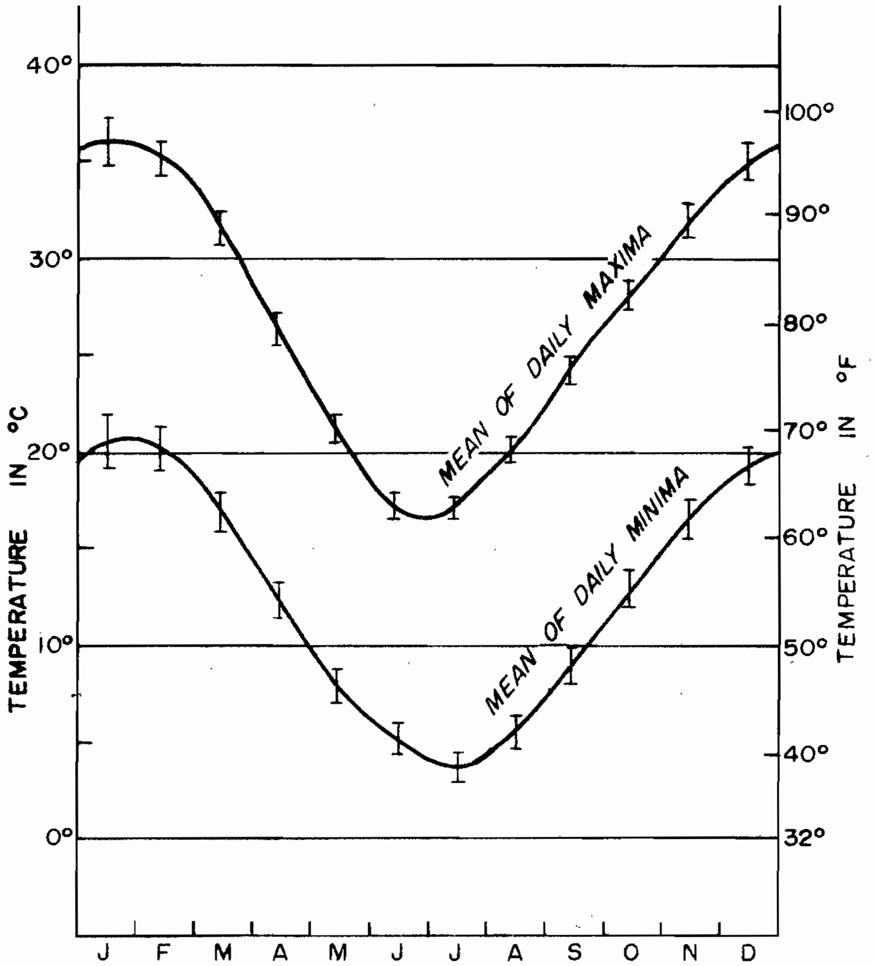


Fig.III-9. - Means and standard deviations of daily maximum and minimum temperatures

(b) *Summer Temperatures*

By most standards the daytime temperatures in the summer half of the year would be regarded as hot. Their values generally exceed 30°C during most afternoons throughout the season, as indicated by the curve of mean daily maxima in Figure III-9. The mean daily minima, representing early morning and night-time conditions, are considerably lower, varying from about 10°C in October to 20°C in February. The summer diurnal range is therefore 15°C or greater, which is similar to ranges in other parts of inland Australia. At Adelaide, and also at the same latitude on the east coast, the summer diurnal range is only 6°C to 10°C, the difference being due mainly to lower daily maxima at the coastal locations. The daily minima at these locations in summer are similar to those in the Fowlers Gap - Calindary area.

Also shown in Figure III-9 are the standard deviations of mean maximum and mean minimum monthly temperatures. These range from 1°C to 2°C in the summer period for both maximum and minimum values, representing a small to moderate degree of variability. January is the month with the most variable maximum and minimum temperatures, while December has the least variable maxima and October the least variable minima.

The highest recorded temperature at White Cliffs is 51.5°C in 1909, not far below the highest on record for New South Wales, i.e. 51.7°C at Bourke in the same year, nor the highest for Australia, which was 53°C at Cloncurry in 1889 (Ashton and Maher, 1954). On the average, 40 days per year have maximum temperatures equalling or exceeding 37.7°C, and when this temperature is reached on two or more consecutive days the condition is described by the Commonwealth Meteorological Bureau (1966) as a heatwave. As many as 24 consecutive heatwave days have been recorded in the vicinity of the survey area, compared with maxima of 9 at Adelaide and only 2 or 3 on the north coast of New South Wales (Department of National Development, 1953).

Frost has apparently not been recorded in the summer half of the year in the Fowlers Gap-Calindary area except for one occasion on October 1st (Foley, 1945).

(c) *Winter Temperatures*

During the winter months daytime conditions are usually mild to warm, as indicated in Figure III-9 by mean daily maxima which range from 17°C in July to 27°C in April. Early morning and night-time conditions are relatively cool, with mean daily minima ranging from 4°C in July to 13°C in April. The mean diurnal range of about 13°C is therefore a little smaller in winter than summer, contrary to coastal conditions where the mean diurnal range is usually larger in winter. However, the coastal winter diurnal range is still smaller than that in the survey area, mainly due to the higher minimum temperatures on the coast.

The variabilities of winter maxima and minima are slightly lower than those for the summer months as shown by the standard deviations of monthly values in Figure III-9. April is the most variable and July the least variable month for both maximum and minimum temperatures.

Closely related to low winter temperatures is the occurrence of frost which may be detrimental to stock and vegetation in association with other weather conditions. The susceptibility of a particular location to frost may depend on topographic controls as much as on the synoptic situation, with the result that certain gullies or hollows could be affected much more frequently than nearby rises. At places with average exposures in the survey area, heavy frosts, as indicated by screen temperatures below 0°C, may be expected 4 or 5 times per year. Light frosts, when screen temperatures are between 0°C and 2.5°C, occur more frequently, usually 8 to 10 times per year. Although heavy frosts have been recorded at White Cliffs as early as April 20th and as late as September 19th, the most likely period of occurrence is between the middle of June and the beginning of August. Light frosts have been recorded as early as April 7th and as late as October 1st. The average length of the frost-free period (i.e. without light or heavy frosts) is 270 days at White Cliffs, 304 days at Tibooburra and 298 days at Broken Hill (Foley, 1945, Commonwealth Bureau of Meteorology, 1966).

The lowest official temperature recorded at White Cliffs was minus 6°C in 1940, which is typical of extreme low temperatures in most of the western part of the State.

V. OTHER CLIMATIC ELEMENTS

(a) *Humidity and Dew*

Humidity data have been published for Broken Hill, Tibooburra, and Wilcannia (Commonwealth Bureau of Meteorology, 1969). At all three stations the mean monthly 9 a.m. and 3 p.m. values correspond quite closely, the greatest difference in relative humidities at these times being less than 4 per cent. It seems reasonable to assume, therefore, that similar values apply to the survey area. In Figure III-10, which shows some of these data for Broken Hill and Tibooburra, an index of mean daily relative humidity has been adopted rather than the 9 a.m. value. This index is calculated from the 9 a.m. dew point and the mean daily temperature in lieu of the 9 a.m. temperature, and it is presented by the Bureau of Meteorology (1969) as a reasonable approximation of the daily mean relative humidity.

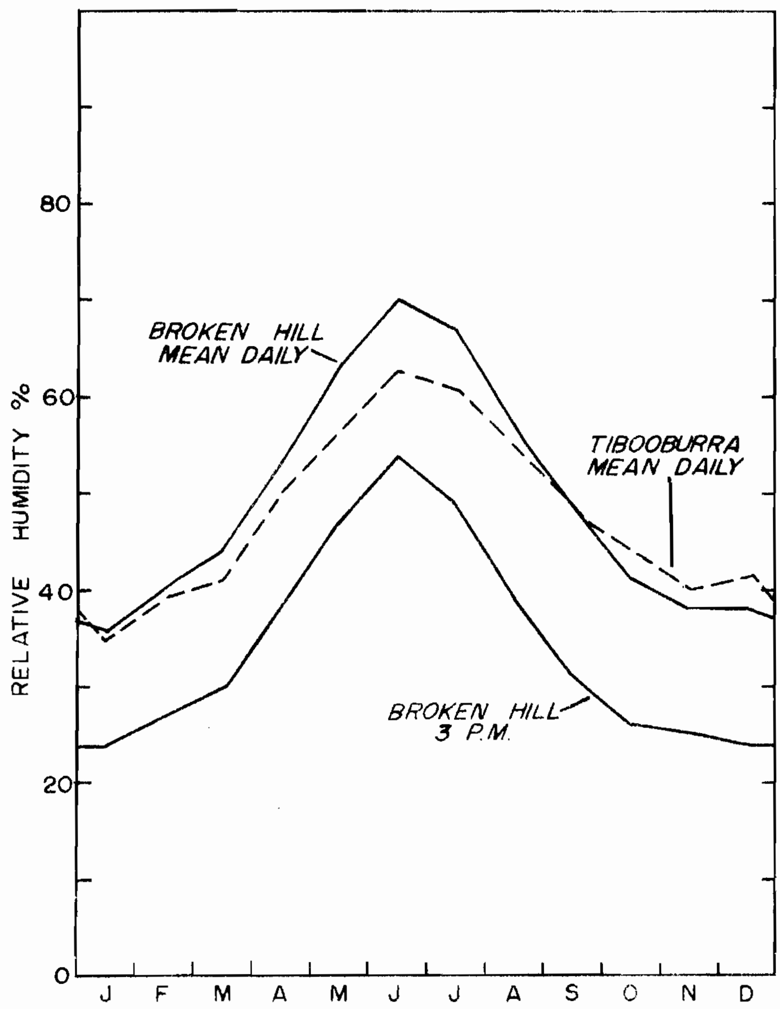


Fig.III-10. - Mean Daily and 3 pm relative humidities

It may be seen from Figure III-10 that the highest values are in winter and the lowest in summer, giving a monthly pattern that varies inversely with the monthly temperature pattern as a consequence of the inverse relationship between these elements. The mean values of about 70 per cent in June and July are surprisingly high; in fact they are not far below those at Sydney and other coastal locations for these months. However, the 3 p.m. relative humidities at Broken Hill and Tibooburra are considerably lower than at coastal locations throughout the year, so it may be inferred that night-time and early morning humidities in winter months in the survey area are quite high. If the effects of temperature are ignored by considering absolute humidities rather than relative humidities, then the seasonal pattern is different. The vapour pressure, which is directly proportional to absolute humidity, is highest in February and lowest in August, with mean daily values of 12.9 mb and 8.0 mb respectively.

Dew is an important factor in the survival of vegetation in some arid areas (Angus, 1958). Unfortunately, few direct measurements of this element have been made in Australia and there is virtually no quantitative information available for the vicinity of the Fowlers Gap-Calindary area. An idea of its possible frequency of occurrence may be obtained from estimates of the number of days when minimum temperatures are less than the calculated dew points. At Broken Hill the daily minimum temperatures are usually close to or less than the calculated dew points in the five months April to August inclusive, and dew should therefore occur frequently in these months; at Tibooburra, similar conditions apply in the four months May to August. These data give an indication of what may be expected in the survey area and are consistent with the previous conclusion concerning high early morning humidities in the winter months. The low relative humidities and associated low dew points during the summer months October to March suggest that dew is uncommon in this season.

Data on persisting high dew points are important in hydrometeorology and hydrology, where they are used in the estimation of extreme precipitation and severe floods. The highest dew point likely to persist for 24 hours in the survey area is about 23°C according to the map published by the Commonwealth Bureau of Meteorology (1947).

(b) *Wind*

Unpublished daily wind velocities and directions are available from the Bureau of Meteorology for 9 a.m. and 3 p.m. at Broken Hill and Wilcannia, and for 9 a.m. only at Tibooburra. Continuous anemograph records of velocity and direction are available for Broken Hill since 1952, and 9 a.m. anemometer readings showing miles run of wind per day have been observed at Stephens Creek since 1965.

The results of a seasonal direction-frequency analysis of the 9 a.m. Broken Hill and Tibooburra data for the 10-year period 1945-54 have been plotted in Figure III-11. The corresponding frequency pattern at Wilcannia was found to be similar to that of Broken Hill and therefore was not plotted. Places in the survey area are expected to reflect aspects of both the Broken Hill and Tibooburra patterns depending on their relative proximities to these stations.

Although the analyses of Figure III-11 are for a relatively brief period and are based only on observers' daily estimates, they are probably reasonably representative of the 9 a.m. wind characteristics at each station, as the Broken Hill frequencies agree quite well with the results of a simple analysis of the anemograph data for the period 1961-65. These more recent and reliable anemograph data were not used for Figure III-11, however, because of their lack of correspondence in time and method of observation with the Tibooburra data.

In general, the wind characteristics are directly related to the prevailing positions and directions of movement of the pressure systems mentioned earlier. Essentially the wind directions are a consequence of anticlockwise circulation about the eastward moving subtropical highs and clockwise circulation about cyclones or lows. The leading edges of the subtropical highs give rise to southerlies that predominate in most seasons both at Broken Hill and at Tibooburra, as shown in Figure III-11. The trailing edges of the highs give rise to northerlies which occur with moderate frequency in all seasons, reaching their maximum prevalence in the December-February period at Broken Hill. In the June-August period, when the highs are furthest north, the westerlies associated with the mid-latitude lows become an important influence at both stations. At the same time the southerlies decline in frequency at Broken Hill, but this decline apparently does not extend as far north as Tibooburra.

Except in the mid-winter months, easterlies are frequent at Tibooburra due to the circulation around the northern edges of the anticyclones. The influence of these easterlies is considerably less at Broken Hill, even in the mid-summer months.

Figure III-11 is based on 9 a.m. observations, which differ somewhat from the 3 p.m. observations in that there is a tendency towards a smaller proportion of easterly winds (NE, E, and SE) and a larger proportion of westerlies in the afternoons in all seasons. These effects are associated with diurnal variations in the horizontal thermal gradients over the Australian landmass, but they are subsidiary to the influences of the circulations around the pressure systems on a synoptic scale.

During an average year the wind condition at 9 a.m. is described as calm on approximately 10 per cent of days at both Broken Hill and Tibooburra. These are generally days with very light winds (less than

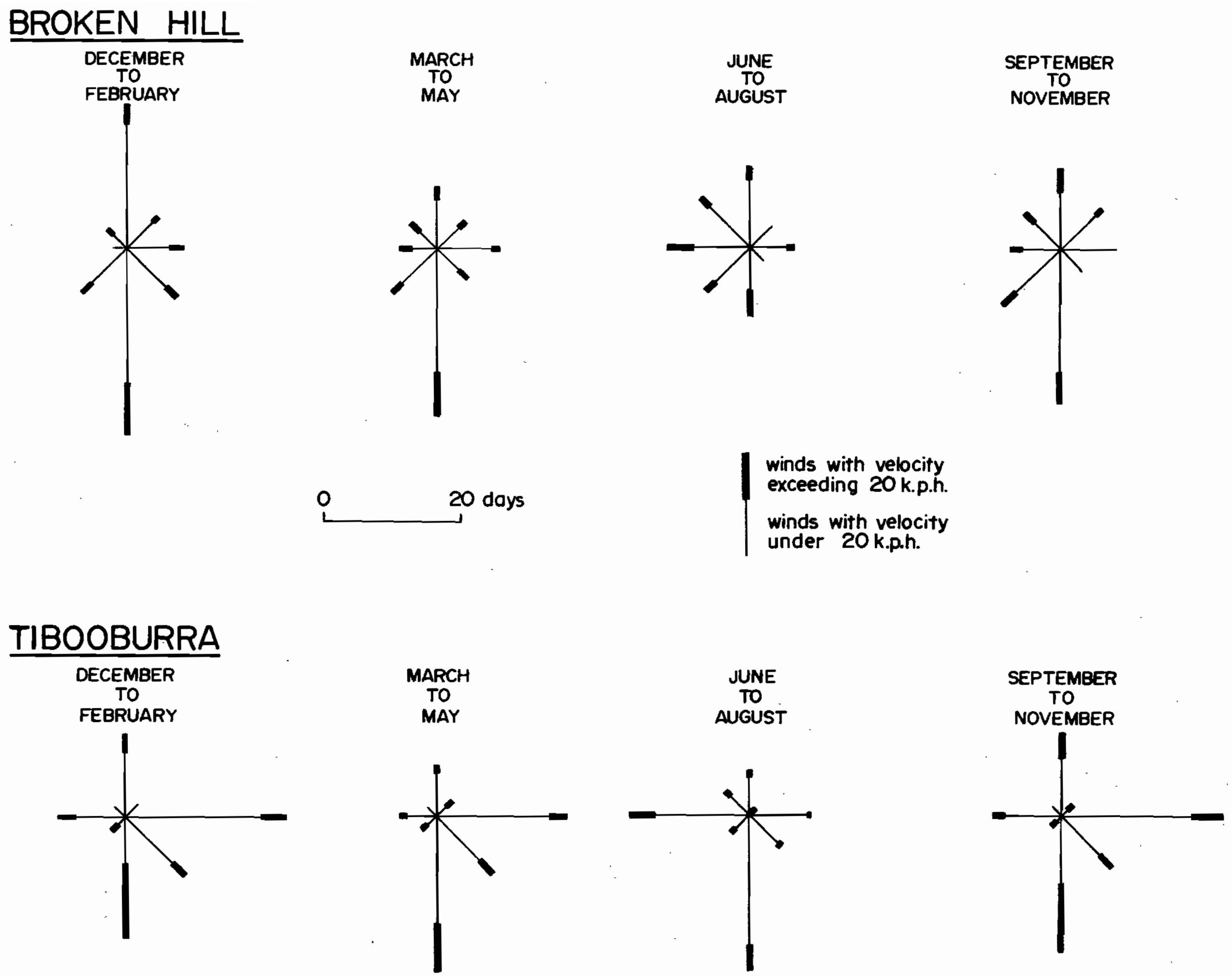


Fig. III-11. - Broken Hill and Tibooburra 9 am seasonal wind roses

1 kph) rather than with no wind at all, as verified by analyses of the Broken Hill anemograph records on an hourly basis. Such light winds tend to be slightly more frequent in winter months than in summer months, reflecting early-morning atmospheric stability in winter. Observations of calms are particularly susceptible to local bias due to factors such as station exposure, method of wind estimation, and observer judgment. Bias is also often evident in observers' judgments of wind direction, with the result that greater frequencies tend to be recorded for cardinal and other favoured directions than actually do occur (Brookfield, 1970). No adjustments have been made for these effects in Figure III-11, although it is likely that some are present.

Stronger winds, i.e. with velocities exceeding 20 kph, have similar seasonal frequency patterns to those for winds less than 20 kph except for the higher proportion of strong southerlies occurring in summer at Tibooburra (see Figure III-11). According to Whittingham (1964), extremely strong gusts over short periods (as used in architectural and engineering design of structures) may occur from any direction in the vicinity of Broken Hill and are more likely in summer than in winter months. This is because they are associated with the sudden downdraughts of severe local convective storms rather than with the broader synoptic patterns of airflow. Whittingham's frequency estimates of such strong gusts at Broken Hill are 1 per cent and 10 per cent probabilities of occurrence in any year of gusts of 140 and 110 kph respectively.

Data on run of wind are desirable for the design of watering systems involving windmills and they may also be required for evaporation and energy-balance studies. The monthly means and standard deviations for the five-year period 1965-69 at Stephens Creek are given in Table III-2 and provide a reasonable indication of what may be expected in the Fowlers Gap-Calindary area. It appears that the summer months are windier than the winter months, the highest mean value being 267 kilometres per day for December compared with the lowest mean value of 131 kpd for June. These are equivalent to average daily velocities of 11 kph and 5.5 kph for December and June respectively. As shown by the relatively low coefficients of variability, the monthly pattern should not differ much from year to year.

Dust storms are experienced in the survey area, but there does not appear to be any readily available information on their frequency of occurrence and on accompanying winds or other associated climatic conditions. Such information would be useful in studies of erosion, for instance.

(c) *Evaporation*

Observations of evaporation are available from Umberumberka since 1912 and from Stephens Creek since 1940 (Hounam, 1961), both stations being about 60 miles south of Fowlers Gap. Monthly and annual means for Umberumberka are given in Table III-3 together with similar data

TABLE III-2. RUN OF WIND IN KILOMETRES PER DAY FOR STEPHENS CREEK, 1965-69 INCLUSIVE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	240	235	198	161	140	131	156	199	219	225	265	267	2436
Standard Deviation	46	35	39	40	31	17	35	29	43	29	31	33	244
Coeff. of Variability (%)	19	15	20	25	22	13	22	15	20	13	12	12	10

TABLE III-3. EVAPORATION IN MILLIMETRES FOR SURVEY AREA AND UMBERUMBERKA, AND ESTIMATES OF MEAN POTENTIAL EVAPOTRANSPIRATION FOR BROKEN HILL

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Survey Area Mean Evaporation	335	265	225	160	110	76	69	110	155	215	265	300	2300
Umberumberka Mean Pan Evaporation	325	275	235	150	105	72	73	100	145	215	260	310	2270
Standard Deviation	28	27	25	20	18	15	13	18	20	25	28	35	190
Coeff. of Variability (%)	9	10	11	13	17	21	18	18	14	12	11	11	9
Broken Hill Estd. Mean Potential Evapo-transpiration	220	175	150	97	66	48	56	76	105	140	170	215	1515

for the survey area interpolated from maps of evaporation for the whole of Australia issued by the Bureau of Meteorology (1966). It seems preferable to refer mainly to the latter data as these are directly comparable with data from other parts of Australia, having been adjusted to allow for the large variations that may be attributed to different types of evaporation pan. Accordingly, the mean annual evaporation for the survey area is taken on 2300 mm with a coefficient of variation of about 9 per cent. The area therefore has evaporation rates that are among the highest in New South Wales, although they are exceeded in the far northwestern corner of the State near Olive Downs, where mean annual values approach 2800 mm.

By comparing Table III-3 with Figure III-3, it may be seen that mean evaporation is considerably greater than mean rainfall in every month of the year, ranging from 69 mm in July to 335 mm in January. The summer monthly values are particularly high, being generally more than twice the corresponding monthly values on the New South Wales coast. Small to moderate variations in seasonal patterns of evaporation may be expected from year to year, the monthly coefficients of variability being 9 per cent to 12 per cent in summer months and 13 per cent to 19 per cent in winter months.

It should be noted that the evaporation values quoted above are for the Australian 91 cm diameter sunken tank which was for many years the standard instrument for this country. The corresponding evaporation losses from a large reservoir or lake would probably be between 10 and 30 per cent lower, depending on the season and other factors (Hounam, 1961; Fleming, 1964). Similarly lower are the corresponding values of potential evapotranspiration, which are the losses of water by transpiration and evaporation that might be expected from short well-watered vegetation (Penman, 1963). Estimates of these values for Broken Hill are given in Table III-3, based on calculations from other meteorological data by McAlpine *(pers. comm.)*

VI. COMBINED EFFECTS OF CLIMATIC ELEMENTS

Although evaporation and potential evapotranspiration have been treated above as climatic elements, these quantities may also be regarded as measures of the combined effects of several other elements of a more fundamental nature, namely net radiation, air temperature, humidity and wind, as expressed in the Penman formula. Other theoretical combinations of the basic elements have been found useful in expressing aspects of the climate that are directly relevant for studies of vegetation response, runoff, human comfort etc.

Fitzpatrick and Nix (1970) have developed light, thermal and moisture indices for assessing the growth of pasture in response to a complex of climatic variables. Work by CSIRO with similar objectives for desert vegetation has emphasised the moisture factor, adopting a simple water balance model for estimating the changes in available soil moisture with weekly inputs of rainfall and potential evapotranspiration (McAlpine *pers. comm.*) These water balance approaches have developed from more generalised concepts of effective rainfall which attempt to give quantitative measures of the combined effects of rainfall and evaporation in relation to plant germination and growth.

(a) *Effective rainfall*

Initial effective rainfall is a total rainfall in a 7-day period equalling 40 per cent of the pan evaporation for that period. It is regarded as the rainfall required to germinate ephemerals and to stimulate growth of perennial plants in arid parts of Australia. To maintain the growth of the plants for at least a month, effective carryover rainfall is required, and this is defined as the total rainfall in a 28-day period (including the week of initial effective rainfall) equalling 20 per cent of the pan evaporation for that period. These measures have been adopted by Slatyer (1960, 1962) following earlier work by White (1955).

Table III-4 shows the monthly probabilities of occurrence of the above values of effective rainfall at Broken Hill and Tibooburra as calculated by Turner (1969). By these criteria, winter is more favourable for plant growth than summer, the highest probabilities being in June and July and the lowest in December and January. Broken Hill is more favourable than Tibooburra, particularly in the winter months. The corresponding values for the survey area would be somewhere between the two, with generally higher probabilities than Tibooburra and lower probabilities than Broken Hill.

Prescott (1958) proposed a measure of effective rainfall calculated on a monthly or annual basis from the ratio $P/E^{0.75}$ where P and E are rainfall and evaporation respectively, both expressed in inches. If calculated on a mean monthly basis, the number of months for which the index exceeds 0.4 is an approximation of the average length of the growing season. For the survey area this season is only two months, namely June and July. Calculated on an average annual basis, the index has been used to define the boundaries of the arid zone, and has also been correlated with soil and vegetation types and with streamflow régimes. It places the survey area well within the Australian arid zone.

(b) *Runoff*

Runoff and streamflow are also dependant on the combined effects of rainfall and evaporation, particularly in humid regions where reasonable estimates of mean annual runoff may be made from climatic data alone (Langbein *et al.*, 1949; Bell, 1966). In arid regions however, runoff from areas of less than a few square kilometres is characterised by extreme variability in space and time, due partly to the spasmodic and localised nature of the rainfall and partly to slopes and land-surface

TABLE III-4. PROBABILITY OF OCCURRENCE OF INITIAL EFFECTIVE RAINFALL AND EFFECTIVE CARRYOVER RAINFALL AT BROKEN HILL AND TIBOOBURRA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Broken Hill Initial effective rainfall (mm)	27	24	19	13	8	6	5	8	13	17	22	24
Probability (%)	21	21	23	31	48	63	56	61	25	30	23	17
Tibooburra Initial effective rainfall (mm)	36	30	25	18	12	9	7	12	19	24	29	33
Probability (%)	13	26	19	20	28	41	38	22	15	22	16	20
Broken Hill Carryover (mm)	55	49	39	26	16	12	11	16	25	35	43	49
Probability (%)	7	14	14	21	39	45	47	37	16	18	11	7
Tibooburra Carryover (mm)	71	61	49	37	24	18	15	24	38	47	59	65
Probability (%)	9	13	13	10	25	36	28	15	7	13	7	6

conditions which may range from highly impervious rock outcrops to highly porous soils of coarse texture. On this scale, areas of run-on are also of interest, being important in studies of vegetation adaptation and soil erosion. Unfortunately, no useful quantitative data on these factors are yet available for the survey area.

An indication of runoff characteristics of well-developed drainage systems with catchments between about 50 and 2000 sq km may be obtained from the long records of streamflow at Stephens Creek and Umberumberka Reservoir. Over a 42-year period (1916-1957) the mean annual values of runoff from these catchments were equivalent to 15 mm and 13 mm respectively, representing approximately 7 per cent of the mean annual rainfall (200 mm). At each station the highest decile of annual runoff was estimated to be 30 mm and the lowest decile 1.5 mm, and there were two years with virtually no runoff (Gerny, 1962). Smaller values of runoff are suggested for the region by the Department of National Development (1967), based on a mean annual value of 4 mm for the Bulloo River catchment in south-western Queensland. This represents about 2 per cent of the mean annual rainfall, which is probably appropriate for catchments larger than 5000 sq km, or for smaller catchments with poorly developed drainage systems.

(c) *Effective Temperature*

Although it is sometimes used in other contexts (e.g. in vegetation response studies), the term effective temperature in this chapter refers to a measure of the sensation of warmth or cold felt by humans (following Ashton, 1964). This sensation may differ significantly from the dry bulb thermometer reading, being affected also by humidity, wind, and radiation from the sun or surrounding surfaces. Additionally, physiological factors such as health, age and previous acclimatisation influence human threshholds of discomfort and corresponding temperature judgments.

Appropriate combinations of dry bulb temperature and wet bulb or humidity observations have been adopted by Ashton (1964) for the estimation of effective temperatures throughout Australia. An indoor value of 27^{o}C represents the level above which most people would feel discomfort, even if acclimatised to hot weather. According to Ashton's estimates these conditions occur in the survey area approximately 30 days per year on the average.

A considerable number of people are uncomfortable at effective temperatures above 24^{o}C and the average frequency of this value is 85 days per year, indicating the length of period for which air conditioning is a desirable facility. There are a few people, mainly unacclimatised migrants from Great Britain and northern Europe, who feel uncomfortably hot at effective temperatures as low as 21^{o}C, which are reached in the survey area on an average of 150 days per year. It should be noted, however, that the induction of air movement by the use of fans can reduce the above temperatures by as much as 3°C, as no significant wind effects are assumed in the estimates.

Leeper (1970) suggests that the upper temperature limit of comfort is approximated by a mean daily wet bulb reading of 21.1°C. According to this criterion, the survey area is favourably placed, having less than one month per year with wet bulb readings above the limit, but there is some doubt about the validity of such a measure in an arid environment.

VII. REFERENCES

ANGUS, D.E. (1958). - Measurements of dew. *Climatology and Microclimatology*, UNESCO, Paris, 301-3.

ASHTON, H.T. (1964). - Meteorological data for air conditioning in Australia. *Engineering Bull.*, 47

ASHTON, H.T., and MAHER, J.V. (1954). - *Australian Forecasting and Climate*. pub.by authors, Melbourne.

BELL, F.C. (1964). - Rainfall-depth-duration-frequency maps of New South Wales and Victoria. *Water Res.Found.Aust. Bull.*, 8.

BELL, F.C. (1966). - Improved techniques for estimating runoff with brief records. *Univ.N.S.W. Water Res.Lab.Rept.*, 91.

BERRY, F.A., BOLLAY, E., and BEERS, N.R. (1945). - *Handbook of Meteorology*. McGraw-Hill, N.Y.

BLACK, J.N. (1958). - Light intensity and plant growth. *Climatology and Microclimatology*, UNESCO, Paris, 178-80.

BROOKFIELD, M. (1970) - Winds of arid Australia. *CSIRO Aust.Div.Land Res. Tech.Pap.*, 30.

BUDYKO, M.I. (1956). - *The Heat Balance of the Earth's Surface.* U.S. Weather Bureau, Washington, 1958.

COMMONWEALTH BUREAU OF METEOROLOGY (1947). - *Map of Highest Persisting Dew Points.* Aust.Comm.Bur.Met.

COMMONWEALTH BUREAU OF METEOROLOGY (1960). - *Fifty Years of Weather, New South Wales. 1908-1957.* Aust.Comm.Bur.Met.

COMMONWEALTH BUREAU OF METEOROLOGY (1966). - The climate and meteorology of Australia. *Aust.Comm.Bur.Met.Bull.*, 1.

COMMONWEALTH BUREAU OF METEOROLOGY (1969). - Climatic averages, Australia. *Aust.Comm.Bur.Met.Summ.*

De BEUZEVILLE, W.A.W. (1943). - *The Climatological Basis of Forestry.* Forestry Comm. of N.S.W.

DEPARTMENT OF NATIONAL DEVELOPMENT (1953). - *Atlas of Australian Resources; Temperature.*

DEPARTMENT OF NATIONAL DEVELOPMENT (1967). - *Atlas of Australian Resources; Surface Water Resources.*

FITZPATRICK, E.A. (1953). - *Probability Analysis of Rainfall Factors in Drought in New South Wales.* (M.A. Thesis, Univ. of Sydney). Rural Bank of N.S.W.

FITZPATRICK, E.A., and NIX, H.A. (1970). - The climatic factor in Australian grassland ecology. *in* Moore, R.M. (Ed.), *Australian Grasslands*, A.N.U. Press, Canberra, 1-26.

FLEMING, P.M. (1964). - Evaporimeter relationships at Griffith, N.S.W. *Civil Eng.Trans.I.E.Aust.Vol.CE6,* 1.

FOLEY, J.C. (1945). - Frost in the Australian region. *Aust.Comm.Bur. Met.Bull.,* 32.

FOLEY, J.C. (1956). - 500mb. contour patterns associated with the occurrence of widespread rains in Australia. *Aust.Met.Mag.,* 13.

GERNEY, J.S. (1962). - Rainfall and stream flow in South Australia. *J.Inst.Eng.Aust.,* 34, 45-57.

GIBBS, W.J. and MAHER, J.V. (1967). - Rainfall deciles as drought indicators. *Aust.Comm.Bur.Met.Bull.,* 48.

HOUNAM, C.E. (1961). - Evaporation in Australia. *Aust.Comm.Bur.Met. Bull.,* 44.

HOUNAM, C.E. (1963). - Estimates of solar radiation over Australia. *Aust.Met.Mag.,* 43, 1-14.

INSTITUTION OF ENGINEERS, AUSTRALIA (1958). - *First Report of the Stormwater Standards Committee of the Institution on Australian Rainfall and Run-Off.* pub. by the Institution.

KARELSKY, S. (1956). - Classification of the surface circulation in the Australasian region. *Aust.Comm.Bur.Met., Met.Study,* 8.

KÖPPEN, W. (1936). - Das geographische System der Klimate. *Handbuch der Klimatologie,* Vol. 1, Pt. C, Borntraeger, Berlin.

LANGBEIN, W.B. *et al.* (1949). - Annual run-off in the United States. *U.S. Geol.Survey Circ.,* 52.

LANGBEIN, W.B., and SCHUMM, S.A. (1958). - Yield of sediment in relation to mean annual precipitation. *Amer.Geophys.Union Trans.*, 39, 1076-84.

LEEPER, G.W. (1970). - *The Australian Environment.* 4th Ed., M.U.P., Melbourne.

LOEWE, F. (1962). - The intake of solar radiation by slopes with cloudless sky. *Aust.Comm.Bur.Met.Bull.*, 45.

MACFARLANE, W.V. (1958). - Experimental approaches to the functions of tropical livestock. *Climatology and Microclimatology*, UNESCO, Paris, 227-34.

McILLWRAITH, J.F. (1953). - Rainfall intensity-frequency data for New South Wales Stations. *J.Inst.Eng.Aust.*, 25, 133-9.

MEIGS, P. (1953). - *Reviews of Research on Arid Zone Hydrology.* UNESCO, Paris, 203-10.

PENMAN, H.L. (1963). - Vegetation and hydrology. *Comm.Bur.Soils, Harpenden, England, Tech.Comm.*, 53.

PHILLIPS, R.O. (1951). - Sunshine and shade in Australasia. *Aust.Comm. Exper.Build.Stn, Tech.Study*, 23.

PRESCOTT, J.A. (1958). - Climatic indices in relation to the water balance. *Climatology and Microclimatology*, UNESCO, Paris, 48-51.

PRESCOTT, J.A., and THOMAS, J.A. (1949). - The length of the growing season in Australia as determined by the effectiveness of rainfall. *Proc.Roy.Geog.Soc.A'asia, S.A. Branch*, 50, 42-6.

SLATYER, R.O. (1960). - Agricultural Climatology of Katherine Area, N.T. *CSIRO Aust.Div.Land Res.Reg.Surv.Tech.Pap.*, 13.

SLATYER, R.O. (1962). - Climate of the Alice Springs area. *CSIRO Aust. Land Res.Ser.*, 6, 109-28.

STEWART, J. (1960). - Rainfall intensities in New South Wales. *Soil Cons. Journ.*, 16, 171-85.

THORNTHWAITE, C.W. (1948). - An approach towards a rational classification of climate. *Geog.Rev.*, 38, 55-94.

TURNER, J.C. (1969). - The climate of the region. *in The Pastoral Industry in Western New South Wales, Resources and Problems of the Environment*, Univ.N.S.W., 17-24.

WHITE, R.C.L. (1955). - Drought and effective rainfall frequency in pastoral New South Wales, west of the wheat belt. *Aust.Comm.Bur.Met. Study*, 5.

WHITTINGHAM, H.E. (1964). - Extreme wind gusts in Australia. *Aust.Comm. Bur.Met.Bull.*, 46.

CHAPTER IV. GEOLOGY OF THE FOWLERS GAP-CALINDARY AREA

By M.E. Sullivan

I. REGIONAL STRUCTURE

The survey area encompasses parts of three structural units (Figure IV-1). The first of these, the Barrier Range Block, is part of the ancient Platform or rigid geologic base of the continent and represents the northeastern extension of the Adelaide Geosyncline. The Block is here separated into three parts by the second unit, the Palaeozoic Bancannia Trough. There is a large outlier of the Block in the centre of the area and a smaller portion south of this, whilst the main part of the Barrier Range is included only in the extreme southwest of the survey area. The Bancannia Trough connects in the north with the third unit, the Great Artesian Basin.

The rock succession in each of these units is given in Table IV-1 and a diagrammatic cross-section in Figure IV-2.

(a) *Barrier Range Block*

Of the three rock groups which make up the Barrier Range Block, the Middle Proterozoic Wonominta Beds form the two central outliers. These are a mixture of calcareous shale and subordinate phyllite, schist, and quartzite, which have been severely folded and locally faulted, chiefly along axes running west of north. The shale forms lowlands, whilst the phyllite and schist give rise to hilly tracts. In the north, the edge of the Block is here formed by the Koonenberry Fault, where Ordovician quartzite, limestone, and claystone form the spectacular Koonenberry Mountains.

That limited part of the Barrier Range proper within the survey area consists mainly of Upper Proterozoic rocks of the Torrowangee and Farnell Groups, chiefly calcareous shale, limestone, and dolomite with some sandstone, quartzite, and conglomerate, all much folded on axes trending west of north, strongly intruded by quartz veins and silicified or otherwise partly metamorphosed. These rocks mainly form undulating lowlands with minor strike ridges of domomite and quartzite. On the east side, the Far-Away-Hills Quartzite of the Caloola Syncline forms prominent hogback ranges characteristically expressive of the steep dips of the Proterozoic strata.

In the extreme southwest of the area are Proterozoic gneiss and schist of the Willyama Complex (Vernon, 1969), the oldest of the rock groups, which is elsewhere the main relief builder in the Barrier Range Block.

All three groups of rocks are intruded by quartz reefs and by Lower Palaeozoic basic dyke rocks, mainly lamprophyres, which generally build low ridges and which in this environment are particularly stable and show virtually no soil development.

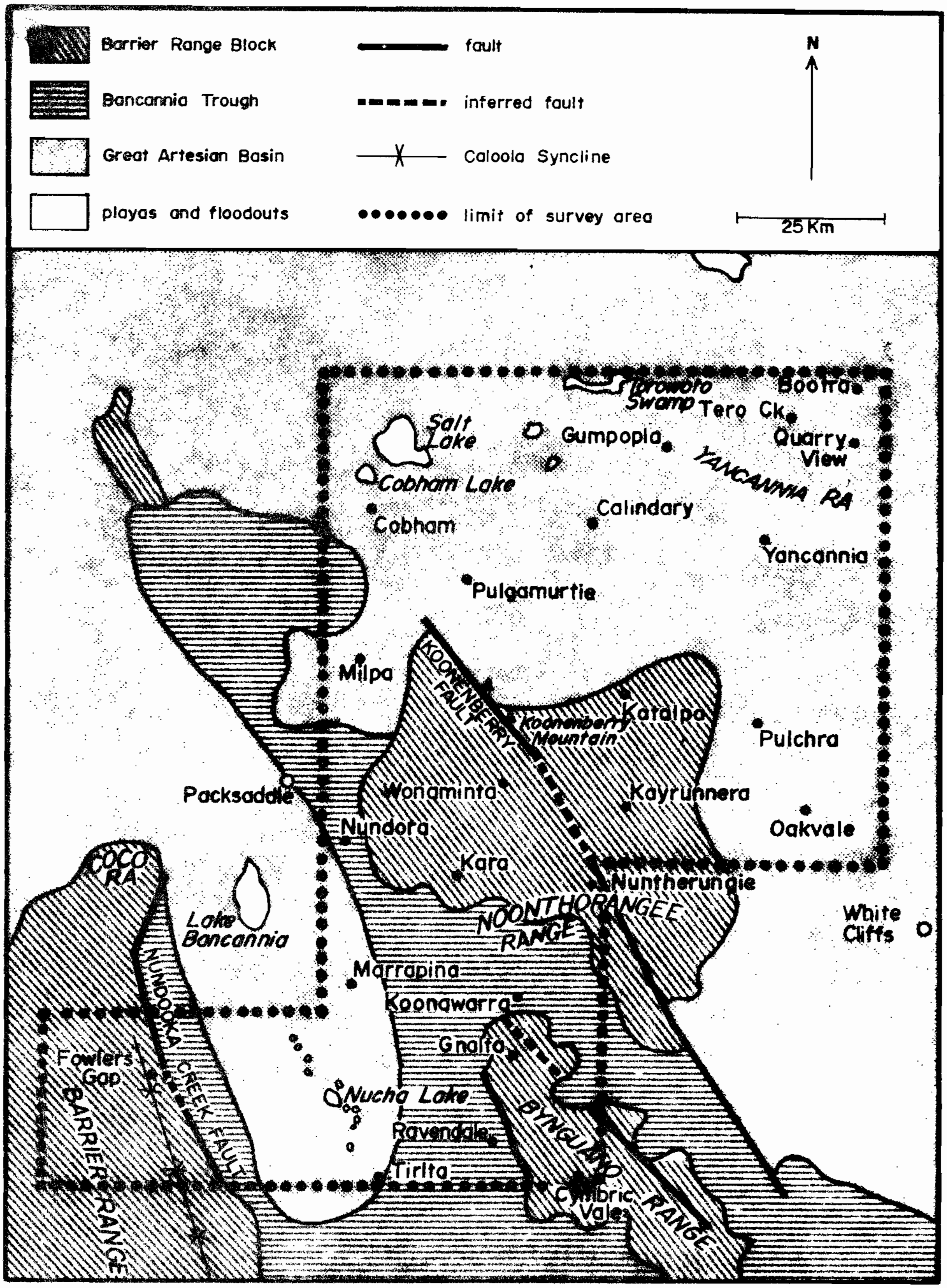


Fig IV-1 - Structural Units

TABLE IV-1. STRATIGRAPHIC SUCCESSION IN FOWLERS GAP-CALINDARY AREA

Age	Rock Group	Subdivisions in Survey Area	Lithology	Structure	Approximate Thickness (metres)
Quaternary			Alluvial sand, silt, clay, aeolian sand; secondary limestone; evaporites	Unconsolidated	At least 100 m in parts
Tertiary			Silcrete duricrust; silicified sandstone and conglomerates; porcellanite	Horizontal or slightly domed	Duricrust to 5 m
			Unconformity		
Cretaceous	Rolling Downs Group		Sandstone, arkose, clay-sandstone, conglomerate, siltstone, claystone, shale, limestone	Horizontal	To 1000
Jurassic			Sandstone, claystone	Horizontal	To 50 m in patches exposed
			Unconformity		
Upper Devonian	Ravendale Formation		Clayey quartz sandstone, shale, quartzite	Cross bedded, flat lying	To some thousands
	Nundooka Sandstone		Quartz sandstone	Moderate dip	1000
	Coco Range Beds		Quartz sandstone, siltstone, conglomerate	Slight dip	800
Devonian	Snake Cave Sandstone		Sandstone, conglomerate, siltstone	Moderate to steep dips	Over 2000
			Unconformity		
Ordovician			Quartzite	Steeply dipping	200
	Mootwingee Group	Rowena Formation	Shale, siltstone, limestone	Moderate to steep dips	2500
		Bynguano Quartzite	Quartzite, limestone, shale	Steeply dipping	2000
		Nootumbulla Sandstone	Sandstone, shale, siltstone	Moderate dip	200
			Probable Unconformity		
Middle Cambrian	Gnalta Group	Coonigan Formation	Shale, limestone, sandstone	Moderate dip	Over 800
			Probable Unconformity		
?Upper Proterozoic			Quartz, porphyry, dolerite, lamprophyre, other basic rocks	Intrusive, massive crystalline	
Upper Proterozoic	Farnell Group	Fowlers Gap Formation	Shale, sandstone, quartzite, limestone; quartz intrusions	Steeply dipping, severely folded, faulted	1500
		Par-Away-Hills Quartzite	Quartzite, sandstone, minor shale and limestone; quartz intrusions	Steeply dipping	40
	Torrowangee Group	Teamsters Creek Subgroup - Teamsters Creek Beds	Shale, limestone, dolomite, some quartzite and sandstone; quartz intrusions	Steeply dipping, severely folded, faulted	To 2000
		Euriowie Subgroup - Floods Creek Formation	Calcareous sandstone and interbedded siltstone	Steeply dipping	1000
			Probable Unconformity		
Middle Proterozoic	Wonominta Beds		Shale, phyllite, schist, quartzite, sandstone	Steeply dipping, severely folded, faulted	?
			Unconformity		
Lower Proterozoic	Willyama Complex		Gneiss, granite-gneiss, schist, amphibolite	Massive, severely folded and faulted	At least 100 m in areas exposed

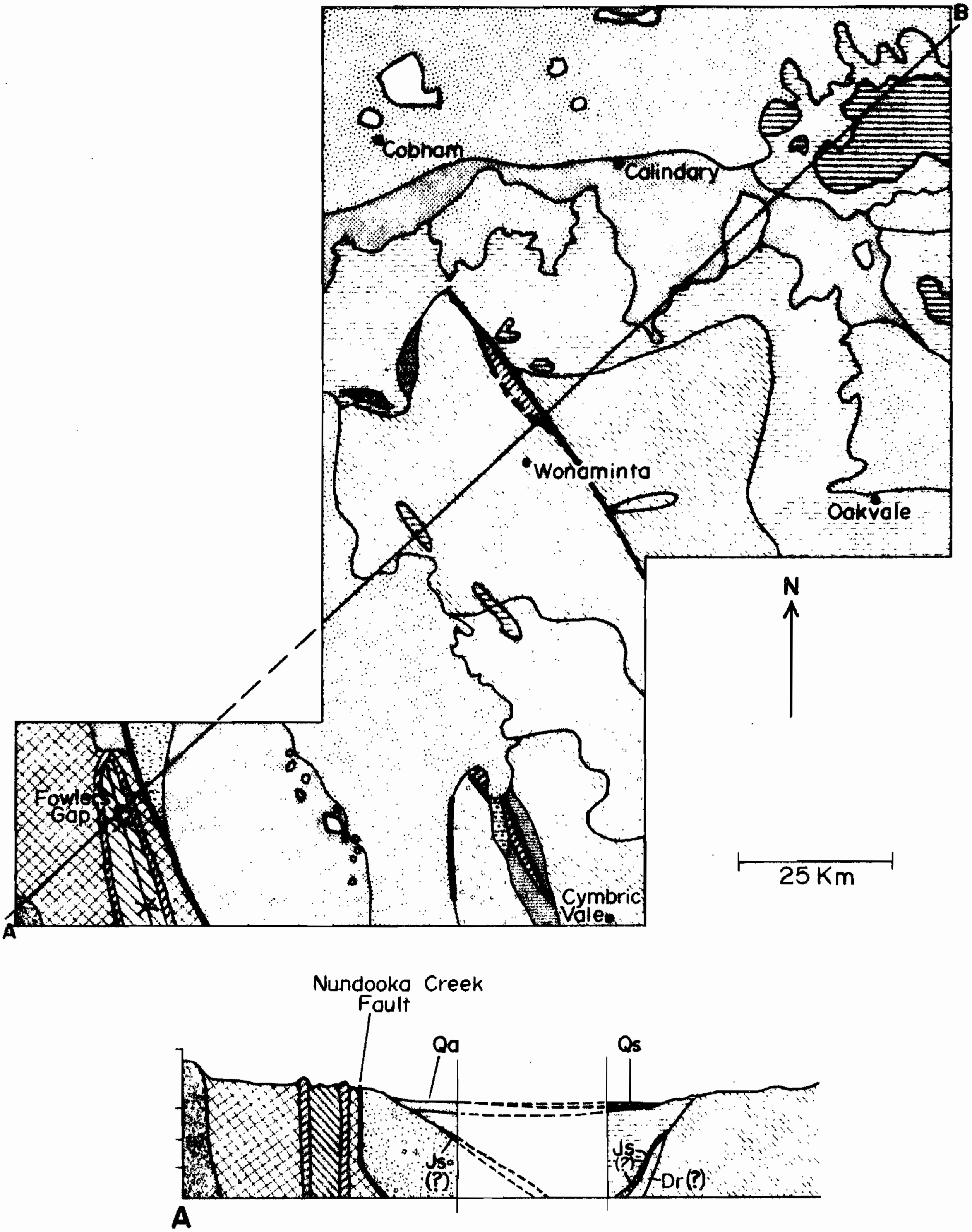


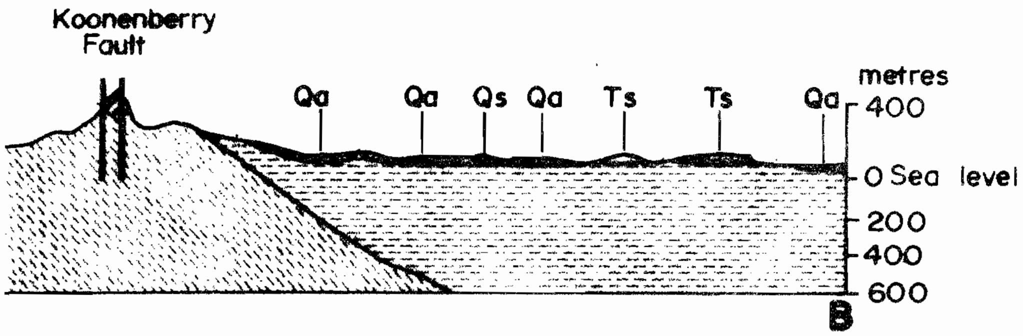
Fig. IV-2. - Geology of the Fowlers Gap-Calindary area, with sections along AB

REFERENCE

Cainozoic	Quaternary			Qa	Alluvium
				Qs	Alluvium and aeolian sand
					Pan deposits including evaporites
	Tertiary			Ts	Silcrete duricrust
Mesozoic	Cretaceous	Rolling Downs Group			Weathered sandstone, siltstone, claystone
	Jurassic			Js	Sandstone, siltstone
Palaeozoic	Upper Devonian		Ravendale Formation	Dr	Flaggy quartz sandstone, minor quartzite
			Nundooka Sandstone / Coco Range Beds		Arkosic quartz sandstone with calcareous lenses, siltstone, conglomerate
	Devonian		Snake Cave Sandstone		Sandstone, conglomerate, siltstone
	Ordovician				Quartzite
		Mootwingee Group	Rowena Formation		Shale, siltstone, limestone
			Bynguano Quartzite		Quartzite, sandstone
	Upper Cambrian		Nootumbulla Sandstone		Sandstone, shale, siltstone
	Middle Cambrian	Gnalta Group	Coonigan Formation		Shale, limestone, sandstone
Proterozoic	Upper Proterozoic	Fornell Group	Fowlers Gap Beds		Shale, sandstone, quartzite
			Far-Away-Hills Quartzite		Quartzite
		Torrowangee Group	Teamsters Creek Beds / Floods Creek Formation		Shale, limestone, dolomite, quartzite, sandstone
					Basic dyke rocks
	Middle Proterozoic		Wonominta Beds		Shale, phyllite, sandstone, schist, quartzite
	Lower Proterozoic	Willyama Complex			Gneiss, granite–gneiss, schist, amphibolite

MAP SYMBOLS

Fault — Inferred Fault — Axis of syncline — ● Station Homestead



(b) *Bancannia Trough*

This structural depression is filled by Devonian, Ordovician, and Cretaceous rocks and extends NNW between the main part of the Barrier Range Block and the two outliers. The boundaries of the Trough against the Block are faults along which outcrops of Palaeozoic rocks occur (Packham, 1969). The Nundooka Creek Fault is the western boundary and the Devonian sandstone and conglomerate along this line are the Nundooka and Coco Range Beds (Ward, Wright-Smith and Taylor, 1969). The eastern limit is the faulted edge of the Bynguano Range, where Ordovician and Upper Cambrian calcareous shale, quartzite, and sandstone of the Mootwingee Group occur as the Rowena Formation, Bynguano Quartzite, and Nootumbulla Sandstone, along with the Middle Cambrian Coonigan shale of the Gnalta Group and Devonian Snake Cave Sandstone. The southeastern limit is the extension of the Koonenberry Fault, where Devonian Ravendale sandstone, siltstone, and conglomerate occur. The Palaeozoic rocks are flatter-lying than the adjacent Proterozoic beds and so give rise to broader uplands with tableland or cuesta forms. Metamorphism in these rocks is restricted to localised and partial silicification, mainly along faults.

(c) *Great Artesian Basin*

This unit occupies the northeast of the survey area (Hind and Helby, 1969), and is a basin filled with Mesozoic sedimentary rocks which also extend southwards into the central part of the Bancannia Trough. The Mesozoic rocks in the survey area are mainly sandstone and siltstone of the Cretaceous Rolling Downs Group, but Jurassic clayey sandstone and siltstone have also been exposed in minor marginal areas adjoining the Wonominta Beds of the Barrier Range Block in the south of the Basin, with other small exposures further north.

These rocks were weathered to depths of 50 m during the Tertiary Period, involving kaolinisation and zonal ferruginisation at depth, probably in conjunction with the formation of a silcrete duricrust to 5 m thick. Subsequently the rocks were subjected to various phases of gentle warping. Dome structures find expression as uplands with radial drainage, as in the Yancannia Range south of Quarry View Homestead.

II. GEOLOGY AND LAND SURFACES

(a) *Erosional Surfaces*

The structural units described above are reflected in the major outlines of relief and drainage. The Barrier Range Block forms higher ground from a combination of generally harder rocks and structural highs. The western part forms a watershed between two disorganised systems of interior drainage, namely those of Lake Frome and Lake Bancannia; the central outliers form the watershed against the Bulloo drainage to the north and the Paroo-Darling system to the east and south. In detail, relief and drainage are strongly controlled by NNW structural trends in the Block, and the higher ground is in part sharply fault-bounded.

The Bancannia Trough forms a structural lowland, the axis of which is occupied by a series of pans extending to Lake Bancannia, and is extensively mantled with Quaternary alluvium and aeolian sand.

In the Great Artesian Basin a combination of gentle dips and little-consolidated rocks gives rise to gently rolling plains with tabular relief and steep breakaway escarpments formed by remnant cappings of resistant silcrete. A colluvial mantle, mainly of silcrete gravel, surrounds the uplands and extends over much of the adjoining plains. Doming and warping within the Basin have given rise to a complex system of radial drainage, ultimately leading westwards to Lake Frome or north to the Bulloo River overflow. A dense network of channels has deposited Quaternary alluvium over the lower-lying parts of the Basin.

(b) *Depositional Surfaces*

(i) Aeolian Sand. - Approximately 40 per cent of the survey area consists of Quaternary cover, and about two-thirds of this is aeolian sand. In only two very small areas do the sands rest on rocky surfaces; in the main they occur in the lower-lying tracts, around and beyond the drainage terminals, indicating their origin as alluvial deposits subsequently reworked by wind. They are characteristically reddish quartz sands and consist of over 60 per cent coarse grades (0.2 - 2.0 mm diameter).

(ii) Alluvium. - Alluvium extends as broad plains downslope from the main erosional areas, and continues for longer distances in floodplain tracts. Its great extent on lowland surfaces reflects the tendency for piedmont deposition by ephemeral streams under an arid regime.

Most of the alluvia are sandy, especially on the levees, but some backplains and terminal floodouts consist of finer material and show pronounced gilgai development.

(iii) Evaporites. - Soil analyses indicate widespread but moderate salinity in alluvial deposits, generally increasing towards terminal pans, where there may be evaporite crusts of halite and underlying horizons of halite and gypsum.

Secondary limestone is commonly found with aeolian sand and areas of associated alluvium, either as an illuvial concentration, for instance hardpan layers which may have been exposed by erosion, or as a crust near pan margins. Nodular and massive varieties of limestone occur.

III. GEOLOGY AND LAND SYSTEMS

Geology affects the land systems in various ways: the composition and structure of the rocks control landforms, physical resistance to breakdown and chemical composition are reflected in thickness and nature of soils, whilst rocks may affect vegetation not only indirectly through their control of factors mentioned above but also directly through the environment they offer to the growing plant. In the following account these aspects of the rock types are reviewed.

(a) *Erosional Land Systems*

In the erosional land surfaces there is a close control of major relief by structure and of detailed landform and soils by lithology. This is particularly characteristic of arid environments, where weathering tends to be superficial and to involve disintegration before decomposition, so emphasising the physical composition and detailed structure of the rock. Since rate of removal exceeds rate of weathering, bedrock tends to be extensively exposed in upland areas and the rock finds full expression in surface features. In this setting, land system boundaries and geologic boundaries coincide.

Table IV-2 sets out the relationships between structure, lithology and erosional land systems in the area. Of the crystalline rocks the most commonly occurring are quartz reefs, mainly in the Torrowangee and Wonominta Beds. Although forming only very small ridges, they are important as providing the widespread quartz stone in land systems underlain by these rocks. The resistance of massive crystalline basic dyke rocks in Kayrunnera land system and gneiss of the Willyama Complex in Barrier land system is reflected in upland forms and scant coarse soils with no evidence of clay-weathering.

Steeply dipping quartzites such as the Far-Away-Hills and Bynguano formations are very resistant in comparison with less metamorphosed sedimentary rocks nearby and so give rise to the prominent narrow hogback ridges of Faraway land system as near Fowlers Gap and in the spectacular Koonenberry Mountains. The partially silicified Cambrian and Devonian sandstones are less prominent in relief and more readily weathered. This is particularly true of the Nundooka and Coco Range sandstones of Nundooka land system, which are arkosic or calcareous in part and which locally bear relatively deep slope soils. The flat-lying flaggy sandstone of the Ravendale Formation is little weathered, and forms stepped stony surfaces with shallow sandy soil in Kara Hill and the dissected Ravendale land systems. The Cretaceous Rolling Downs sandstones are clayey, weakly consolidated and thoroughly weathered and have mainly been reduced to lowlands, as in Oakvale land system, except where hard silcrete cappings or stripped ferruginised zones give tabular relief, as in Quarry View, Flat Top, Pulgamurtie and Pulchra land systems. The silcrete breaks down to hard gibbers which form a widespread stone cover in the east of the area comparable with the quartz gravel mantle in the west.

Dolomite and limestone horizons within the Teamsters Creek Beds and Floods Creek Formation are physically and chemically resistant in this arid environment, but because of their thin bedding they generally form only narrow strike ridges within broader shale lowlands. The ridges are closer and more prominent in Teamsters land system, smaller and more widely spread in Floods Creek land system. Although soil-free, the ridges provide an environment for calciphyllous shrubs.

TABLE IV-2. RELATIONSHIP BETWEEN LITHOLOGY, STRUCTURE, AND EROSIONAL LAND SYSTEMS

ROCK TYPE	LITHOLOGY	STRUCTURE				
		High Resistance			Moderate Resistance	Low Resistance
		Massive rocks: uplands	Steep dips: ridges	Negligible dips: tablelands	Steep dips: aligned hills	Steep dips: plains
Igneous dyke rocks	Lamprophyre, dolerite	KAYRUNNERA				
Metamorphic rocks of igneous origin	Gneiss	BARRIER				
Metamorphic rocks of sedimentary origin	Quartzite		FARAWAY (part)			
	Phyllite				WONAMINTA	
Sedimentary rocks	Mainly sandstone		NUNDOOKA	KARA HILL RAVENDALE	FARAWAY (part)	PULCHRA TEKUM OAKVALE (part)
	Mainly shale					CYMBRIC NUNTHERUNGIE KATALPA NUNDORA (part) FLOODS CREEK (part)
	Mainly limestone		TEAMSTERS FLOODS CREEK (part)			
Weathering crust	Silcrete	QUARRY VIEW PULGAMURTIE FLAT TOP				

Proterozoic shale and phyllite of the Torrowangee and Wonominta Beds form characteristic lowlands in which weakly structured and relatively impervious beds give rise to rounded slopes and a close-textured drainage. These features are exemplified in a series of land systems, Cymbric, Nuntherungie and Katalpa, which vary only in degree of drainage dissection. The shales and the relatively deep soils formed from them are largely calcareous with illuvial lime concentrations, but have leached cappings on more stable surfaces with dense quartz stone cover. Prominent gilgai bands on moderate slopes suggest a content of swelling clay. Relatively deep soil and weathered rocks beneath facilitate deep gullying of lower slopes, whilst areas of strongly calcareous soils are subject to "bulldust" formation and wind erosion.

In a zone bounded by the Koonenberry Fault, the shales and interbedded sandstone have been metamorphosed into phyllite and schist which give the higher rounded ridges of Wonaminta land system.

(b) *Depositional Land Systems*

In depositional land systems there is a close genetic link, through process, between the landform and the material of which it is constructed (see Table IV-3). This theme is pursued in Chapter V; in this section the more direct geologic controls are discussed, principally that of parent material over the composition and texture of derived sediments. Superposed on this is the effect of sorting with distance, which accounts for the gradation from piedmont gravel, through coarse alluvium to the finer-textured deposits of terminal floodouts and pans.

Rounded gravel of quartz, silcrete, and quartzite occurs adjacent to ridges of the Barrier Range in Sandstone Tank and Gap Hills land systems, where it is probably inherited from silcrete cappings and older fills to the west. There is sufficient swelling clay admixture to allow the formation of contoured gilgai patterns.

The Mesozoic sandstone in the north and east has yielded sandy alluvia, as in Yancannia land system, which may have provided the wind-sorted sands in this area. In the south and east there is a mixture of sandy material from the sandstone, quartzite, and gneiss of the Barrier Range with a finer component from the extensive shale, and this is expressed in the alluvia of Fowlers and Conservation land systems. The more clayey deposits of the floodouts of Caloola land system and of the large pans of Cobham and Nucha land systems reflect the finer loads carried towards the terminal parts of drainage nets.

The lower-lying parts have an extensive cover of wind-sorted sand with dune relief, particularly in Gumpopla and Marrapina land systems. These grade upslope through sandplains of Nucha and Rodges land systems to the predominantly alluvial surfaces of Allandy land system.

TABLE IV-3. RELATIONSHIP BETWEEN SUPERFICIAL MATERIAL AND DEPOSITIONAL LAND SYSTEMS

DEPOSITED MATERIAL	LAND SYSTEM
Alluvium	SANDSTONE TANK GAP HILLS CALOOLA FOWLERS CONSERVATION YANCANNIA
Alluvium / Aeolian sand	OAKVALE (part) ALLANDY RODGES NUCHA GUMPOPLA COBHAM
Aeolian sand	NUNDORA (part) MARRAPINA

IV. REFERENCES

COOPER, P.F., and TUCKWELL, K.D. (1971). - The Upper Precambrian Adelaidean of the Broken Hill area a new subdivision. *N.S.W. Geol.Surv.Quart.Notes*, 3, 8-16.

HIND, M.C., and HELBY, R.J. (1969). - The Great Artesian Basin in New South Wales. Ch.VII *in* The Geology of New South Wales. *J.Geol.Soc.Aust.*, 16, 481-97.

PACKHAM, G.H. (1969). - The Palaeozoic sequences. Ch.II Pt.IV *in* The Geology of New South Wales. *J.Geol.Soc.Aust.*, 16, 67-72.

VERNON, R.H. (1969). - Archaean or Lower Proterozoic rocks. The Willyama Complex, Broken Hill area. Ch.II Pt.I *in* The Geology of New South Wales. *J.Geol.Soc.Aust.*, 16, 20-55.

WARD, C.R., WRIGHT-SMITH, C.N., and TAYLOR, N.F. (1969). - Stratigraphy and structure of the north-east part of the Barrier Ranges, New South Wales. *J.Roy.Soc.N.S.W.*, 102, 57-71.

The following maps have been consulted:

Australia 1:250,000 Geological Series -

Broken Hill
Cobham Lake
White Cliffs

Tectonic Map of Australia 1:2,534,400

CHAPTER V. GEOMORPHOLOGY OF THE FOWLERS GAP-CALINDARY AREA

By J.A. Mabbutt

I. OUTLINES OF RELIEF AND DRAINAGE

Depositional plains and erosional lowlands and plains each comprise about two-fifths of the survey area, with the remainder made up of ranges and tablelands. Comparison of Figures V-1 and V-2 shows that the depositional plains lie generally below the 150 m contour and that only limited parts of the ranges exceed 300 m. The altitudinal zones shown in Figure V-1 correspond closely with the structural units defined in Chapter IV (Fig. IV-1) in that the main depositional plains are within the Great Artesian Basin and the older structural units form higher ground. The lowest parts of the survey area, near the drainage terminals of The Salt Lake, are approximately 85 m above sealevel.

Despite the limited extent of high ground the survey area includes important drainage divides as shown in Figure V-1. The only external drainage, to the Darling River, is in the extreme southeast. By far the largest part has interior drainage into three basins defined by Tertiary earth movements: the Lake Frome drainage in the northwest, the Bulloo drainage in the north, and the smaller area of Bancannia drainage in the southwest. The tectonically defined base levels of these systems lie outside the survey area, but the local drainage is disorganised such that most networks terminate in small pans and floodouts within the area.

II. PHYSIOGRAPHIC REGIONS

In Figure V-2 the land systems have been classified into landform types which have been further grouped to define five physiographic regions. These provide a basis for systematic description of the geomorphology and form a common locality reference for the various sections of this Report.

(a) *Barrier Range*

This southwestern region occurs where the Barrier Range is declining in altitude towards its northern end. The uplands comprise rugged gneissic hills in the southwest and more prominent sandstone ranges in the east. Despite a relief of up to 150 m locally , the latter barely attain 300 m above sealevel. They are traversed by the Bancannia drainage in Fowlers and Sandy Creeks. Between the uplands are rounded lowlands and footslopes with extensive quartz gravel cover. These lowlands are mainly between 200 and 230 m but attain 250 m in the northwest, where they form the divide between the easterly Bancannia drainage and that leading north and west to Lake Frome.

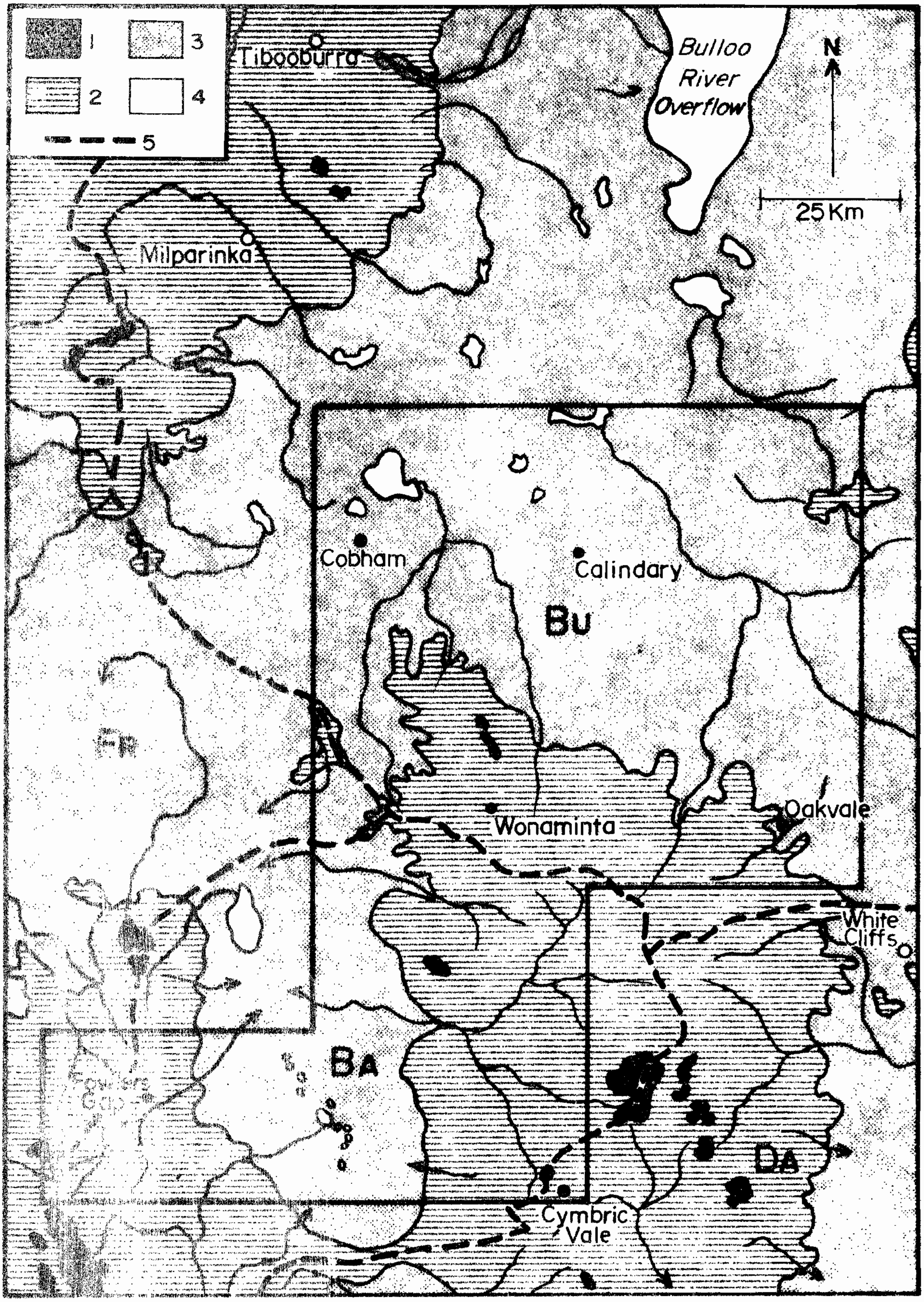


Fig. V-1. - Altitudinal Zones and Drainage Systems. 1. above 300 m; 2. 150-300 m; 3. below 100 m; 4. playas and floodouts; 5. main drainage divides. DA - Darling drainage; BA - Bancannia drainage; BU - Bulloo drainage;

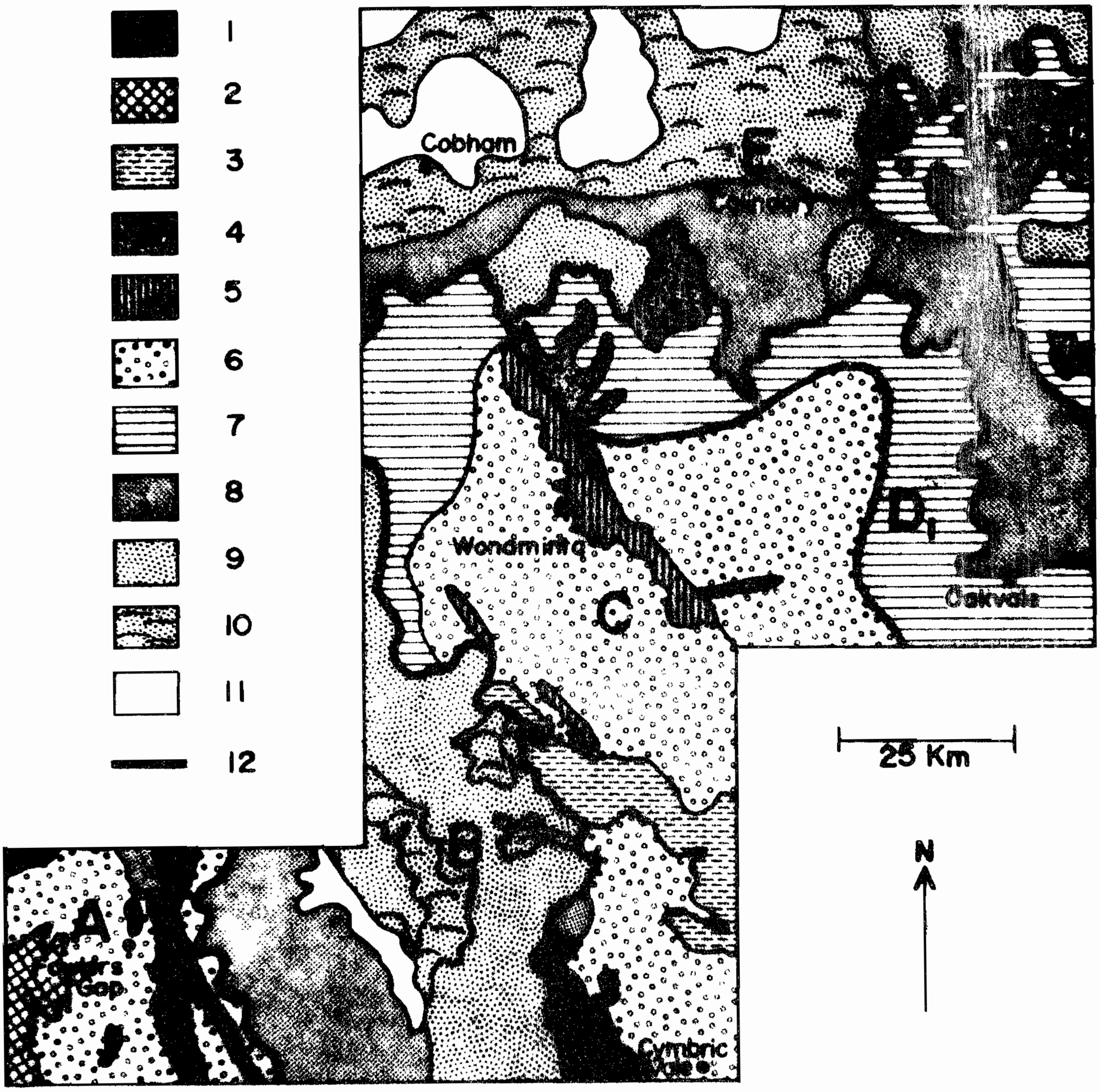


Fig. V-2. - Physiographic Regions and Landform Types. A - Barrier Range; B- Bancannia Plains; C - Central Ranges and Slopes; D - Stony Tablelands and Plains (D_1 - Pulgamurtie Subregion; D_2 - Quarry View Subregion); E - Cobham Plains. 1.ranges on tilted strata; 2.rugged uplands on metamorphic rocks; 3.plateaux on flat-lying sandstone; 4.stony tablelands on duricrusted, weathered rock; 5.hills on steeply-dipping metamorphic or intrusive rocks; 6.lowlands on soft rock; 7.plains on weathered rock; 8.alluvial plains; 9.sandplain; 10.dunefield; 11.playas; 12.boundaries of physiographic regions

(b) *Bancannia Plains*

The Bancannia Plains are the topographic expression of the structural Bancannia Trough and of the extension within it of the Great Artesian Basin. They form the larger part of the Bancannia drainage basin and the NNW-trending axis of the Plains marks a former drainage towards Lake Bancannia; this has since disintegrated into a series of playas, of which the largest in the survey area is Nucha Lake.

Alluvial plains predominate in the western part and aeolian sand surfaces in the east. The alluvial surfaces are of two types, namely active floodouts of finer-textured alluvium of Fowlers and Caloola Creeks, and intervening stable plains of coarser material. The eastern Plains consist mainly of undulating sandplain with small pans and minor irregular sand dunes.

(c) *Central Ranges and Slopes*

This central region coincides with the main outlier of the Barrier Range Block and the NNW structural grain is clearly expressed in trends of relief and drainage. It lies mainly above 150 m, includes the highest ground and most spectacular relief in the survey area, and is an area of drainage dispersal to all the systems delineated in Figure V-1.

The prominent ridge of the Koonenberry Mountains in the north and the parallel ranges of the Bynguano Range in the south have quartzite and sandstone as the main relief builders. Summits attain 460 m in the Bynguano Range and 440 m in the Koonenberry Mountains, about 200 m above the surrounding plains. The other main upland forms are sandstone plateaux and mesas in the southwest, which exceed 300 m locally as in Kara Hill. Most of this region consists of undulating lowlands and plains with quartz gravel cover as in the Barrier Range.

(d) *Stony Tablelands and Plains*

This northeastern area forms part of the Great Artesian Basin and its landforms are characteristic of that geologic setting, with extensive gibber plains broken by tabular uplands with silcrete caps. Most of the plains lie below 150 m and generally descend northwards, in which direction they are drained towards the Bulloo system. The region is separated into two parts by sandy and alluvial plains along Yancannia Creek.

(i) Pulgamurtie Subregion. - Silcrete cappings are less extensive and plains predominate in this western portion. The uplands, mainly in the north and west, consist of somewhat rounded low plateaux up to 30 m above the plains. The remainder forms extensive stony plains, with ferruginous rises in the south.

(ii) Quarry View Subregion. - This is dominated by the tableland of the Yancannia Range with a relief of 60 m.

(e) *Cobham Plains*

The survey area is here at its lowest level. Most of this northern region consists of parallel, ENE-trending, vegetated low dune ridges with intervening small pans. The north-going drainage has become disorganised and floods out separately into the many pans of the region. By far the largest of these terminals is The Salt Lake, with an area of 50 km^2. Many of the playas are strung along former channels and most of them are rimmed by lunettes on the northeast.

The plains rise south in a broad tongue, mainly on the west side of Yancannia Creek, as alluvial plains with a partial cover of aeolian sand which decreases in relative importance upstream. The active riverine surfaces include the through-going sandy floodplain of Yancannia Creek and tributary floodouts and backplains of finer-textured alluvium with many gilgai.

III. MORPHOGENETIC STATUS

Under most morphoclimatic classifications (Peltier, 1950; Tricart and Cailleux, 1965) the Fowlers Gap-Calindary area would be defined as arid. Tricart and Cailleux list as characteristic of such a morphogenetic system:

- absence of deep soil or rock waste; hence clarity of structural expression in landforms, angular outlines, and sharp junctions of hill and plain
- superficial weathering and encrustation of rock surfaces and deposits due to capillary return of moisture under strong evaporation
- efficacy of sheet wash in fashioning piedmont plains
- deranged systems of ephemeral streams with connected drainage nets confined to the uplands and only the larger channels persisting across the plains into terminal basins of interior drainage
- accumulation of alluvia in extensive plains in the lower parts of the landscape
- concentration of salts in terminal alluvial flats and playas
- forms due to wind action, including dunes and sandplains and deflated pavements.

The features of the survey area generally accord with these criteria, but its position close to the semiarid margin of the desert zone is reflected in a suppression of aeolian relative to fluvial processes. This places the area into the class of moderate deserts of de Martonne (1925), in which aeolian surfaces have mainly been stabilised by vegetation and in which stream action predominates on sloping ground.

Annual runoff in upland catchments in the area is likely to average between 10 and 20 mm, probably towards the lower value in view of the element of low-intensity winter rainfall. Estimates of frequency of ephemeral floods in the region can be made on evidence from Fowlers Gap Station (Perrens, unpublished data) and from a questionnaire addressed to local landholders. Local flows sufficient to cause recharge of farm dams occur with falls of 10-15 mm on hills and piedmont lowlands, that is about four times each year. Floods in moderately large channels in piedmont plains can be expected on two or three occasions annually, correlating with falls of between 50 and 100 mm. Runoff from the open alluvial plains tends to occur at intervals of one to two years, with extensive rainfalls exceeding 100 mm, but flooding of entire drainage systems into terminal basins probably only occurs with general heavy rains at intervals of between two and ten years.

An estimate of fluvial erosion rates based on Langbein and Schumm (1958) suggests a moderate erosive activity with a probably annual sediment yield of between 40 and 80 tons per sq km, approaching the higher value on the soft shale which forms many footslopes.

Wind erosion is active only selectively - on dune crests, on exposed sites as around pan margins, on vulnerable soils, particularly calcareous and alluvial soils, and in areas of disturbance, for instance around watering points.

IV. GEOMORPHIC DESERT TYPES

The area is physiographically complex and contains three desert types (Mabbutt, 1969): mountain and piedmont desert (30 per cent), stony desert (40 per cent), and sand desert (30 per cent). The first two accord with the Barrier Range Block and Great Artesian Basin structural provinces respectively, and sand desert occupies topographic lows throughout the area.

(a) *Mountain and Piedmont Desert*

Upland forms range from homoclinal ridges on steeply dipping quartzite in the Barrier and Bynguano Ranges, through broad cuestas on gently dipping sandstone, to structural plateaux on horizontal sandstone. Relief is mainly between 30 and 100 m. Structural expression is clear, with etching of bedding and joint planes in relief and with many small rock faces and ledges on steep slopes. There is extensive rock outcrop and slope mantles are generally thin. Each such upland area supports an aureole of radiating drainage channels, most of which do not persist beyond the piedmont.

Dissected stony footslopes and piedmont lowlands form the other main element of this desert type. True pediments are restricted to areas of horizontal thin sandstone and shale below plateaux of more massive sandstone, where slopes may have retreated. Dissected gravel cones occur on the east flank of the Barrier Range. Piedmont slopes facing west are commonly sand-mantled.

(b) *Stony Desert*

The characteristic feature of this desert type is a widespread gravel pavement, and the landforms include duricrusted tablelands and mesas preserving a Tertiary profile of deep weathering, and extensive stony plains formed in the soft near-horizontal rocks typical of the Great

Artesian Basin. The lowest parts generally include alluvial plains and sand-ridge country with pans, the latter forming the terminals of moderately connected systems of interior drainage. These assemblages are well represented in the northeast of the survey area.

The flattish upland crests are capped with silcrete which breaks down into a dense mantle of rounded boulders. Vertical partings in the silcrete give prominent cornices or breakaways. Mottled zones are not prominent in the profiles of this area (Langford-Smith and Dury, 1965), but pallid zones as revealed in the hillslopes exceed 50 m locally. Ferruginous horizons are locally exposed in the lower part of the pallid zone as structural benches or elsewhere remain as stony rises above the plains.

Smooth pediments typify these landscapes of retreating capped hillslopes. Studies of pediments near the survey area (Langford-Smith and Dury, 1964; Dury, 1966a, 1966b, 1970) confirm the generally concave profiles, mainly between 3 and 15 per cent and up to 500 m long. The pediments continue downslope into the gently undulating stony plains which give this desert type its name and for which the term pediplain is appropriate (Dury, 1966a). They are mantled with silcrete cobbles bearing a brown desert varnish. Such stone mantles have traditionally been regarded as lag gravels, a protective armour left after the removal of fines by deflation or sheetwash, but where they occur on and in topsoils above stone-free subsoils which overlie a similar stone source they are probably the result of upward extrusion of stone through a residual soil or depositional mantle due to the action of swelling clays (Mabbutt, 1965; Jessup, 1960). The presence of such clays is indicated by the occurrence of gilgai locally.

The stony plains pass downslope beneath the depositional peripediment, the result of backfilling with interior drainage. Drainage tracts here open into broad distributary floodouts and drainage lines lose definition. There follows a downslope transition from an alluvial into an aeolian environment; the alluvial plains pass as corridors between sand ridges which increase in height, continuity, and regularity downslope, and surface drainage disintegrates into aligned pans between the dunes.

(c) *Sand Desert*

In the survey area, sand desert is mainly represented by parallel low sand ridges, generally between 5 and 10 m high, with a characteristic ENE trend and spaced about 400 m apart, but nowhere attaining the height and continuity of the major Australian sand-ridge systems. This results partly from a situation near the margins of fluvial plains. The fluvial imprint on the sand desert is strongest in the south, where the uplands bordering the Bancannia Plains are no more than 50 km apart and where numerous channels flood out into the sand country. Here there is a transition northwards (away from the floodouts) and eastwards (downwind) from sandplain with unorientated low sand rises to elongate ridges. This area has many small pans and a widespread lime hardpan. The same alluvial elements persist in the dunefields of Cobham Plains in the north. The alluvial plains extend downslope as wide interdune corridors in the western part of each dune area; these generally narrow and become sandier eastwards until intersected by another drainage floodout, giving rise to another belt of alluvial belts and pans.

V. INHERITED LANDFORMS AND RELATED LAND SYSTEMS

The geomorphology of the survey area has so far been considered as an expression of its present climate and tectonic setting, but regional climate has changed over the period of landscape evolution such that many landforms, erosional and depositional, are relict from previous morphogenetic systems. To recognise these inherited forms is to appreciate their associated attributes, for instance weathering mantles; this is necessary for the predictive mapping of land systems and for an understanding of their dynamic status. Hence the history of the landscape is considered here, particularly in relation to past climates.

(a) *Tertiary Weathered Land Surface*

The oldest landforms in the area were part of a land surface with less relief than the present landscape and with more rounded outlines. It survives in two main forms, as upland surfaces in the ranges and as duricrusted flat summits above the plains.

(i) Upland Surfaces. - These are represented in undulating summits at between 280 m and 300 m on the cuestas of Nundooka land system in the north of Fowlers Gap Station and in the sandstone plateaux of Kara Hill land system at 300 m in the southwest of the Central Ranges and Slopes. Now preserved only on resistant rock, the remnants are too fragmentary to allow reconstruction of the former surface. They stand above piedmont cappings of silcrete and above the shoulders of valleys grading to the silcrete level, as along the east front of the Barrier Range.

Discordant drainage, notably the transverse valleys of Fowlers Creek and Sandy Creek through the Barrier Range, may have been inherited from this upland surface. The present ridges formed unimpressive relief on the Tertiary surface; the main watershed lay to the west of the ranges and the rivers crossed the fold structures in open valleys. The extent of bevelling of ridge crests suggests that transgressive drainage was formerly more widespread and this is supported by the occurrence on crestal surfaces in the Barrier Range of rounded gravels including quartz derived from areas further west.

Weathering of arkosic sandstone under former moister conditions may explain the occurrence on crests and gentle upper slopes of moderately thick mantles with stone-free clayey subsoils resting abruptly on little-weathered rock. The resistant rocks which preserve the upland surfaces, mainly quartzite and sandstone, are commonly silicified at the surface and are locally ferruginised. Coatings and shallow fillings of silcrete occur on many low rock outcrops, cementing rounded quartz gravels, and it appears that silcreted detrital mantles formerly extended across the upland surfaces.

(ii) Duricrusted Surface. - The silcrete cappings above the plains decrease in altitude northeastwards across the survey area, following the present regional slope from about 300 m in the southwest to a little over 150 m above sealevel in the Yancannia Range. The duricrust preserves a land surface particularly associated with the soft rocks of the Great Artesian Basin. It stood below the upland levels of the hard rock ranges and rose smoothly towards them with gentle concavity, such that it has been termed a pediplain (Dury, 1966). It also extended into structural lowlands within the ranges, as shown by silcrete-capped residuals on low strike ridges.

It was mainly an erosional surface planed across soft and weathered rocks, but the silcrete locally caps weakly-consolidated terrestrial sand and gravel (Ward, Wright-Smith and Taylor, 1969) and is commonly thicker where these occur. Such fills are characteristic of areas of Tertiary relief and sediment supply, as near the Barrier Range.

There may have been considerable deposition in the Bancannia Trough before duricrusting occurred. Silcrete remnants along the western margin, on Fowlers Gap Station south of Sandy Creek, stand topographically above exposures of sands 10-20 m thick which dip eastwards. More than 250 m of deposits were penetrated by the Bancannia No.2 Oil Well at a distance of 17 km into the Plains, and the semiconsolidated bottom 60 m of this fill, with clay and lignite horizons, may predate the silcrete (A.D.M. Bell, unpublished data). The silcrete cappings stand about 50 m above the Plains along the east front of the Barrier Range and slope down eastwards, suggesting that the Tertiary land surface was lower-lying in the area of the Bancannia Plains. No silcrete remnants have been found in the central part, but an outlier of weathered sandstone rises about 10 m above the dunefield south of Marrapina Creek, indicating that the silcrete surface here stood above the present Plains level.

The silcrete rarely attains 5 m thick; it is commonly conglomeratic and characteristically overlies weathered profiles with poorly developed mottled zones but with prominent pallid zones up to 50 m thick, frequently with ferruginous horizons near the base (Langford-Smith and Dury, 1965; Dury, 1966a). The formative climate is not known, but continuous smooth erosional slopes and the deep weathering of bedrock together indicate moister conditions than at present; the land surface must certainly have been relatively stable. The main extent of the silcrete in the Great Artesian Basin is regarded as mid-Miocene or older (Dury, Langford-Smith, and McDougall, 1965).

(b) *Deformation and Destruction of the Tertiary Land Surface*

The duricrusted surface was subsequently deformed in domal anticlines and basins, as over much of the Great Artesian Basin. On a large scale, these earth movements defined the Bancannia and Bulloo Basins of interior drainage; more locally they gave rise to secondary watersheds, for instance an updoming of the Yancannia Range is expressed in its radial drainage. The remnants of silcrete are now too isolated fully to reconstruct the tectonics, but the arc of survivals in the west of the Pulgamurtie Subregion indicates a second dome centred near Kayrunnera, forming a divide between Turkey and Noonthorangee Creeks. Two intersecting regional tectonic trends are evident in these movements, namely NW-SE and NE-SW. These earth movements set in motion the erosion of the Tertiary land surface. Dissection, as measured by heights of surface remnants, has been mainly between 50 and 75 m and generally decreases northeastwards across the survey area.

(i) Erosion of Upland Surfaces. - Rejuvenation and incision of valleys into resistant rock have led to increased adjustment to geologic structure under a progressively more arid regime. Bevelled crests, smoothed shoulders and tributary plains remain perched above narrow steep-sided younger valleys, and the margins of strike ranges have been trimmed back and steepened along geologic boundaries, leaving former slope facets as sloping piedmont benches. Even where the gross outlines of the Tertiary upland surface have remained there has been stripping, as shown by thin soils and by fragments of silcreted gravel. Some pre-weathered material may have moved into slope mantles on the flanks of the upland survivals, as in the Barrier Range. Transgressive drainage on the subdued Tertiary upland surface has often persisted during down-cutting.

(ii) Erosion of the Duricrusted Surface. - This has involved the initiation of escarpments and pediplanation by escarpment retreat (Dury, 1966a), such that the silcrete now has less than one twentieth of its original extent. Marginal dissection of the updomed tableland of Yancannia Range constitutes an early stage of destruction; a later stage involves the breaching of anticlines and the retreat of escarpments ringing an axial lowland, as near Kayrunnera. Survival of duricrust has been favoured along the piedmont east of the Central Ranges and Slopes, where incision has predominated over valley-widening and escarpment retreat, and locally in valleys of the Barrier Range where the silcrete had extended across harder strata.

This mode of landform evolution typifies the Stony Tablelands and Plains region, where the tablelands of Quarry View land system and the mesas of Flat Top land system remain above the extensive stony plains - a form of etchplanation with the weathering front controlling the level of stripping. The pallid zone is exposed in the hillslopes and strongly influences the derived alluvial flats. Occasionally, a harder ferruginous zone within the lower profile has resisted stripping, leaving the dark stony rises of Pulchra land system within the plains. More rounded silcrete-mantled uplands of Pulgamurtie land system in this area form an exception to the destruction of the silcrete surface by escarpment retreat, in that the duricrust seems here to have been fragmented and let down *in situ*. That down-wearing as distinct from back wearing is always present in some degree is shown by the imperfect grading of silcrete fragments across the pediments, in particular by the occurrence of low rises or clusters of coarse boulders which mark the disintegration of the duricrust in place (Dury, 1970).

Silcrete cappings are few on the lowlands of the Barrier Range and Central Ranges and Slopes, but a former cover is indicated by remnant summits, by silcrete gravel, and by weathering of the shale. The destruction of the duricrusted surface here has taken place in two stages, the first involving stripping of the capping and of the pallid zone and the second - still in progress - dissection into the rounded forms of the present lowlands. The achievement of a plain during the first stage is shown in the accordance of flattish interfluve crests with leached stony cappings which include transported material. This surface has survived intact in the perched upper valley of Sandy Creek, protected downstream by the Barrier Range, but elsewhere it has been eroded into the rounded interfluves characteristically found in Nuntherungie land system.

Where these leached mantles survive, slopes have been transformed into contour patterns of alternating stony bands and partly shrub-covered, relatively stone-free bands, analagous to the sorted stone steps of desert gilgai (Ollier, 1966), but more connected and regular and rendered striking by the stark whiteness of the quartz. In detail the profiles are stepped, the stony bands forming the steeper fronts of natural terraces a few metres wide and the stone-free areas marking the flats. Gilgai depressions are ranged along the flats and impart an arcuate element to the banded pattern.

Such microtopographic sequences are associated with alternations in soils and in vegetation which are briefly described in this Report. They are a series of repetitive hydrologic units in that the risers and flats are areas of ephemeral sheet runoff and run-on respectively, thus maintaining the gilgai systems which in turn perpetuate the essential microrelief and the associated variations in soils and vegetation. The pattern is a system in dynamic equilibrium, in which the essential factors are the leached slope mantles with their element of swelling clay, and the hydrologic regime.

The pattern becomes less regular where slopes are too gentle to maintain the stepped sequence, as near the crests of interfluves and on the more subdued lowlands of Katalpa land system, where the second phase of erosion has advanced furthest. It is also lacking in areas of stronger stream dissection and steeper slopes, as in Cymbric land system, from which leached mantles are absent. The same cause, or possibly the presence of more calcareous rocks, may explain the occurrence of narrower-crested interfluves of calcareous brown solonised soils which lack these patterns.

(c) *Older Depositional Surfaces*

The onset of interior drainage led to the accumulation of alluvium in tectonic depressions, accentuated locally by continuing subsidence in the Bancannia Trough where more than 250 m of sands and gravels have been recorded (A.D.M. Bell, unpublished data). The extension of alluvial surfaces was favoured by the change towards a drier climate in the late Tertiary and Pleistocene, with consequent disorganisation and retraction of drainage systems and widespread deposition by ephemeral streams in piedmont lowlands. In common with much of arid Australia, the Fowlers Gap-Calindary area has extensive stable alluvial plains beyond the ambit of the present channels. Many of these surfaces have since been modified by wind action consequent on further deterioration of climate.

(i) Stable Alluvial Surfaces. - These are mapped as Conservation land system. They occur mainly in the west of the Bancannia Plains and are formed of medium to coarse-textured alluvium laid down at stream exits from the Barrier Range. Their stability is shown by their occurrence between the active floodplains and floodouts of the present drainage and by the well-developed soil profiles. Prior drainage lines can be traced in levee rises, gravel trains, and in the shallow linear depressions still used by sluggish floodwaters.

The predominant sands and gravels are piedmont deposits which grade outwards into silts and clays. However, much of the former terminal plains of fine-textured alluvium has since been covered with aeolian sands, and the remainder are here considered with the active floodouts.

A feature of these stable alluvial surfaces is the extensive scalding or superficial erosion by wind and water of vulnerable loose topsoils above clayey B horizons. Although enlarged under excessive grazing, original scald patterns are revealed from the air as forming fairly regularly spaced series with each scald elongated transverse to the fall of the plains; the latter in fact have stepped profiles in which the scalds occupy the flats. It is not known whether the patterns reflect a repetitive microrelief and soils system, like the contoured steps of the lowland slopes - for there appear to be essential differences between the soils under scalds and those between them, or patterns of original alluviation, or the rhythmic action of present-day erosion.

(ii) Aeolian Sand Surfaces. - These cover 20 per cent of the survey area, mainly in the lowlands of the Bancannia and Cobham Plains. Their occurrence here, beyond the terminals of active drainage, indicates their alluvial origin, as do the many playas within them. There is a distinct alluvial character in the inter-dune flats over much of these surfaces, even in the extensive dunefields; in fact, the range of sand forms reflects varying degrees of fluvial interference. Sand surfaces in the area are moderately stabilised by vegetation and most aeolian forms can be considered fossil. Exceptions are some dune crests of deeper sand and sparser cover, margins of playas and river channels where water-deposited sand is available for wind transport, and areas subject to excessive grazing and trampling; in these areas sand movement continues.

There is a striking separation of alluvial surfaces in the west of the Bancannia Plains from aeolian sand surfaces in the east, a partition resulting from two causes. First is the past dominance of westerly sand-driving winds which have enabled larger creek systems in the west to persist whereas the drainage in the east has been obstructed by aeolian movement of sand upslope and eventually obliterated by wind-reworking of its own deposits. Second is the contrast between rock types in the upland margins of the Plains, for the shale and limestone to the west have given rise to mixed alluvia whereas the sandstone in the east has yielded abundant sand.

Undulating sandplain mapped as Nucha land system is well-developed in the east of the Bancannia Plains and shows a maximum fluvial interaction; many minor channels, floodouts, and small pans occur within it. This is also reflected in the light reddish-yellow colour of the sands and in the occurrence of subsoil pans and nodular layers of calcrete which are presumed to have formed in an alluvial environment. The low sand rises pass northeastwards into linear crests, reflecting increasing wind fetch and decreasing fluvial influence as the Bancannia Plains widen out. Within the sandplain, irregular sand dunes of Marrapina land system are found near major floodplains feeding out from the sandstone uplands to the east.

The widespread sand ridges of Gumpopla land system occur on the open Cobham Plains. Although the ridges are unimpressive in relief, the past dominance of wind transport in this landscape is expressed in the regularity of spacing and the consistent trend of the dunes. Minor channels entering the dunefields have been forced to follow this trend.

The dune trend denotes a dominant formative wind from the WSW, since the ridges are seen to have extended eastwards and the few dune convergences point in that direction; this is consistent with the position of lunettes on the east and northeast margins of playas. Since this dune trend accords with the resultant vector of weighted winds for Broken Hill shown in Figure V-3, the dune pattern offers no evidence of shift in the pressure-wind system following the more arid phase of general sand movement. There is a tendency for each ridge to be steeper on the south flank, but this asymmetry is much less marked than in the Simpson Desert to the northwest. Transverse profiles are rounded and there is no general distinction here between stable flank and more mobile crest, as occurs on the higher ridges of the Simpson Desert. Considerable age and stability of some dunes are indicated by clay-cemented cores which have locally been exposed by sand movement on lower dune flanks. The greater age of these evolved ridges compared with the sandplain is indicated by the deep red colour of the iron-stained sands.

Surfaces with partial aeolian sand cover occur as Rodges land system in the Stony Tablelands and Plains region, where sandplain is transitional to stable alluvial plains, and also further downslope along the southern margin of the Cobham Plains in Allandy land system, where dune ridges have formed within or extended across plains of finer-textured alluvium. The ridges are less regular here and - as always where firm ground appears extensively - are wider-spaced, being as much as 2 km apart compared with the 400-500 m characteristic of the main dunefields.

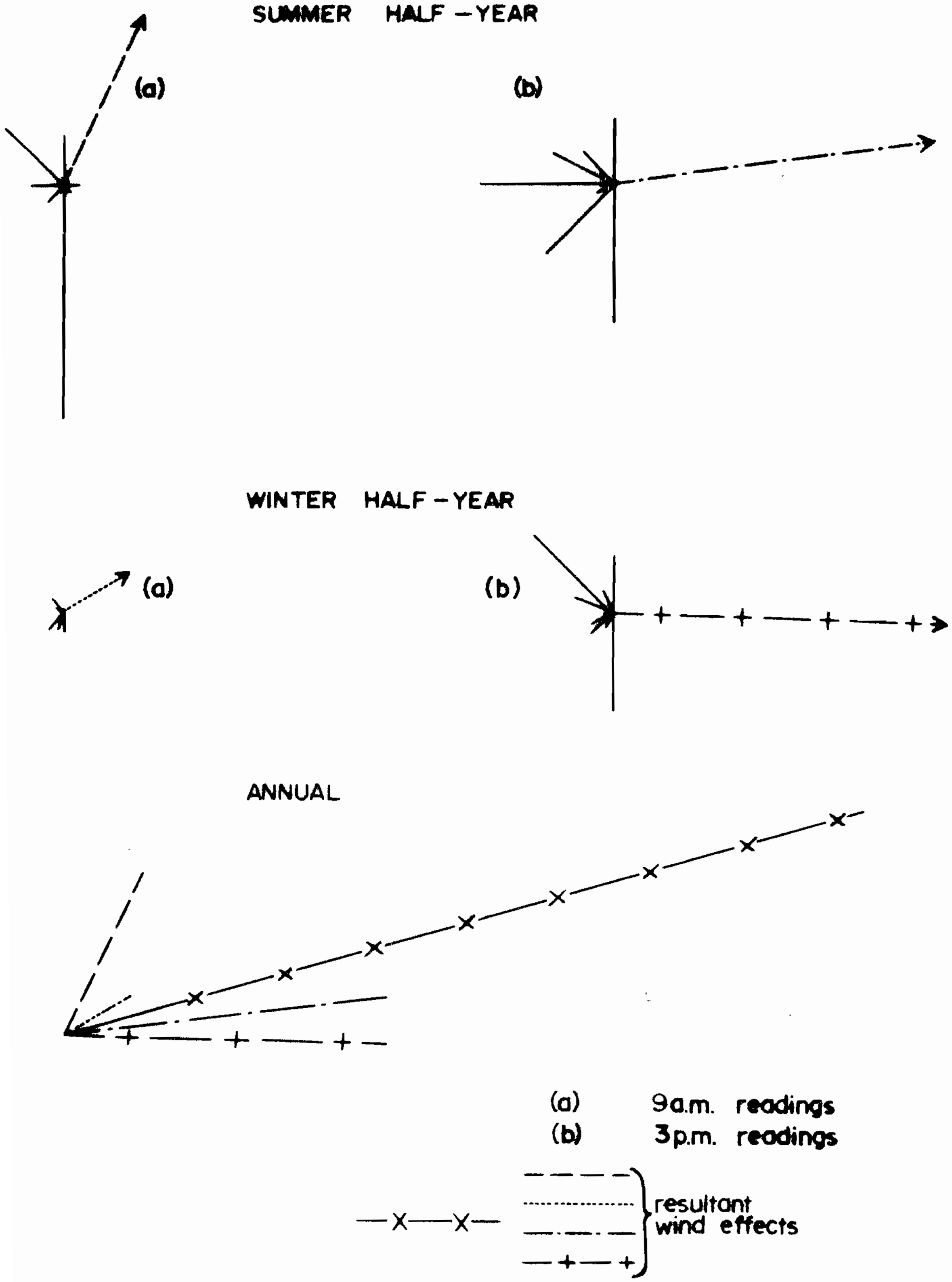


Fig. V-3. - Wind regime at Broken Hill (1961-65) weighted for sand movement

The lunette barriers around northeastern playa margins consist of pale, slightly crusted clayey sand or clay aggregates and are also regarded as fossil aeolian forms. They confer a characteristic convexity to the lee margins of playas in the survey area.

VI. ACTIVE LAND SURFACES AND RELATED LAND SYSTEMS

In this section, emphasis is placed on landform elements related to the present arid regime, in the broad categories of erosional and depositional surfaces.

(a) *Erosional Surfaces*

The boundaries of erosional land systems closely follow geologic limits, whilst gross relief, slope form, and drainage pattern, which define the physical character of a land system, are largely geologically controlled. This lithological basis of land system differentiation has been expressed in Chapter IV and in Table IV-1, and emphasis is here placed on the relief classes of land systems.

(i) Ranges. - These land systems have between 50 and 150 m relief and form local watersheds. They consist of relatively resistant rocks and mainly have steep slopes in which rocky faces alternate with smooth, débris-covered facets on softer and less massive strata. The main contrast within this group is between the less-ordered rugged relief of Barrier land system on massive gneiss, and the ridge country on bedded sedimentary and metamorphic rocks comprising quartzite, sandstone, dolomitic limestone, shale, phyllite, and schist. Minor footslopes on softer rocks, often with colluvial mantles, are commonly included in these land systems. Colluvial mantles are generally thin, but bedding and joint crevices on rocky outcrops may provide water storage and give a footing for larger vegetation. Stream density is moderate to dense, becoming very dense on the impervious soft phyllite of Wonaminta land system, for these are the main sources of runoff in the region but valleys are narrow and steep-sided and alluvial flats are lacking or very minor. A trellis pattern of drainage is typical, due to strong structural alignment.

Inherited facets include crest bevels and valley shoulders of the Tertiary upland surface and associated pre-weathered slope mantles locally. These latter give rise to slope microforms associated with stone movement in a clay-rich matrix, particularly to stone-fronted lobes which are subject to piping and periodic collapse and which consequently alternate with systems of disconnected small gullies. The footslopes of Teamsters and Wonaminta land systems also include leached mantles with contour banding similar to those of Nuntherungie land system.

(ii) Tablelands. - These land systems, with up to 60 m of relief, owe their tabular outlines to flat-bedded resistant sandstone, as in Kara Hill land system, or to a protective duricrust capping which may be intact, as in Quarry View land system, or let down as in Pulgamurtie land system. The upland forms are inherited from the Tertiary land surface but soils are thin or absent. Linear drainage is mainly restricted to the steep escarpments.

(iii) Hills and Plains. - These include the more dissected equivalents of Kara Hill and Quarry View land systems, namely Ravendale and Flat Top land systems, similar to them in upland form and relief but including intervening lowlands. In the sandstone Ravendale land system these are largely sand-covered, whereas the lowlands in Flat Top land system are gibber-mantled pediments and plains. Incised channels on the hillslopes open into alluvial flats on the lowlands, but surface drainage is largely absent from the sandy plains of Ravendale land system.

This relief category also includes Kayrunnera land system, with flat-crested aligned hills of basic dyke rock which resists weathering in this arid setting.

Inherited facets include summits of the Tertiary land surface and leached loamy mantles on the lowland interfluves of Kayrunnera land system, with characteristic contour banding.

(iv) Lowlands and Footslopes. - These land systems have less than 30 m relief and occur mainly in areas of unresistant shale and soft sandstone. Four sub-groups are recognised.

The first consists of undulating lowlands on calcareous shale traversed by low ridges of dolomitic limestone (particularly in Teamsters land system), quartzite, or reef quartz. Drainage patterns are dendritic and range from dense in areas of vigorous dissection, as in Cymbric land system, to open on the subdued lowlands of Katalpa land system, where there are broad alluvial tracts. All these land systems are characterised by a mantle of quartz stone derived from the many small reefs in the parent shale. An important inherited characteristic is the leached capping of loamy material, up to 1 m thick, which commonly survives on interfluves except in the strongly eroded Cymbric land system, and which relate to a former land surface which is identifiable in the accordant rounded crests. These form the contour-banded, stepped slopes described above, which have their best development in the moderately undulating Nuntherungie land system and which decline in regularity on the gentler slopes of Katalpa land system. Although generally protected by the stone pavement, the loam mantle is locally subject to strong gullying and sheet erosion on steeper slopes. Nundora land system occurs downslope from Katalpa land system and is differentiated from it by fairly extensive areas of parallel sand ridges and sandy flats.

In the second group of lowland land systems, the gravelly loamy mantle survives almost undissected. This group includes the perched valley plains of Sandstone Tank land system west of the Nundooka Range, and the slightly dissected, gravel-mantled spurs of Gap Hills land system along the east front of the Range. The smooth slopes have prominent contour banding analagous to Nuntherungie land system, but the gravels here are mainly silcrete, quartzite, and sandstone.

A third group consists of the stony pediplains typical of the Stony Tablelands and Plains region. These plains are characteristically mantled with silcrete gibbers derived from the destruction of the duricrusted Tertiary surface in this area. Much of Katalpa land system comes into this group, whilst the lowest, flattest parts of the plains, where they pass gradually beneath an alluvial cover, have been identified as Oakvale land system. Pulchra land system has been mapped where harder ferruginous horizons of Tertiary weathered profiles remain as dark stony rises in the plains. Pulchra land system also occurs in the first group of lowland land systems in the Central Ranges and Slopes where basic igneous rock occurs within the shale of the Wonominta Beds.

Somewhat apart is Tekum land system, consisting of sand-mantled footslopes and rocky lowlands adjoining the sandstone plateaux of Kara Hill land system.

(b) *Active Depositional Surfaces*

These comprise floodplains of the larger rivers, mainly in piedmont zones, and the active floodouts beyond. The former are mapped as Fowlers land system and consist mainly of coarse sand and gravel; the latter, mapped as Caloola land system, are formed of fine sand, silt and clay, reflective of increasing distance from upland sources and associated with a downstream decline in gradient such that the floodouts have a fall of less than 0.5 per cent. Plains of finer-textured alluvium are relatively more extensive and are developed further upstream where the catchments include large areas of fine-grained rock, such as Proterozoic shale or the clayey sandstone of the Stony Tablelands and Plains.

The floodplains mainly have sinuous or braiding, shallow bedload channels, prominent levees, and sandy backplains which are prone to extensive scalding through wind and sheet erosion. The floodouts have meandering or distributary channels with lower width-depth ratios indicative of relatively larger suspended loads. These channels are subject to periodic abandonment, the former courses being marked by paired scalded levees flanking shallow depressions. Commonly the distributaries feed into elongate flood basins with marked gilgai microrelief, often with network gilgai. Behind the scalded levees the main floodout plains are characterised by widespread circular gilgai and by small shallow flood channels. In the Bancannia Plains these floodouts form open expanses, but in the east of the survey area they are also found as linear tracts between stony erosional plains.

Yancannia land system is defined as floodplains extending through sandy terrain. The main channel form resembles that of Fowlers land system and the floodplain itself is generally sandy, but there are numerous small floodout basins with deeper sinuous channels and with gilgai microrelief.

The main drainage terminals are the playas of Cobham land system. These show increasing salinity in a downstream direction, as a function of flood regimes and of proximity to tectonically defined groundwater terminals. Swamp basins with linear gilgai networks occur as lateral or intermediate sumps, particularly where large channels penetrate dune country; the main claypans, with puffy salt-crusted floors and circular gilgai, are generally true terminal basins, although upslope from the tectonic baselevels; the salina of The Salt Lake, with its level salt-covered floor, occurs in a still lower situation, close to the regional groundwater table, and forms an evaporative unit in a closed hydrologic system. The lake floor deposits are saturated almost to the surface at all seasons. Most of these playas occur in the Cobham Plains, on the southern margin of the Bulloo drainage depression.

VII. REFERENCES

DURY, G.H. (1966a). - Duricrusted residulas of the Barrier and Cobar pediplains of New South Wales. *J.Geol.Soc.Aust.*, 13, 299-307.

DURY, G.H. (1966b). - Pediment slope and particle size at Middle Pinnacle, near Broken Hill, New South Wales. *Aust.Geog.Studies*, 4, 1-17.

DURY, G.H. (1970). - Morphometry of gibber gravel at Mt.Sturt, New South Wales. *J.Geol.Soc.Aust.*, 16, 655-66.

DURY, G.H., LANGFORD-SMITH, T., and McDOUGALL, I. (1965). - A minimum age for the duricrust. *Aust.J.Sci.*, 31, 362-3.

JESSUP, R.W. (1960). - The stony tableland soils of the south-eastern portion of the Australian arid zone and their evolutionary history. *J.Soil Sci.*, 11, 188-96.

LANGBEIN, W.B., and SCHUMM, S.A. (1958). - Yield of sediment in relation to mean annual precipitation. *Amer.Geophys.Un.Trans.*, 36, 1076-84.

LANGFORD-SMITH, T., and DURY, G.H. (1964). - A pediment survey at Middle Pinnacle, near Broken Hill, New South Wales. *J.Geol.Soc.Aust.*, 2, 79-88.

LANGFORD-SMITH, T., and DURY, G.H. (1965). - Distribution, character and attitude of the duricrust in the northwest of New South Wales. *Amer.J.Sci.*, 263, 170-90.

MABBUTT, J.A. (1965). - Stone distribution in a stony tableland soil. *Aust.J.Soil Res.*, 3, 131-42.

MABBUTT, J.A. (1969). - Landforms of arid Australia. *in* Slatyer, R.O. and Perry, R.A. (eds.) *Arid Lands of Australia*, ANU Press, Canberra, 11-32.

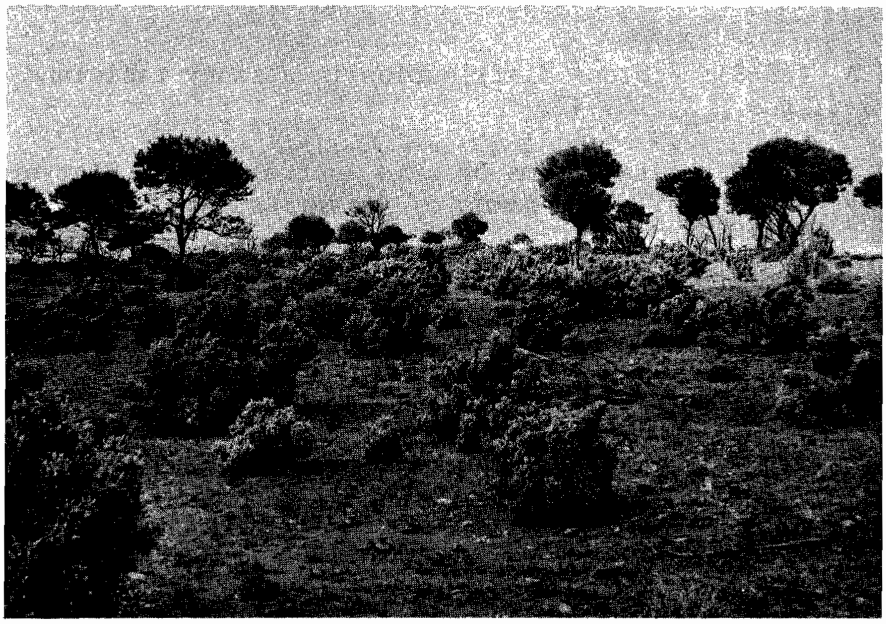
de MARTONNE, E. (1952). - *Traité de Géographie Physique, Tome II, Le Relief du Sol.* Armand Colin, Paris.

OLLIER, C.D. (1966). - Desert gilgai. *Nature*, 212, 581-3.

PELTIER, L.C. (1950).- The geographic cycle in periglacial regions as related to climatic geomorphology. *Ann.Assn.Am.Geog.*, 40, 215-35.

TRICART, J., and CAILLEUX, A. (1965). - *Introduction à la Géomorphologie Climatique.* Sedes, Paris.

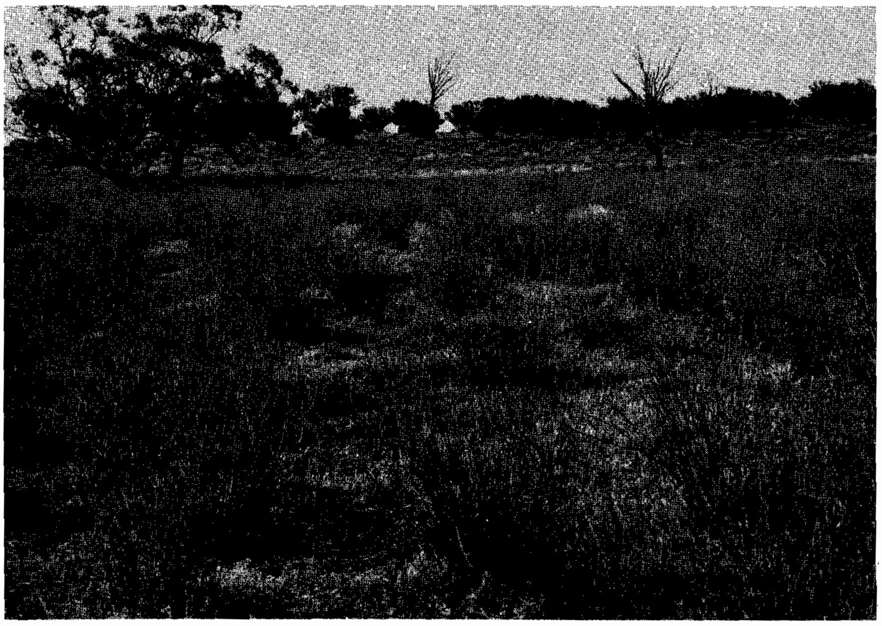
WARD, C.E., WRIGHT-SMITH, C.N., and TAYLOR, N.F. (1969). - Stratigraphy and structure of the north-east part of the Barrier Ranges, New South Wales. *J.Roy.Soc.N.S.W.*, 102, 57-71.



A. Nundooka land system, showing mulga (*Acacia aneura*) and pearl bluebush (*Kochia sedifolia*) above a sparse ground-layer community on calcareous sandstone

B. Flat Top land system, with silcrete-capped mesas preserving the Tertiary duricrusted land surface. Stony hillslopes mantled with silcrete boulders support mulga, bladder saltbush (*Atriplex vesicaria*) and copper-burrs (*Bassia* spp.)

A. Nuntherungie land system, with alternate bands of bladder saltbush (*Atriplex vesicaria*) community on flats with gilgai, and bare stony risers in a contour pattern of microrelief



B. Cobham land system, showing a swamp margin with lignum (*Muehlenbeckia cunninghamii*), black box (*Eucalyptus largiflorens*), and a bordering lunette ridge with turpentine (*Eremophila sturtii*) community

CHAPTER VI. SOILS OF THE FOWLERS GAP-CALINDARY AREA

By Janice R. Corbett

I. FIELD TECHNIQUES

The soils on Fowlers Gap Station were examined in February and May 1968 and the remainder in February 1969. Since exposure was mainly by bucket auger, overall estimates of macro-structure were not possible, but the structure of the top 50 cm of soil was described from spade samples. Samples of all soils studied in the field were collected for mechanical analysis and determination of carbonate content, and textures cited in this chapter are based on those mechanical analyses plotted on a texture triangle (Marshall, 1947), rather than on estimates of texture made in the field.

Field estimation of pH was made with Raupach's indicator and barium sulphate, and laboratory determinations were based on a 1:5 soil-water suspension using a glass-electrode pH meter. Field tests for carbonates were made with 4N hydrochloric acid.

Only surface soils are considered here. The morphology of the Tertiary deep-weathering profiles has been discussed in Chapter V, and these profiles are considered here only in relation to the modern soils derived from the exposed horizons.

II. PROPERTIES OF THE SOILS

Generally, the colour, texture, structure, calcareousness, and salinity of the soils of the area are typical of the Australian arid zone, but two features are somewhat surprising. Firstly, the soils with best-developed profile features are found in areas devoid of vegetation, especially under stone-cover; secondly, scald and claypan surfaces are areas of salt depletion rather than of salt accumulation, although abundant salts occur at depth. Leached surfaces are common on all pans except for major terminals such as Nucha and Cobham Lakes and The Salt Lake.

(a) *Soil Depth*

Upland soils in the area are generally shallow, but the relatively stable crestal surfaces of sandstone and quartzite in Faraway, Nundooka, Kara Hill, and Ravendale land systems have remarkably well organized soils up to 40 cm deep, which may reflect materials derived from previous cycles of weathering. The depth of soils on the resistant silcrete cappings of Quarry View and Pulgamurtie land systems averages only 20 cm. Shallow soils, lacking profile development, occur on uplands of unresistant shale in Teamsters, Cymbric, Floods Creek, and Wonaminta land systems, where marked dissection and stripping are taking place.

The well-developed shallow soils on sandstone and quartzite uplands and the massive shallow soils on silcrete in Quarry View and Pulgamurtie land systems rest abruptly on hard fresh rock, with no C horizon, but the shallow upland soils on shale usually grade into a C horizon which commonly persists for considerable depth before firm rock is encountered.

The depth of soils on lowland slopes (both stony and stone-free contour bands) is notably greater in the dominantly shale Nuntherungie and Wonaminta land systems than in the dominantly sandstone Pulchra land system, as is the degree of profile organisation. This is the reverse of the upland situation, suggesting that rapidity of weathering is more important than resistance to erosion in these situations.

The depth of the aeolian and alluvial soils was not generally ascertained, since augering was stopped at 100 cm; however, some dunes were augered more deeply to determine the depth of leaching. From evidence of deeper augering on Fowlers Gap Station (Charley, unpublished; Corbett, in press) it may be predicted that the soils on transported materials consist of a complex series of buried profiles.

(b) *Colour*

Iron oxides and salts appear to be the main colour pigments, with organic matter of little importance except in some alluvial soils where there are black surface crusts and black skins on subsoil peds, and in some better-vegetated areas like Caloola land system, where the surface is reddish-brown (5 YR5/4) instead of the usual red colour (2.5YR 5/6 or 4/6). The red colour mainly takes the form of thin iron oxide coatings on quartz grains, and these coatings remain during mechanical analysis such that the settled sand is still as red as the field soil whereas the suspended silt and clay is normally less red (5 YR 4/4 to 6/6). Leached sand dunes and leached upland soils are usually intensely red (2.5YR 4/6 - 5/8), as there are no salts to mask the red hue, but soils in which lime has accumulated are noticeably less red (7/5 YR 4/4 to 6/6). Sandy alluvium along through-going rivers such as Fowlers and Yancannia Creeks also tends to be brownish-red (7.5 YR 5/4) rather than red, through absence of iron coatings and an associated lack of free colloids.

(c) *Texture*

Samples of the soils from each land unit were analysed by the Bouyoucos hydrometer method into coarse sand, fine sand, and silt plus clay fractions* after removal of carbonates with dilute hydrochloric acid. Gravel content was estimated separately by sieving hand-ground soil. The particle-size percentages include the gravel fraction, and

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* International (Atterberg) size gradings were used: gravel more than 2 mm diameter; coarse sand 2-0.02 mm; fine sand 0.2-0.02 mm; silt 0.02-0.002 mm; clay less than 0.002 mm.

where textures have been plotted on a texture triangle the gravel fraction has been included with the total sand fraction. Thus some gravelly soils are shown as lighter-textured. This applies particularly to some soils of Wonaminta, Cymbric, Kayrunnera, Katalpa, Oakvale, Faraway, Nuntherungie and Pulgamurtie land systems, which contain up to 60 per cent gravel. Most soils however contain less than 30 per cent gravel.

Dune soils in the area generally consist of at least 60 per cent coarse sand, commonly more than 70 per cent, with less than 10 per cent silt plus clay.

Alluvial soils usually contain more fine sand than coarse sand, except on the levees and in the channels, where coarse sand predominates. Alluvium derived from the Proterozoic shale and limestone in the south-west of the area, on and near Fowlers Gap Station, is noticeably finer than that to the north and east, derived from sandstone of the Great Artesian Basin. The alluvial soils of Caloola and Conservation land systems contain more than 60 per cent silt plus clay, and some even have more than 40 per cent clay alone, mainly soils of the floodouts; in contrast, the alluvial soils of Oakvale and Allandy land systems in the northeast contain less than 30 per cent silt plus clay and less than 15 per cent clay.

The soils in terminal pans such as Nucha Lake and The Salt Lake are variable in texture but usually contain more fine sand than coarse sand and less than 30 per cent silt plus clay, with silt usually more abundant than clay.

As might be expected, heavy-textured residual soils are found on shale and limestone, as in Nuntherungie, Cymbric, and Floods Creek land systems, but surprisingly heavy-textured soils also occur on stable upland surfaces of sandstone and quartzite in Faraway and Nundooka land systems; there is in fact very little textural difference between the soils on these contrasting rock types, perhaps indicating that the sandstone and quartzite soils could be transported or relict, or that the parent rocks are arkosic.

(d) *Structure*

With the exception of dune sands, most coarse-textured soils are massive rather than loose (apedal single-grain) in structure. Alluvial sands (less than 8 per cent silt and 8 per cent clay) and loamy sands (less than 25 per cent silt and 11 per cent clay) are usually quite coherent, in spite of their low colloid content, although loose sandy soils are found on levees and in channels. This general coherence may result from the percolation of soluble salts through the soils during leaching, causing consolidation. Soils of the dune swales (except in Marrapina land system) are usually massive, possibly because of cementing by accumulated salt and lime.

Peds are restricted to soils beneath relatively stable surfaces, for instance the deep soils below stony bands on slopes in Nuntherungie and Gap Hills land systems, but are less developed in shallower soils on patterned slopes in Pulchra and Kayrunnera land systems. Soils of sandstone uplands tend to be more pedal than those of shale uplands, for reasons discussed above. Soils on silcrete uplands, although leached, are massive rather than pedal. Some alluvial soils also show development of peds.

Peds beneath stony surfaces are remarkably similar in colour, having prominent red clay skins (2.5 YR 4/6), and also in size and shape (0.5 - 2 cm, polyhedral). They occur immediately beneath the stone mantle in a shallow horizon, usually less than 40 cm deep, which is entirely pedal. In all other pedal soils, varying amounts of loose or massive soil material occur with the peds, which here are not generally as strong nor as water-stable.

Peds are typically developed in horizons which have been depleted of free lime, with a pH not exceeding 8.0 and with no free soluble salts. The textures of the pedal horizons range from loamy sand to light clay. Strongly saline soils are very loose and puffy, whilst soils with high pH but no free sodium salts, and soils rich in free lime tend to be massive.

(e) *Soil Reaction*

Soil pH was found to range from 6.0 to 10.0. Values less than 7.5 are found only in leached soils; soils in which chlorides accumulate have pH between 7.5 and 10.0, but soils in which lime accumulates always have pH of 8.5 or above.

Lowest pH values (6.0) are found in the soils of dune crests, as in Marrapina land system; topsoils in the swales were usually 0.5-1.0 pH units higher than on the crests. Sandy alluvial topsoils, and topsoils in scalds, claypans and stony slope bands, and some upland soils on sandstone, quartzite, and silcrete also have pH between 6.5 and 7.0.

In most soils, pH increases down the profile, attaining its highest value in or just below the zone of maximum lime accumulation. Very few soils have pH more than 8.0 throughout the profile; these include solonchaks in terminal pans, brown solonized soils (Nuntherungie, Cobham and Floods Creek land systems), and stripped lithosols lacking surface leaching.

The pH of soil crusts is very variable; some are alkaline, although the soil beneath may be neutral, and in some the converse holds true. Few crusts reacted to hydrochloric acid, but some reacted to silver nitrate irrespective of the calcareousness or salinity of the soil beneath.

These stated pH values should be treated with caution because they vary with environmental conditions; for instance, the pH of the surface soil decreases immediately after rain, or again it temporarily increases under a dying salt bush.

(f) *Lime Content*

Illuviation of calcium carbonate has been perhaps the most ubiquitous soil-forming process in the area. Most soils contain lime at depth, although dune soils may be leached to pH as low as 6.0-6.5 for more than a metre. Some dunes in Marrapina land system were augered for more than two metres without encountering lime, before further augering was prevented by the loose nature of the sand. Some of the dune sands may have been leached of lime before aeolian transport, just as some of the alluvium on Fowlers Gap Station which did not contain lime at depth may have been leached before fluvial transport.

With the exception of the dune and alluvial soils mentioned, all other soils contain lime within the profile. In sands, illuvial lime has accumulated from depths of a metre or more; in heavier-textured soils on lowlands it occurs from 20 cm, but the original depth of illuviation is hard to ascertain because of frequent subsequent stripping which in some cases has exposed lime at the surface. Carbonate content is generally higher in heavy-textured soils than in sands. The greatest degree of lime accumulation is found in the brown solonized soils on calcareous shale in Nuntherungie land system, where the lime hardpan contains more than 50 per cent carbonates. Subsoils with more than 20 per cent carbonates are found on basic igneous rocks (Kayrunnera land system), calcareous rocks (Floods Creek land system), in land systems undergoing erosional stripping (Pulchra), and in land systems with many drainage terminals (Nucha). Calcareous lithosols in Nundooka and Cymbric land systems also contain more than 20 per cent carbonate.

With the exceptions of the leached and the lime-rich soils mentioned above, all soils examined contained between 1 and 10 per cent carbonates.

(g) *Chloride Content*

Silver nitrate was added to soil filtrate to test for the presence of chlorides. Strong precipitates were obtained in some soils with pH ranging from 7.5 to 10.0, but generally pH was between 9.0 and 10.0 if chlorides were present. Soils in the bed of The Salt Lake had pH values between 7.0 and 8.5 owing to the accumulation of neutral salts (sodium chloride and calcium sulphate) and much less lime. Other terminals such as Nucha and Cobham Lakes had higher pH values (9.0 or more) and quite strong chloride precipitates, although they lacked visible chloride crystals. Soils in these pans, which are vegetated, contained less visible chloride than those in The Salt Lake, although their colloids are also presumably dominated by alkalis rather than by alkaline earths.

Chlorides are generally absent from soils of upland areas, as in Faraway and Nundooka land systems, but chlorides were found in soils on limestone, as in upland units in Teamsters land system.

In most other soils including soils of claypans and scalds chlorides have been eluviated and have accumulated within or immediately below the zone of maximum lime accumulation. That chlorides should have been eluviated from soils below claypans and scalds rather than have accumulated at the surface, is unexpected, but this eluviation could have preceded scalding and have been reinforced by removal of the vegetation from the surfaces during scalding.

III. CLASSIFICATION OF THE SOILS

(a) Earlier Schemes

The fact that soils were exposed only by augering made classification into Great Soil Groups difficult, although some soils would obviously have fitted into Great Soil Groups.

The Soils Map of the Atlas of Australian Resources (Department of National Development, 1960) shows five Great Soil Groups in the Fowlers Gap-Calindary area. Arid red earths are shown to dominate the area, and these are a reasonable generalisation for some of the alluvial, dune, and upland soils. The designation of skeletal soils in the Barrier Ranges is only partly appropriate, because soils with developed profiles are also found in these upland areas. Stony desert tableland soils, shown to the north of the survey area, could well be extended south into the area to embrace the soils on slopes with contour bands, where stone-mantled soils alternate with stone-free surfaces. The desert loams shown in the west of the area could include all other soils. Considering the difference between the scale of the Atlas of Resources map and that of this survey, the agreement is quite good.

The larger-scale Sheet 10SE of the Atlas of Australian Soils (CSIRO, 1968) maps the soils of the area into six main profile types, with more consideration of landforms than in the earlier Soils Map. Red earths with gradational texture and neutral reaction trend are shown to dominate in the north and centre of the area, over a considerable part of the sand country and on some of the alluvial plains. In fact, uniform sandy texture was found to be more common than gradational texture in these soils. The southeastern and southwestern parts of the area are shown as having soils with contrasting texture profiles, with crusted loamy topsoils and red clayey subsoils, alkaline reaction trend, and a sporadically bleached A_2 or E horizon. Such soils correspond to the differentiated alluvial soils mapped in this survey, except that no bleached horizon was found. Through-going creeks, such as Fowlers and Yancannia Creeks, are shown as flanked by uniformly-textured brown self-mulching cracking clays, but field observations showed these soils to be sandy, especially in the channels and on the levees, and brown cracking clays were not found in the survey area.

The soils east of Koonawarra are shown as coherent shallow sands of uniform texture and minimal profile development, but the sands in these areas, as in Marrapina land system, are generally loose and quite deep.

between Nundora and Lonsdale, the soils are shown as coherent and shallow loamy soils with minimal profile development and uniform texture, and in some parts of the Barrier Range the soils are mapped as shallow dense loamy soils with weak pedologic development and uniform texture. Neither of these categories takes into account the strong profile development found in many upland soils.

In effect, the soils as mapped in the Fowlers Gap-Calindary survey correspond more closely with the representation in the Soils Map than in the Atlas of Australian Soils, but neither scheme has sufficient categories to describe the soils as surveyed here and therefore the following alternative scheme is proposed:

Upland Soils
- shallow soils, less than 40 cm deep
- deep pedal loamy sands
- brown solonised soils

Soils in Transported Materials
- loose sands of dunes and alluvial tracts
- massive loamy sands of drainage tracts, sandplains, and dune swales
- alluvial soils with marked profile development
- solonchaks

Soils on Contour-Banded Slopes
- reddish soils of the stony unvegetated areas
- brownish-red massive or weakly pedal soils of the vegetated depressions

Tables VI-1, VI-2 and VI-3 divide these soils into sub-categories on the basis of colour, texture, structure, calcareousness, and salinity.

IV. DESCRIPTION OF THE SOILS

(a) *Upland Soils*

These soils occupy most of the land systems of the Ranges, Tablelands, and Hills and Plains, and the non-alluvial parts of land systems of the Lowlands and Footslopes. Although they rest on rock, they have not necessarily formed *in situ*. Some are probably in place, as they grade through a C horizon into fresh rock, but others, especially on sandstone and quartzite, rest abruptly on the rock without a C horizon. They have been separated into three groups on the basis of depth and degree of profile development (Table IV-1), but there are some soils which are transitional between the groups.

(i) Shallow Soils. - These soils are less than 40 cm deep, but otherwise show a complete range from stony calcareous saline loose loamy sands to stone-free leached pedal loams.

Shallow lithosolic soils are found in dissected units in land systems on phyllite and calcareous sandstone (Wonaminta and Gap Hills land

TABLE VI-1. CATEGORIES OF UPLAND SOILS

Soil Characteristics			Sites of Occurrence	Land System and Land Unit
Shallow soils - less than 40 cm deep	Lithosolic - loose and stony throughout	Brownish to yellowish unleached loamy sand or sand	Uplands on calcareous and basic rocks	Faraway 3 Nundooka 3 Teamsters 1 Kayrunnera 1 Floods Creek 1
			Strongly dissected slopes and crests	Wonaminta 2 Gap Hills 2
		Brownish to yellowish unleached loam	Less stable slopes and uplands	Teamsters 3 Pulgamurtie 1 Cymbric 1 Floods Creek 3 (transitional to solonised brown soils)
		Brownish to yellowish leached loamy sand	Phyllite hillslopes	Wonaminta 1
		Reddish leached loamy sand	Escarpments and footslopes on silcrete and silicified sedimentary rocks	Quarry View 2 Pulgamurtie 2
	Massive loamy sand	Reddish, generally leached and stony	Quartzite ridges	Faraway 2
		Reddish unleached and stone-free	Uplands and hillslopes on sandstone	Nundooka 3 Kara Hill 2 Flat Top 2
		Reddish leached and stone-free	Plateau surfaces on silcrete and sandstone	Quarry View 1 Flat Top 1 Tekum 1
			Footslopes on weathered sedimentary rocks	Quarry View 3
		Brownish or yellowish leached and stony	Low rocky ridges	Nuntherungie 3
	With pedal horizon	Reddish leached stone-free loamy sand	Ridges and crests on sandstone and quartzite	Faraway 3 Nundooka 1, 2
		Reddish unleached stony loamy sand	Calcareous areas on sandstone plateaux	Kara Hill 1 Ravendale 1
		Reddish leached stone-free loam	Stable uplands on sandstone	Nundooka 3
Deep pedal loamy sands	Thin leached topsoil	Reddish	Footslopes on sandstone	Kara Hill 3 Ravendale 2 Faraway 4
		Reddish-yellow	Footslopes and plains on sandstone	Flat Top 3
	Unleached throughout	Reddish	Footslopes on sandstone	Tekum 2
Brown solonised soils	Loose unleached loamy sand to silty loam	Deep soil with well developed lime hardpan	Less stable shale interfluves	Nuntherungie 2
		Shallow soil with less prominent lime hardpan	Less stable surfaces	Floods Creek 3 Katalpa 2
			Calcareous areas in sandstone uplands	Faraway 4 (in Bynguano Range)

systems) and in areas of resistant but calcareous rocks (Faraway and Nundooka land systems).

The best-developed shallow soils, i.e. those that are leached and contain peds and clay skins, occur on resistant quartzite and sandstone in Faraway, Nundooka, Kara Hill, and Ravendale land systems, but not on silcrete, where leached massive soils lacking clay skins could be transitional between lithosols and developed soils. The developed shallow soils may be leached throughout to a pH as low as 6.5 or have a leached topsoil, with lime below 10 cm. The heaviest textures, best-developed peds and clay skins, and lowest pH values are associated with dense stone cover and generally stone-free profiles (except for large boulders). The stone cover, which presumably protects the surface from being stripped, points to surface concentration over a long period of pedogenesis. In contrast, the unleached lithosols are stony throughout with weathering rock commonly through the solum, suggesting that pedogenesis at no time overtakes surface stripping.

(ii) Deep pedal loamy sands. - These soils, which are more than 40 cm deep, occur on sandstone and quartzite but are not found in land systems on soft rocks. Their greater depth probably results from their position on footslopes, with marked colluvial accession. Although they are coarse-textured (loamy sand), a pedal horizon with clay skins is usually present at or near the surface. Lime has usually been illuviated, so that the pH of the surface soil is 7.0 or less, but salt accumulation can occur low in the profile, where the pH may be as high as 9.5. Reddish (5 YR 5/6) rather than brownish (7.5 YR 5/4) colours are common. These soils are frequently stone-covered but are not very stony through the profile, although large boulders may occur.

(iii) Brown solonised soils, or mallee soils (mallisols). - These are saline and calcareous throughout, with lime concentrated in a hardpan at between 40 and 100 cm depth. They attain their best development on stripped interfluves of Nuntherungie land system. Shallower, less-developed brown solonised soils are also found on footslopes and spurs in the Bynguano Range occurrence of Faraway land system, in Floods Creek land system, where they are transitional to calcareous lithosols, and in Katalpa land system, where the hardpan is poorly developed.

The soils are brownish (7.5 YR 6/4) rather than red, contain less than 5 per cent gravel, and grade downwards into calcareous weathering rock. The main soil-forming processes seem to have been a concentration of lime accentuated by surface stripping, and salt accumulation throughout the profile, but greatest near the surface (pH 9.5-10) where saltbush has returned the alkali cations. The soils appear to have developed *in situ*.

Fine sand (more than 45 per cent throughout the profile) and silt (up to 40 per cent in some horizons) dominate, and most of the soils are classed as silty loam, with clay content usually less than 10 per cent throughout. Carbonates range from 5 to 60 per cent, being highest in

TABLE VI-2. CATEGORIES OF SOILS IN TRANSPORTED MATERIALS

Soil Characteristics			Sites of Occurrence	Land System and Land Unit
Loose sands of dunes and alluvial tracts	Leached to at least 50 cm	Reddish and layered	Drainage tracts through resistant rocks and silcrete-capped plateaux	Nundooka 5 Barrier 2 Quarry View 4 Flat Top 4
		Reddish and non-layered	Dunes	Nundora 1 Allandy 1 Rodges 1 Gumpopla 1 Marrapina 1
			Dune swales	Marrapina 2
			Young alluvial plains	Oakvale 2 Fowlers 1
			Channels and drainage tracts	Yancannia 3 Nucha 4
			Pans and terminal floodouts	Rodges 1, 3
		Brownish and layered	Channels and levees	Caloola 5 Fowlers 2, 3
		Brownish and non-layered	Lunettes and pan margins	Cobham 5
	Unleached throughout or from 15 cm	Reddish and layered	Drainage tracts	Katalpa 4
		Reddish and non-layered	Flat-floored depressions	Nucha 2
		Brownish and layered	Levees	Caloola 4
		Brownish and non-layered	Pan margins	Cobham 4
Massive loamy sands of drainage tracts, sand-plains and dune swales	Reddish	Leached to at least 20 cm	Drainage tracts	Pulgamurtie 3 Pulchra 3 Conservation 6 Floods Creek 5 Conservation 1
			Sandplains and stony plains	Tekum 3 Oakvale 1 Yancannia 1, 2
			Pans	Nucha 3
			Swales	Nundora 2
		Unleached	Drainage tracts	Kara Hill 4 Ravendale 3 Sandstone Tank 4 Tekum 4
			Alluvial plains and corridors	Rodges 2 Cobham 6 Gumpopla 2
	Brownish	Leached to at least 20 cm	Alluvial plains, pans, and swamp basins	Allandy 2, 3 Rodges 2 Gumpopla 3 Cobham 3
		Unleached	Drainage tracts	Wonaminta 4 Cymbric 4 Nundora 2 Katalpa 3

TABLE VI-2 (CTD)

Soil Characteristics			Sites of Occurrence	Land System and Land Unit
Alluvial soils with marked profile development	Reddish, with texture contrast	Leached for at least 30 cm with pedal horizon	Drainage tracts	Faraway 6 Gap Hills 5
		Unleached with pedal horizon	Lower tracts of plains	Caloola 1
		Unleached and massive	Lower-lying tracts	Conservation 2
			Sand splays	Conservation 5
	Uniformly textured loamy sand	Reddish with pedal horizon for at least 30 cm, covered by loose sand	Shallow drainage tracts	Gap Hills 4
		Reddish and unleached with pedal horizon	Scalds and clay pans	Conservation 4
		Brownish and unleached with pedal horizon	Drainage tracts	Kayrunnera 3 Nuntherungie 4, 5
	Uniformly textured loam	Brownish and leached for at least 30 cm, with pedal horizon	Minor drainage tracts	Floods Creek 4
		Reddish and unleached with pedal horizon	Drainage tracts	Teamsters 4
		Reddish, leached for at least 30 cm, covered by loose sand	Feeder floodplains	Caloola 2
Solonchaks	Salt accumulation throughout; minimal profile differentiation	Saturated soil with pH 7-8 and abundant free chlorides and gypsum	Saline floors	Cobham 1
		Puffy soil with high pH (9-10)	Claypans	Cobham 2

the hardpan. Because of high lime and alkali cation content and low clay content, these soils are loose (apedal single grain) in structure, save in the hardpan which is massive and firmly cemented.

(b) *Soils in Transported Materials*

These soils occur in land systems of the Alluvial Plains, the drainage tracts of many erosional land systems, and throughout the Sand Country and Pans. With the exception of some soils in the southwest of the area and those in some pans, soils in this group are generally sands or loamy sands. They have been divided into four sub-categories each with distinctive formative processes (Table IV-2).

(i) Loose sands of dunes and alluvial tracts. - Most of these sands are red (2.5 YR 4/6), especially those of the dunes, but some through-going creeks such as Fowlers Creek have adjoining tracts with soils which are less red in colour. The depth of leaching is very great and exceeds 2 m in some cases; it is possible that some leaching occurred before emplacement of the sands, as in Marrapina land system, but had leaching taken place *in situ* one would have expected alluvial bedding to have been obliterated, which is not always the case. Loose sands near terminal pans are either not leached or leached only to depths of less than 50 cm; 20 cm of leached capping is quite usual.

(ii) Massive loamy sands of drainage tracts, sandplains, and dune swales. - Vegetated areas between dunes and away from active channels are commonly underlain by consolidated sand which is quite coherent when augered and which frequently has gravelly bands. There is little evidence of profile formation, apart from obliteration of bedding and illuviation of lime and salt to a shallow depth in some of the soils. The pH is generally higher than in the loose sands. These soils usually have a higher salt and clay content than the loose sands, but are similarly dominated by coarse sand which typically comprises at least 60 per cent of the soil.

Illuvial lime horizons in these soils are usually not strongly calcareous (generally less than 6 per cent carbonates), but pH values of 9.5 are not uncommon in the subsoils. The main soil-forming process appears to have been consolidation of the coarse sand by fine particles which may have been deflated or washed from adjoining areas. Although weak illuviation of salt and lime has occurred in some of these soils, the soil surfaces are probably not sufficiently stable nor old enough to have permitted further pedogenesis.

(iii) Alluvial soils with marked profile development. - These soils, which occur on stable alluvial surfaces, have a high degree of pedologic organisation and prominent clay skins. Nearly all contain a pedal horizon, and some scald surfaces as in Conservation land system may be underlain by horizons with peds comparable to those of the stone-mantled soils, which are the most pedal soils in the area. Some of these soils may be relict, as they are overlain by deep layered sands.

In the southwest of the area the soils closely resemble solonetz or solodised solonetz (Stace *et al.*, 1968), but since exposure was by auger, domed columnar structure could not be observed. These soils show a strong texture-contrast from loamy sand or sandy loam in the topsoil to sandy loam, loam, or light clay in the subsoil. Some soils are saline and calcareous throughout (solonetz), whereas others have a leached topsoil (solodised solonetz). Some subsoils have prominent reddish clay skins and black organic coatings on the peds. These soils are found in well-defined drainage tracts on low-lying back-plains where there is sufficient run-on for clay illuviation.

In the north, centre, and east of the survey area are tracts of sandy alluvium with well-developed alluvial soils which tend to be loamy sand, sandy loam, or loam throughout. Strongest soil development in these areas is associated with unvegetated surfaces, with or without stone, where a strongly pedal horizon with red clay skins is encountered at between 10 and 50 cm depth. In these soils, lime and chlorides have usually been illuviated to below the pedal zone, where the structure reverts to massive or loose. In vegetated areas, in contrast, the pedal zone is usually not so concentrated in depth, but neither peds nor clay skins are here as well-developed as in the soils of the bare areas.

(iv) Solonchaks. - In these soils chloride concentration is high throughout the profile and lime and gypsum also commonly accumulate. There is little evidence of profile differentiation, and coarse sand and gravel are interbedded with finer materials, with various salts interspersed throughout, often as coarse crystals. Because of the high concentration of neutral salts, pH is usually not high (7.0 - 8.0 is common). In The Salt Lake the soil is always saturated and the surface is flat with a very thin white crust, but in Cobham and Nucha Lakes the surface when dry is very irregular and puffy, suggesting a sodium-dispersed colloid. The pH tends to be higher here than in The Salt Lake.

(c) *Soils on Contour-Banded Slopes*

These soils occur as elements of the extensive contour-banded patterns on fairly stable slopes, mainly in land systems of the Lowlands and Footslopes but to a lesser extent in corresponding geomorphic sites in the Hills and Plains country. Although closely linked as parts of a repetitive microrelief and necessarily considered together, they are too dissimilar to be classified together into any of the preceding categories. They correspond most closely to the well-known stony tableland soils with strong gilgai (Jessup, 1960; Mabbutt, 1965). There is a marked difference between the soils of the stony risers and flat stony areas, which are mainly unvegetated, and those of the relatively stone-free, vegetated depressions (Table VI-3). The stony areas have well-organised soil profiles which suggest long periods of undisturbed pedogensis; monotonously similar profiles were encountered under stone cover throughout the area. The soils in the stone-free depressions are more variable, especially in pH, calcareousness, and salinity, all of which seem to be more related to the state of the vegetation cover than to any other factor. These soils have far less-developed profiles.

(i) Reddish soils of the stony unvegetated areas.— These soils have the best-developed profiles in the survey area; the only exceptions are the soils in Kayrunnera and Pulchra land systems, which do not contain a strongly pedal horizon, probably because of geomorphic or lithologic factors which have prevented the full development of the banding patterns. Depth of these soils varies between land systems. In Sandstone Tank land system rock may usually be encountered by 140 cm, whereas in Nuntherungie and Gap Hills land systems augering was still possible at 240 cm. The stony mantle is usually shallow (less than 10 cm), and below it there is very little stone until the weathered rock of the C horizon is encountered.

The pedal horizon, which is usually immediately beneath the stone, is distinctly red (2.5 YR 4/6). The peds are quite strong and angular blocky with prominent clay skins, and range from 0.5 to 2.0 cm diameter, the smaller sizes occurring beneath the densest stone cover and the larger sizes near the vegetated area downslope where the peds give way to more massive soil. The soil remains entirely pedal when disturbed. The thickness of the pedal horizon varies from about 20 cm under the densest stone cover to more than 50 cm where pedality diminishes.

These soils are mainly leached to below the pedal horizon, but some are weakly calcareous and/or weakly saline within the pedal horizon as well as below. Carbonates do not usually exceed 10 per cent in the top metre of soil, however. The pH of the pedal horizon varies between 8.0 and 9.0 but usually rises to 9.5 - 10.0 below the peds, where lime and chlorides normally occur. Lime masks the red colour and breaks down the structure of the soil in the lower horizon. Stones are absent to a depth of about 120 cm, where both quartz fragments and weathered rock are encountered, the latter increasing in size and frequency with depth. The soils are variable in texture, but silt content is usually high and increases with depth. Clay content is usually at a maximum in the pedal horizon and decreases with depth.

(ii) Brownish-red massive or weakly pedal soils of the vegetated depressions.— Occurring in the lowest parts of the microrelief, these soils remain wet for longer periods than do the nearby stone-mantled soils, but in spite of the greater opportunity for chemical weathering they are not noticeably heavier-textured. They commonly show a maximum clay content at about 60 cm depth rather than at the surface, presumably because of the gilgai processes, and therefore tend towards a texture-contrast profile.

The colour of these soils is brownish-red (5 YR 5/6), in contrast to the red soils of the stony areas. They exhibit minimal ped development and have less prominent clay skins, consisting of about 40 per cent of easily-broken, coarse (average 2 cm) rounded blocky peds in massive

TABLE VI-3. CATEGORIES OF SOILS ON CONTOUR-BANDED SLOPES

Soil Characteristics			Sites of Occurrence	Land System and Land Unit
Reddish soils of the stony unvegetated areas	Strongly pedal horizon	Leached to at least 30 cm depth or to below the pedal horizon; light texture	Stony risers on stable interfluves on shale	Katalpa 1 Nuntherungie 1
		Leached to at least 30 cm depth, or to below the pedal horizon; heavy texture	Stony risers on phyllite and limestone	Wonaminta 3 Floods Creek 2
		Weakly calcareous and/or saline throughout; light texture	Stony risers on interfluves with loamy gravel cover	Sandstone Tank 1, 2
		Weakly calcareous and/or saline throughout; heavy texture	Stony risers on calcareous shale footslopes below limestone ridges and on spur crests on calcareous sandstone	Teamsters 2 Gap Hills 1
			Stony steps on alluvial lobes	Gap Hills 3
	Weakly pedal horizon; leached to below the pedal horizon	Light texture	Stony bands on slopes below ridges of basic rock	Kayrunnera 2
		Heavy texture	Stony bands on plains on shale	Pulchra 2
Brownish-red massive or weakly pedal soils of the vegetated depressions	Leached to at least 20 cm depth	Light texture	Less stony steps on stable interfluves on shale	Gap Hills 1 Nuntherungie 1
		Heavy texture	Stone-free steps on shale slopes and plains	Wonaminta 3 Nuntherungie 1
			Less stony bands on stable interfluves on calcareous shale	Floods Creek 2
	Unleached	Light texture	Less stony bands on stable interfluves and plains on sandstone	Kayrunnera 2 Pulchra 2 Katalpa 1
		Heavy texture	Less stony steps on footslopes on calcareous shale	Teamsters 2
			Stone-free steps and risers on alluvial lobes	Gap Hills 3

soil in the top metre, overlying entirely massive subsoil. Stones occur throughout the profile. Salinity and calcareousness of the upper profile are closely related to vegetation; under saltbush, high chloride content and high pH values (9.5) are found at the surface, and under thick grass lime is also encountered, whereas it is usually leached to a shallow depth elsewhere.

V. REFERENCES

BOUYOUCOS, G.D. (1936). - Directions for making mechanical analysis of soils by the hydrometer method. *Soil Sci.*, 42, 225-9.

CHARLEY, J.L. *Soil salinity-vegetation patterns in Western New South Wales and their modification by overgrazing*. Unpublished Ph.D. Thesis, New England Univ. Nov. 1959.

CORBETT, J.R. (in press). - Soils of Fowlers Gap Station. *Fowlers Gap Res.Ser.*, 3.

CSIRO (1968). - *Atlas of Australian Soils*, Sheet 10SE.

DEPARTMENT OF NATIONAL DEVELOPMENT (1960). - *Atlas of Australian Resources; Soil Map of Australia.*

JESSUP, R.W. (1960). - The stony tableland soils of the south-eastern portion of the Australian arid zone and their evolutionary history. *J.Soil Sci.*, 11, 188-96.

MABBUTT, J.A. (1965). - Stone distribution in a stony tableland soil. *Aust.J.Soil Res.*, 3, 131-42.

MARSHALL, T.J. (1947). - Mechanical composition of soil in relation to field descriptions of texture. *CSIRO Bull.*, 224.

STACE, H.C.T. *et al.* (1968). - *A Handbook of Austalian Soils.* Rellim, Adelaide.

CHAPTER VII. VEGETATION OF THE FOWLERS GAP- CALINDARY AREA

By P.L. Milthorpe

I. INTRODUCTION

Vegetation in the survey area shows a marked xerophytic character reflecting the harsh arid climate which prevails, with trees being stunted and gnarled in form, the perennial shrub vegetation dormant for long periods, and forbs and grasses often absent. This chapter briefly discusses the controls exercised by climate and soils over the type and distribution of vegetation, the plant communities which exist, and the relationships of the various layers of the vegetation to one another. It concludes with a brief description of each of the recognised plant communities. Main sources of reference for plant names mentioned in the text are Black (1943-57), Eichler (1965), Morris (1966), and Anderson (1968).

II. ENVIRONMENTAL CONTROLS OF VEGETATION

(a) *Climate*

The vegetation throughout the survey area is largely controlled by a climate which during summer features long hot dry periods with extreme day temperatures, often accompanied by strong winds and low humidity. Rain periods are infrequent and offer little relief from these conditions. When rain does fall, it is frequently storm rain of moderate intensity, resulting in high runoff and reducing its effectiveness for plant growth. Winter conditions are mild with a very short frost period, but the country is frequently drought-stricken due to lack of seasonal rains. In spite of this, conditions for plant establishment are generally more favourable in winter because temperature and evaporation are lower, resulting in increased effectiveness of available moisture.

Depending on their drought-survival mechanism, the plants can be classified into three types, namely drought-resisting perennials, drought-evading perennials, and drought-evading ephemerals. The two drought-evading types exhibit few xerophytic traits, whereas the drought resisting type shows many such traits. The drought resistors are the most important group of plants in the area because of their persistence and the protection they afford the soil from the ravages of wind and water.

Examples of xerophytic characters are the replacement of leaves by phyllodes, which are more fibrous than normal leaf tissue and hence able to withstand greater desiccation without damage. The acacias, particularly *Acacia aneura* (mulga) and *A. tetragonophylla* (dead finish), display this character. Other characters commonly exhibited by trees in the area are reduction in size and surface area of shoots, restriction of foliage to the ends of the branches, and the general vertical orientation of leaves. Some plants, for example *Dodonaea attenuata* (hopbush), have trichomes on the leaves which reduce air flow across the surface of the leaf and which may also excrete an impervious substance to cover the leaf surface and so reduce transpiration by the plant. Other xerophytic structural traits are thick cuticles and recessed stomata in the leaf tissue. Physiological characters displayed by the xerophytes and which may have some effect on survival include succulency of root, shoot, and leaf tissues, high solute concentrations of plant juices, and conversion of polysaccharides to mucilages, which increase the water-retaining ability of the plant (Canon, 1921). Examples may be found in species from the family *Chenopodiaceae*, particularly the genera *Kochia* and *Bassia*.

An increase in summer dominance of rainfall from south to north, with a consequent decrease in the number of favourable winter seasons in the north, controls the distribution of certain perennial plants in the area. Favourable winter seasons promote the dominance of perennial shrubs such as saltbush and bluebush in the south, while favourable summer periods, or lack of winter rains, foster perennial grasses in the north of the area.

(b) *Soils*

Superimposed on the general climatic control of vegetation is the edaphic control, which is the principal factor governing the local distribution of and variations among plant communities. In turn, the distribution of soil type is governed by the geologic and topographic features of the country.

The physical attributes of the soil such as depth, structure, and texture govern the availability of soil moisture and hence control plant distribution. Such control appears to be a feature of the arid zone (Perry *et al.*, 1962). A local example of control by soil depth is the distribution of *Callitris collumellaris* var. *glauca* (white pine) and mulga as controlled by depth of sand in the sandy country. White pine is restricted to higher dunes of deep sand, as in Marrapina land system, while mulga extends across the lower dunes and sandplain of Nucha land system. The influence of soil texture on plant growth is shown by the response of *Astrebla* spp. on fine-textured soils in Caloola and Fowlers land systems only to moderate or heavy summer storms or to flooding; this contrasts with the response of forbs and grasses to light rainfalls on the sandy soils of Nucha and Gumpopla land systems. The fine-textured soils are capable of supporting growth only after considerable infiltration, at which time sufficient moisture is usually held to enable plants to complete their life cycle or to reach maturity. The coarse-textured soils rely on more frequent small rainfalls to replenish moisture supplies.

The effect of chemical attributes of the soil on vegetation distribution is seen in the characteristic communities on calcareous soils. *Enneapogon avenaceus* (bottlewashers), *Bassia limbata*, *B. paradoxa*, *B. patenticuspis*, *B. eriacantha* (copperburrs), and *Stipa variabilis* (speargrass) are the dominant vegetation on the calcareous soils of Teamsters land system, as also on the calcareous less stable interfluves of Nuntherungie land system and on the calcareous flats of Nucha land system. *Kochia sedifolia* (pearl bluebush) is also an indicator of calcareous soils but has been removed by grazing in most areas, although good stands remain on the calcareous sandstone of Nundooka land system. *Eucalyptus gillii* (curly mallee), which is the only eucalypt in the survey area not controlled by ground-water supply, is restricted to bands of calcareous soil in Faraway land system.

(c) *Topography*

Topography generally affects plant distribution through its control of surface and ground-water supplies, as shown in the growth of the disclimax *Eucalyptus* species. Relatively frequent flows along the major water courses recharge ground-water in bed sediments, and in such situations *E. camaldulensis* (river red gum) dominates the vegetation while *Casuarina* sp. (belah) occurs along lesser channels. The less frequently flooded flats and pans with fine-textured soils on which water stands for long periods are dominated by *E. largiflorens* (black box). Cessation of recharge occasioned by change of course of drainage results in the death of these species, and ample evidence of this exists on the lower reaches of major creeks throughout the survey area, and in Cobham land system. Floodouts, which are naturally areas of fine-textured soils, are the sites of main grasslands of the area.

Local microtopographic differences are also important in controlling vegetation distribution within a community, as exemplified on contour-banded slopes in Nuntherungie and Katalpa land systems. Here *Atriplex vesicaria* (bladder saltbush) is confined to the flatter sectors with gilgai, which are favoured by run-on from the intervening unvegetated sloping stony bands.

(d) *Grazing Animals*

The impact of the grazing animal in the ecosystem has had an even more important modifying effect on vegetation distribution in the area than have topographic and edaphic differences. This control of the distribution and productivity of pasture plants will be dealt with in Chapter VIII.

III. PLANT COMMUNITIES

The majority of species found in the survey area are indigenous to arid Australia, but there are a few introduced species, the most conspicuous being the opportunist *Nicotiana glauca* (tobacco tree), *Argemone mexicana* (Mexican poppy), and *Xanthium pungens* (noogoora burr). These grow along watercourses and around watering points, particularly in silt tanks, and are economically undesirable.

The vegetation of the survey area has been classified previously, but only on a fairly broad basis. Beadle (1948) grouped it into two formations: the scrub formation, which included the *Acacia aneura* (mulga) and *Casuarina cristata-Heterodendron oleifolium* (Belah-rosewood) associations, and the saltbush formation, which included the *Atriplex vesicaria* (perennial saltbush) and *Kochia sedifolia* (bluebush) associations. Each of these associations was in turn made up of various vegetation types or plant communities.

The mulga association is the most extensive, covering about 60 per cent of the survey area. It ranges from communities of sparse to dense mulga on rocky hills to groves of mulga on coarse-textured sand-plain soils. This comprises most of the mountain and piedmont desert and sand desert types as described in Chapter V, although the piedmonts are often treeless and mainly support the saltbush formation. Approximately 30 per cent of the area is treeless and is occupied by the saltbush formation. This area comprises the finer-textured stony desert type of undulating lowlands. The saltbush formation is regarded as an edaphic rather than as a climatic climax.

Other associations described by Beadle but not mapped by him in this area were the *Eucalyptus camaldulensis* (river red gum), *E. microtheca* (coolibah), and *E. largiflorens* (black box) associations from his savanna woodland formation, and the *Astrebla lappacea* (Mitchell grass) association from the grassland formation. They occupy only a small percentage of the total survey area and are found in the lower parts. The eucalyptus associations are regarded as post-climax communities related to a wetter environment and now persisting only in areas of favourable ground-water supply, as along creek banks and in areas subject to flooding.

Following Beadle's survey a revision of the classification of vegetation was made by Beadle and Costin (1952) in an attempt to obtain a uniform ecological classification throughout Australia. Under this revised system the nomenclature used originally by Beadle has been changed so that his associations are now termed alliances, whilst vegetation types within the former associations now become associations. This revised system has been adopted by the Soil Conservation Service of N.S.W. and has been employed in the description and classification of vegetation in various parts of the Western Division (James, 1960; Stannard, 1958, 1963).

The unit of description of vegetation used in this chapter is the association as defined in the revised classification, for it is at this level that descriptions of vegetation best fit the land units defined in the survey.

(a) *Relationship between Upper and Lower Storeys*

Three easily definable vegetation layers are recognisable within the survey area, namely the tree layer, shrub layer, and ground layer. The tree and shrub layers are comprised of drought-resisting perennials, whereas the ground layer consists mainly of drought-evading perennials, or of ephemerals which are only present following favourable growing conditions. The relationships of these three layers to one another are uncertain due to the general sparseness of the tree layer and the diversity of lower-storey communities. This uncertainty has been further complicated by the widespread degradation of the plant communities by domestic stock during the past hundred years. Any account of the vegetation using the relationship of upper-storey to lower-storey communities in their original state must be speculative insofar as it is based on an examination of the isolated relict communities still existing.

Over most of the area either the tree layer or the shrub layer alone now exists with the ground layer, but in a few areas the three layers are still present, as in Nundooka and Nuntherungie land systems in the east of the survey area, and also on the sandplains and dunes in Allandy and Gumpopla land systems in the north, where dense *Eremophila sturtii* (turpentine) is often found beneath a sparse tree layer of mulga.

Relationships between the upper-storey and lower-storey communities are shown in Table VII-1, which lists the 8 upper-storey and 16 lower-storey communities recognised in the area. All but three of the above 24 communities had earlier been recognised by Beadle (1948) as types or associes. The relative extent of these communities in each land system is shown in Tables VII-2 and VII-3, and a description of each is given below.

(b) *Description of Plant Communities*

(i) Upper-Storey Communities (Table VII-2). - Woodlands cover approximately three-quarters of the survey area. Distribution of tree species is sparse, with a stunted growth form for most species. Isolated areas of dense trees exist, as on sandstone hills or on the sand dunes of Marrapina land system, but even here tree height seldom exceeds 10 m. The remaining quarter of the area is treeless and is dominated by a perennial shrub layer or is unvegetated. No land system is entirely devoid of upper-storey communities however, as drainage tracts commonly have them.

A description of the recognizable upper-storey communities is given below, including distribution, form, and associated species.

(1) *Acacia aneura (Mulga).* - This is the most extensive community and covers about 65 per cent of the survey area. There is a great diversity of form with habitat, ranging from sparse stunted trees on ridges with skeletal soils to dense mulga stands on sandplain. There are areas, notably in Kara Hill and Faraway land systems, where good stands of mulga occur on sandstone outcrop with little or no soil. Mulga occurs only on neutral topsoils which may or may not have calcareous accumulations at depth, for example the lime-free loamy

TABLE VII-1. COMBINATIONS OF UPPER- AND LOWER-STOREY COMMUNITIES

LOWER-STOREY COMMUNITIES / UPPER-STOREY COMMUNITIES	*Acacia aneura* (mulga)	*A. victoriae* (prickly wattle)	*Casuarina cristata* (belah)	*Callitris columellaris var. glauca* (white pine)	*Eucalyptus camaldulensis* (river red gum)	*E. largiflorens-E. microtheca* (black box-coolibah)	*E. gillii* (curly mallee)	*Dodonaea attenuata-Eremophila sturtii* (hopbush-turpentine	Absent
Atriplex vesicaria (bladder saltbush)	X		X						X
A. vesicaria-Kochia pyramidata (bladder saltbush-black bluebush)	X	X	X				X		X
K. pyramidata (black bluebush)	X				X				X
K. sedifolia (pearl bluebush)	X								X
K. sedifolia-A. vesicaria (pearl bluebush-bladder saltbush)	X								
Muehlenbeckia cunninghamii (lignum)						X			X
Eragrostis australasica (canegrass)						X			X
Astrebla spp. (Mitchell grass)									X
Enneapogon avenaceus-Bassia spp. (bottlewasher-copperburr)									X
Eragrostis setifolia (neverfail)	X					X			X
Eragrostis eriopoda-Aristida contorta (wollybutt-kerosene grass)	X			X				X	
Cymbopogon exaltatus (scented grass)		X			X				
Stipa variabilis-Bassia paradoxa (speargrass-cannonball)									X
Paspalidium jubiflorum (Warrego summer grass)						X			
B. divaricata (poverty bush)									X
Short grasses and forbs	X		X	X				X	X
Absent	X			X					X

sands of Barrier land system or the neutral red sands of Nucha land system which overlie red calcareous sands at depth. Mulga grows up to 6 m tall, usually with one main trunk supporting a sparse to dense canopy of leaves. Leaf fall occurs during periods of severe drought.

Upper storey species which occur with mulga are *A. tetragonophylla* (dead finish), *Casuarina* spp. (hill oak and belah), and *A. cana* (cabbage tree) on fine-textured soils on footslopes and plains, while on the sandy country *Atalaya hemiglauca* (whitewood), *Heterodendron oleifolium* (rosewood), and *Callitris collumellaris* var. *glauca* (white pine) are the main species. Minor associated species are *A. loderi* (nelia) in Nucha land system in the south of the area. *A. ligulata* (sandhill wattle) and *Owenia acidula* (colane) in the north, principally in Gumpopla land system, and more generally *Hakea leucoptera* (needlewood), *Grevillia striata* (beefwood), and *Codonocarpus cotinifolius* (native poplar).

The inedible shrubs, *Dodonaea attenuata* (hopbush), *Eremophila sturtii* (turpentine) and to a lesser extent *Cassia eremophila* (punty bush) are found in association with mulga throughout the sandy country, with varying density. They are most common on sand dunes adjoining flats with fine-textured soils in Allandy and Nundora land systems, or along old stock routes and near watering points where severe grazing and trampling of the soil have taken place.

Mulga has been removed in several localities through the cutting of trees for drought forage and for fencing material. More serious than this is the mass death of trees, particularly on the sandy Nucha land system, over the past decade or so. Reasons for this widespread death of trees are not apparent, but factors which could be responsible are drought, mistletoe, which is abundant in the area, and overgrazing by stock resulting in the removal of perennial grasses which insulate the soil from intense radiation. The last factor is regarded as a probable cause of the widespread death of mulga in Western Australia (Gardiner, 1952).

The most common ground-storey communities associated with mulga are short grasses and forbs and *Eragrostis eriopoda* (woollybutt)-*Aristida contorta* (kerosene grass) communities on coarse-textured soils, and *Kochia sedifolia* (pearl bluebush)-*Atriplex vesicaria* (bladder saltbush) and *K. pyramidata* (black bluebush) communities on the ranges. There are numerous other minor lower-storey communities associated with mulga.

(2) *Acacia victoriae (Prickly Wattle).* - This community is generally restricted to broad secondary drainage tracts with minor channels, which undergo fairly frequent flooding by slow-moving water. The tree grows only to about 4 m high and is short-lived, so that a large number of dead trees are commonly present. Associated lower-storey communities include *Kochia pyramidata* (black bluebush) and perennial grasses, chiefly *Cymbopogon exaltatus* (scented grass).

TABLE VII-2. DISTRIBUTION OF UPPER-STOREY COMMUNITIES BY LAND UNITS

	Relative Extent in Land System of Land Units on which Community Occurs		
	Large	Moderate	Small
Acacia aneura (mulga)	Faraway 1, 2, 3; Nundooka 1, 2, 3, 4; Barrier 1; Wonaminta 1, 2; Quarry View 1, 2; Kara Hill 1, 2, 3; Rodges 1, 2; Allandy 1, 2; Nucha 1, 2, 4; Yancannia 1; Gumpopla 1, 2	Ravendale 1; Pulchra 1; Pulgamurtie 2	Tekum 1, 2; Nundora 1; Cobham 5; Flat Top 1
Acacia victoriae (prickly wattle)		Fowlers 1	Teamsters 4; Conservation 6; Floods Creek 4, 5; Nundooka 5
Casuarina cristata (belah)		Nuntherungie 1; Cymbric 1	Pulchra 3; Katalpa 1; Oakvale 1; Faraway 4
Callitris collumellaris var. *glauca* (white pine)	Marrapina 1, 2		Faraway 1
Eucalyptus camaldulensis (river red gum)			Faraway 6; Barrier 2; Nundooka 5; Floods Creek 5; Nuntherungie 5; Katalpa 4; Kara Hill 4; Fowlers 3
E. largiflorens-E. microtheca (black box-coolibah)		Yancannia 2, 3; Cobham 3, 6	Rodges 3; Allandy 3; Nucha 3; Gumpopla 3
E. gillii (curly mallee)			Faraway 5
Dodonaea attenuata-Eremophila sturtii (hopbush-turpentine)		Tekum 2; Rodges 1, 2; Allandy 1, 2; Yancannia 1; Gumpopla 1, 2	Nundora 1; Nucha 1; Cobham 5
Absent	Teamsters 1, 2, 3; Flat Top 2, 3, 4; Ravendale 2, 3; Kayrunnera 2, 3; Pulgamurtie 1, 3; Pulchra 2; Floods Creek 1, 2, 3; Sandstone Tank 1, 2, 3, 4; Gap Hills 1, 2, 3, 4, 5; Oakvale 2; Caloola 1, 2, 3, 4, 5; Conservation 1, 2, 3, 4, 5; Cobham 1, 2, 4; Kayrunnera 1	Quarry View 3, 4; Nuntherungie 2, 3, 4; Tekum 3, 4; Nundora 2, 3, 4; Fowlers 2; Katalpa 2, 3	Wonaminta 3, 4; Cymbric 3

A host of annuals such as *Medicago denticulata* (burr medic), *Argemone mexicana* (Mexican poppy), and *Xanthium pungens* (noogoora burr) may also be present.

(3) *Casuarina cristata*. - This community is mainly confined to the east of the survey area and is found on fine-textured stony soils, as in Nuntherungie and Pulchra land systems, or on level sandy country subject to flooding, as in Rodges land system. It occurs elsewhere on stony areas, chiefly on shale in Cymbric and Faraway land systems. The trees attain a height of 8 m and generally have one main trunk but are characterised by a large number of suckers. Leaf fall during drought provides a limited amount of forage for stock, and the tree is also useful for shade.

Associated minor species include *Flindersia maculosa* (leopardwood), *Heterodendrum oleifolium* (rosewood), *Acacia cana* (cabbage tree), and *A. aneura* (mulga). Lower-storey communities include *Atriplex vesicaria* (bladder saltbush), *Kochia pyramidata* (black bluebush), or short grasses and forbs.

(4) *Callitris collumellaris var. glauca (White Pine)*. - This community is restricted to relatively small areas of deep sand in Marrapina land system, or to rocky sandstone ridges in the Bynguano Ranges. Isolated trees are found on sand dunes throughout the area. The tree grows to a height of about 10 m, but unlike the single-trunked form which is characteristic of this species in better rainfall areas, it is here multi-trunked. It is ideal for fence posts, but its small size limits its usefulness for building timber.

Acacia aneura (mulga) is the main species associated with white pine, becoming less abundant on deeper sands. Associated ground-storey species are short grasses and forbs on sandy country, but on rock outcrops there is often little or no other vegetation, the pine itself being confined to crevices.

(5) *Eucalyptus camaldulensis (River Red Gum)*. - This community is conspicuous as a bright green belt of timber across an otherwise drab countryside, being restricted to the channels of the major creeks of the area. These belts are generally only two trees wide, as the trees are confined to the banks, but on broad flat channels they may invade the bed. To survive, they require frequent flows down the channel, and should a channel be abandoned the trees soon die. Trees can exceed a height of 20 m under favourable conditions and may be single or multi-trunked. Where conditions are less favourable, growth is gnarled. The timber is suitable for heavy construction work or fence posts, although it is not resistant to white ants.

Associated tree species consist of *Acacia victoriae* (prickly wattle) and occasionally *A. salicina* (native willow). Lower-storey communities consist of *Kochia pyramidata* (black bluebush) and perennial grasses such as *Cymbopogon exaltatus* (scented grass). *Dichanthium sericium* (Queensland blue grass) and *Panicum* spp. as well as other grasses, forbs, and sedges locally.

(6) *Eucalyptus largiflorens-E. microtheca (Black Box-Coolibah).* - These two species grow in similar habitats and may grow together; however whereas black box is ubiquitous, coolibah is confined to the extreme north of the survey area. The general habitat is flats of fine-textured alluvium which receive occasional flooding. The community is found in and around small pans throughout the sandy country and along the back channels and terminal floodplains of larger creeks. The trees grow to 12 m high and are useful for fence posts and firewood.

Lower-storey communities include *Muehlenbeckia cunninghamii* (lignum), *(Eragrostis australasica* (canegrass), and *E. setifolia* (neverfail). The last-named community is mainly restricted to small pans in the sandy country, while the remainder are more common on broader floodout areas. *Marsilea drummondii* (nardoo) is found in small pans subject to frequent flooding. In Yancannia land system perennial grasses such as *Panicum decompositum* (native millet) and *Paspalidium jubiflorum* (Warrego summer grass) are abundant in regions subject to flooding.

(7) *Eucalyptus gillii (Curly Mallee).* - This small community is restricted to calcareous soils on low foothills in Faraway land system north of Fowlers Gap Homestead. The form of the tree is typically mallee, with several trunks arising from a lignotuber and growing to a height of about 6 m. The tree has little economic value as the leaves are inedible and the timber has no suitable use. Lower-storey communities associated with this mallee are *Kochia astrotricha* (low bluebush) and short grasses and forbs.

(8) *Dodonaea attenuata-Eremophila sturtii (Hopbush-Turpentine).* - This community is widespread, but is confined to coarse-textured soils and for this reason it is characteristic of the sandplains and dunes in the northern part of the area. Stands may range from sparse to dense and may include either or both species. The densest stands are along stock routes or on unstable sandy areas which have been overstocked, since a loose topsoil appears to assist their establishment. In Nundora and Allandy land systems, which have dunes separated by flats with fine-textured soils, these shrubs are abundant on most of the dunes. They grow to a height of 3 m and have a sprawling habit with several main branches and an extensive but shallow rooting system. *Cassia eremophila* (punty bush) is a similar form found in the area, associated with these species but not as common, and mostly confined to calcareous sites.

Ground-storey communities are *Eragrostis eriopoda-Aristida contorta* (woollybutt-kerosene grass) and short grasses and forbs, but where the shrubs are dense there may be little or no ground-storey.

(ii) Lower-Storey Communities (Table VII-3). - These extend beneath most of the upper-storey communities, which have little or no effect on the form or structure of the lower community. However, some 30 per cent of the survey area has no upper-storey community, chiefly areas of fine-textured soils such as the contour-banded slopes on shale and the terminal alluvial plains, which support Mitchell grass. Floods Creek land system, which is on limestone and which has very few areas of

upper-storey vegetation, also generally lacks a shrub layer and is thus protected mainly by ground-storey communities, particularly the *Enneapogon avenaceus* (bottlewasher)-*Bassia* spp. (copperburr) association.

The most widespread lower-storey communities are those including *Atriplex vesicaria* (bladder saltbush), *Kochia pyramidata* (black bluebush), *Astrebla* spp. (Mitchell grass), and *E. avenaceus* (bottlewashers).

There are tracts throughout the survey area which have no lower-storey communities. In some cases the upper-storey may also be absent, as in salt lakes, on stony contour bands, and on scalds. Rock outcrops on hills and ridges commonly have no lower-storey, although *Acacia aneura* (mulga) and *Callitris collumellaris* var. *glauca* (white pine) often form upper-storey communities on these sites.

(1) *Atriplex vesicaria (Bladder Saltbush)*. - This is an extensive community covering the fine-textured soils on contour-banded slopes of shale lowlands of Nuntherungie land system which are treeless except for isolated *Casuarina* spp. The plants grow to a height of 50 cm under favourable conditions and may be so close as to touch; their diameter is up to 50 cm. If grazed out, the area is then invaded by the inedible *Bassia* spp. *B. divaricata, B. longicuspis*, (poverty bushes) which are not as desirable as saltbush, either for soil stability or for forage.

(2) *Atriplex vesicaria-Kochia pyramidata (Bladder Saltbush-Black Bluebush)*. - This community is common on most land units of Faraway land system, on timbered areas of Nuntherungie land system, and along most minor drainage tracts in land systems developed on shale. The bluebush grows slightly bigger than saltbush and may exceed 70 cm in height and diameter. The composition ranges from almost pure stands of saltbush to almost pure stands of black bluebush. The community includes shorter-lived ground-storey species such as *A. spongiosa* (pop saltbush), *A. inflata* (flat-top saltbush) and *Bassia* spp. (copperburrs), as well as short grasses and forbs.

(3) *Kochia pyramidata (Black Bluebush)*.- This is a restricted community confined mainly to the watercourses. It is commonly found on severely scalded and sheet-eroded flats adjacent to channels, as well as along channel banks. Spacing of the plants ranges from sparse to fairly dense with little or no space between bushes. Associated species in these habitats are *Rhagodia spinescens* (berry saltbush), *Cymbopogon exaltatus* (scented grass), and smaller species such as edible *Bassia* spp. (copperburrs) and grasses (*Eragrostis* spp.). In isolated areas where the soil is saline, bluebush may form pure stands with no other vegetation beneath. A minor shrub species sometimes present in such localities is *Enchylaena tomentosa* (ruby saltbush).

(4) *Kochia sedifolia (Pearl Bluebush)*. - This community is confined to small areas around outcrops of dolomite and limestone in Teamsters land system and to calcareous interfluves of Nuntherungie land system. There is also evidence that this bush once occupied calcareous flats

TABLE VII-3. DISTRIBUTION OF LOWER-STOREY COMMUNITIES BY LAND UNITS

Lower-Storey Community	Relative Extent in Land System of Land Units on which Community Occurs		
	Large	Moderate	Small
Atriplex vesicaria (bladder saltbush)	Sandstone Tank 1, 2, 4; Flat Top 2, 3, 4; Gap Hills 1, 3, 4, 5; Katalpa 1; Caloola 1, 2, 3	Floods Creek 2; Nundora 3	Nundooka 4; Teamsters 2; Wonaminta 3; Conservation 2, 6
A. vesicaria-Kochia pyramidata (bladder saltbush-black bluebush)	Quarry View 1, 2, 3, 4; Kayrunnera 2, 3; Cymbric 1, 2; Pulgamurtie 1, 2, 3; Pulchra 2; Nuntherungie 1, 3	Katalpa 2, 3	Faraway 6; Gap Hills 5; Nundora 4; Fowlers 2
K. pyramidata (black bluebush)	Barrier 1, 2	Wonaminta 1, 2, 4; Nuntherungie 4, 5; Pulchra 1, 3	Teamsters 4; Kara Hill 4; Ravendale 3; Floods Creek 4, 5; Katalpa 4; Caloola 5; Fowlers 1; Cobham 4
K. sedifolia (pearl bluebush)			Teamsters 1; Gap Hills 2; Nuntherungie 2; Sandstone Tank 3
K. sedifolia-A. vesicaria (pearl bluebush-bladder saltbush)	Faraway 2, 3, 4, 5; Nundooka 1, 2, 3; Flat Top 1, 2, 4	Kayrunnera 1	Gap Hills 2
Muehlenbeckia cunninghamii (lignum)			Cobham 3, 6; Rodges 3; Allandy 3
Eragrostis australasica (canegrass)			Gumpopla 3; Allandy 3; Cobham 2, 6
Astrebla spp. (Mitchell grass)	Caloola 1, 3, 5	Oakvale 2; Fowlers 1	Conservation 2; Gap Hills 5
Enneapogon avenaceus-Bassia spp. (bottlewasher-copperburr)	Teamsters 1, 2, 3; Wonaminta 1, 2; Floods Creek 3, 4		Nuntherungie 2; Sandstone Tank 2; Katalpa 2
Eragrostis setifolia (neverfail)			Nucha 2, 4; Gumpopla 3; Conservation 2
Eragrostis eriopoda-Aristida contorta (woollybutt-kerosene grass)		Rodges 1; Gumpopla 1; Nucha 1	
Cymbopogon exaltatus (scented grass)		Fowlers 1	Nundooka 5; Teamsters 4; Wonaminta 4; Floods Creek 4, 5; Conservation 6
Stipa variabilis-Bassia paradoxa (speargrass-cannonball)		Nucha 2; Tekum 3	
Paspalidium jubiflorum (Warrego summer grass)		Yancannia 2, 3	
Bassia divaricata (poverty bush)	Oakvale 1, 2		Conservation 5
Short grasses and forbs	Kara Hill 1, 2, 3; Ravendale 1, 2; Yancannia 1, 2; Allandy 1, 2, 3; Rodges 1, 2, 3; Gumpopla 1, 2; Marrapina 1, 2	Nundora 1, 2; Cobham 4, 5; Conservation 1, 5; Nucha 1	Faraway 1; Tekum 1, 2
Absent		Conservation 3, 4; Cobham 1	Faraway 1; Floods Creek 1; Tekum 4

in Nucha land system. This bush grows taller than those mentioned above and may exceed 1 m in height. Associated ground-storey vegetation is the same as in the saltbush and other bluebush communities.

(5) *Kochia sedifolia-Atriplex vesicaria (Pearl Bluebush-Bladder Saltbush)*. - This community is restricted to ridges of sandstone and shale with calcareous subsoils. It is most common in Faraway and Nundooka land systems, where it forms the principal lower-storey vegetation beneath sparse *Acacia aneura* (mulga). Other shrub species associated with this community are *K. astrotricha* (low bluebush) and *K. pyramidata* (black bluebush). Short grasses and forbs are also abundant and the inedible shrub *Bassia longicuspis* is present locally.

(6) *Muehlenbeckia cunninghamii (Lignum)*. - This community is confined to periodically-flooded areas with finer-textured soils, particularly playa floors and small pans where water may lie for long periods. Lignum grows to a height of 2 m in favourable seasons, and may persist for many years, but is regarded as a rather valueless fodder plant. In small pans it is often found in association with *Eucalyptus largiflorens* (black box). Ground-storey communities are short grasses and forbs and *Eragrostis setifolia* (neverfail).

(7) *Eragrostis australasica (Canegrass)*. - Canegrass communities are restricted to habitats similar to those of lignum, that is fine-textured alluvial soils which flood infrequently and where water lies for long periods. They are commonly found in the centres of swamps and in claypans throughout Gumpopla land land system. Canegrass grows above 2 m tall and the plants persist for long periods after death. It has a limited use as a material for thatching, but is only eaten by stock when green and is regarded as useless for fodder. Ground-storey communities are restricted to short grasses and forbs.

(8) *Astrebla spp. (Mitchell Grass)*. - This community has its greatest development on the fine-textured self-mulching gilgai soils of Caloola land system. Where this country is most frequently flooded, almost pure stands exist. It also exists on level stony soils with some gilgai, as in Katalpa and Oakvale land systems, where it is confined to the gilgai depressions, particularly where *Atriplex vesicaria* (bladder saltbush) has been removed by grazing. A summer grower, Mitchell grass produces abundant feed after heavy summer rains, and plants grow to about 1 m in height with favourable conditions. The main species of Mitchell grass present are *A. pectinata* (barley Mitchell grass) and *A. lappacea* (curly Mitchell grass).

Species which also grow with Mitchell grass are *Atriplex* spp. (annual saltbushes), *Bassia* spp. (copperburrs) and *Dactyloctenium radulens* (button grass). These are mainly cooler-season species which grow in favourable seasons while the Mitchell grass is dormant.

(9) *Enneapogon avenaceus-Bassia spp. (Bottlewasher-Copperburr).* - The two land types in which this community is most pronounced are Floods Creek and Wonaminta land systems, which have lime-rich soils. Bottlewashers rarely grow as a pure stand of grass, but generally have *Bassia* spp. (copperburrs) growing with them. The copperburrs, which are larger plants, tend to mask the bottlewashers, although the latter may comprise up to 70 per cent of the plants present. Growing to a height of about 30 cm, bottlewashers make quick growth after suitable summer rains but do not persist.

Bottlewashers are a component of most ground-storey communities throughout the survey area. Where present on fine-textured soils on contour-banded slopes in place of *Atriplex vesicaria* (bladder saltbush), they are regarded as a degenerate species (Charley, unpublished).

(10) *Eragrostis setifolia (Neverfail).* - This community is found on the floors of small pans throughout the survey area, as well as in other depressions subject to flooding. Neverfail grows to about 30 cm, and once it has seeded becomes fibrous and unpalatable. It may occur as a minor species in *Astrebla* spp. (Mitchell grass) communities. Frequently *Eucalyptus largiflorens* (black box) and, in Nucha land system, *Acacia aneura* (mulga) occur as upper-storey species.

(11) *Eragrostis eriopoda-Aristida contorta (Woollybutt-Kerosene Grass).* - This community has tufted perennial grasses as the dominant species, and since it is confined to sandy soils it is most evident on the sandplains and dunes in the north of the area. Neither species exceeds 30 cm in height. Minor species associated with them are *E. dielsii* (mallee love grass) and *Enneapogon avenaceus* (bottlewashers), together with numerous other grasses and forbs. These species are valuable for their stabilizing effect on sandy areas susceptible to wind erosion.

(12) *Cymbopogon exaltatus (Scented Grass).* - This community has a restricted and specialised habitat despite the fact that it is found throughout the survey area. It is largely confined to shallow sandy fills in drainage tracts, although it may extend on to adjacent flats subject to frequent flooding. In minor drainage tracts it characteristically has *Acacia victoriae* (prickly wattle) as an upper-storey species, whilst *Eucalyptus camaldulensis* (river red gum) is the upper-storey species along major drainage tracts. The grass grows to a height of about 50 cm and tussocks may be up to 30 cm in diameter. Other species found in this community include *Argemone mexicana* (Mexican poppy), *Medicago* spp. (native medic), and *Atriplex* spp. (annual saltbushes).

(13) *Stipa variabilis-Bassia paradoxa (Speargrass-Cannonball).* - This community is found mainly in small treeless areas, chiefly in the south of the survey area, in which the soils are calcareous and of sandy or loamy surface texture. It occurs principally on the calcareous margins of small depressions in Nucha land system, in Teamsters land system, and on calcareous interfluves in Nuntherungie and Katalpa land systems.

Speargrass generally grows to a height of about 50 cm but may greatly exceed this height in favourable seasons, having its greatest response to winter and spring rains. *B. paradoxa* and *B. patenticuspis*, which are frequently associated with it, grow to a height of about 30 cm. Other grasses, namely *Tripogon loliiformis* (five-minute grass) and *Enneapogon avenaceus* (bottlewashers), are commonly present. In some areas, particularly in Teamsters land system, it appears that the dominance at any time of either *Stipa variabilis* or *Enneapogon avenaceus* depends on seasonal conditions, summer rains favouring *Enneapogon* and winter rains favouring *Stipa*.

(14) *Paspalidium jubiflorum (Warrego Summer Grass)*. - This is a restricted community confined to the northern part of the survey area, mainly to flats along Yancannia Creek with sandy-textured soils and subject to summer flooding. It grows to a height of about 50 cm and frequently has *Panicum decompositum* (native millet), a grass of similar form, associated with it. The main upper-storey species associated with this community is *Eucalyptus microtheca* (coolibah).

(15) *Bassia divaricata (Poverty Bush)*. - This is the dominant species in a degenerate plant community found on country which once supported *Atriplex vesicaria* (bladder saltbush) communities. It is most commonly found on scalded alluvial soils with texture-contrast in Conservation and Allandy land systems, which are generally treeless. The dominant species are *B. divaricata*, *B. tricuspis*, and *B. longicuspis* (poverty bushes), which grow to about 50 cm in height and diameter. Minor species include *Kochia aphylla* (cottonbush) and *Rhagodia spinescens* (berry saltbush). Ground-storey species consist of abundant grasses and forbs.

(16) *Short Grasses and Forbs*. - This is by far the commonest lower-storey community and occurs in practically all areas, beneath upper-storey communities and also with other lower-storey communities such as *Atriplex* spp. and *Kochia* spp. (saltbushes and bluebushes). The floristic composition of this community is highly variable, the most common species coming from the families *Gramineae*, *Chenopodiaceae*, *Compositae*, *Cruciferae*, *Solanaceae*, and *Malaceae*. The three families first mentioned comprise the bulk of the community, and common species from among these include *Eragrostis dielsii* (mallee-love grass), *Aristida* spp. (wire grasses), *Bassia* spp. (copperburrs), *Atriplex* spp. (annual saltbushes), *Helipterum* spp. (everlasting daisies), and *Craspedia* spp. (billy buttons).

Seasonal conditions determine the composition and dominance of this community. Being herbaceous, it does not persist into drought unless protected by a tree or shrub community.

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V. REFERENCES

ANDERSON, R.H. (1968). - *The Trees of New South Wales.* N.S.W.Govt Printer, Sydney.

BEADLE, N.C.W. (1948). - *The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion.* N.S.W.Govt Printer, Sydney.

BEADLE, N.C.W., and COSTIN, A.B. (1952). - Ecological classification and nomenclature. *Proc.Linn.Soc.N.S.W.*, 77, 61-82.

BLACK, J.M. (1943-57). - *Flora of South Australia*, 2nd edn. Parts I-IV. S.A.Govt Printer, Adelaide.

CANNON, W.A. (1921). - *Plant Habits and Habitats in the Arid Portions of South Australia.* Carnegie Institute of Washington, U.S.A. Publn No.308.

CHARLEY, J.L. (Unpublished). - *Soil Salinity-Vegetation Patterns in Western New South Wales and their Modification by Overgrazing.* PH.D. Thesis, New England Univ., 1959.

CONDON, R.W. (1961). - Soils and land forms of the Western Division of N.S.W. *J.Soil Cons.Serv.of N.S.W.*, 17, 31-46.

CROCKER, R.L., and SKEWES, H.R. (1941). - The principal soil and vegetation relationships on Yudnapinna Station, northwest South Australia. *Trans.Roy.Soc.S.A.*, 65, 44-60.

EICHLER, H. (1965). - *Supplement to J.M. Black's Flora of South Australia.* S.A.Govt Printer, Adelaide.

GARDNER, C.A. (1952). - *Flora of Western Australia*, Vol 1, Part 1. W.A.Govt Printer, Perth.

JAMES, J.W. (1960). - Erosion survey of the Paroo-Upper Darling Region, PART III. *J.Soil Cons.Serv.of N.S.W.*, 16, 185-206.

MORRIS, A. (1966). - *Plant Life of the West Darling.* Barrier Field Naturalists Club, Broken Hill.

PERRY, R.A. *et al.* (1962). - Lands of the Alice Springs Area, Northern Territory, 1957. *CSIRO Aust.Land Res.Ser.*, 6.

STANNARD, M.E. (1958). - Erosion survey of southwest Cobar Peneplain, Part II. *J.Soil Cons.Serv. of N.S.W.*, 14, 30-45.

STANNARD, M.E. (1963). - Erosion survey of the Central East-Darling Region, Part III. *J.Soil Cons.Serv. of N.S.W.*, 19, 17-28.

CHAPTER VIII. PASTURES AND PASTURE LANDS OF THE FOWLERS GAP-CALINDARY AREA

By P.L. Milthorpe

I. INTRODUCTION

Since there is a need for stock to browse on trees and shrubs during the long dry periods experienced in this area, pasture descriptions must include all the vegetation layers. All but the most degraded areas have at least a sparse cover of edible trees or shrubs, the trees mainly being on coarse-textured soils and the shrubs mainly on fine-textured soils.

The response of plants to the regional climate allows plant species to be grouped into pasture types characterised as perennial drought resisters, perennial drought evaders and ephemeral drought evaders. These are described below.

The grouping of land systems with similar dominant pasture types defines combinations of pasture lands. These are differentiated on the basis of geology, landform etc. into individual pasture lands which are areas of similar production requiring similar grazing management.

A final section briefly outlines the history of the area from the first European settlement in the 1860's to the present day, including the subdivision of the area into holdings capable of supporting a family, and their subsequent development and stocking history.

II. PASTURE TYPES

(a) *Pastures Characterised by Drought-Resisting Perennials*

The perennial shrubs are the most important plants in this group as they are readily accessible to stock, whereas the trees, which are also perennial drought resisters, are commonly inaccessible and supply forage mainly as leaf fall and seeds. Most of the shrub species are not very palatable due to their woodiness and high salt content.

Growth of these pasture types occurs during favourable moisture periods, particularly during the cooler months. During the long dry periods the plants remain in a dormant state. It is because of their persistence that these pasture plants are important, both for their enduring supply of forage and for their protection of the soil from wind erosion. After rains there is generally a short-lived ground-layer community of grasses and forbs which is preferentially grazed.

(i) Bladder Saltbush Pastures. - These are the most extensive shrub pastures in the survey area, being found on medium to fine-textured saline soils commonly characterised by some gilgai microrelief. They are widespread on undulating shale lowlands and footslopes but also extend on to the hills where pockets of medium-textured soils occur.

The dominant species is *Atriplex vesicaria* (bladder saltbush), which attains a height of about 60 cm, with a similar diameter. Spacing of bushes varies; around gilgai depressions the bushes may touch whilst intervening areas are bare. Short grasses and forbs are usually present beneath the saltbush after favourable rains and supply the bulk of the forage to grazing stock in normal seasons. The density and composition of these ephemerals vary greatly throughout this pasture type. Usually there is no top-feed other than isolated trees of *Casuarina* spp., which are mostly found on hillslopes, but where *Kochia astrotricha* (low bluebush) is associated with the saltbush, as in Faraway land system, scattered *Acacia aneura* (mulga) may also be present.

Bladder saltbush is sufficiently palatable to maintain stock during droughts and this pasture type is therefore suited to medium stocking rates which it is able to maintain for long periods.

This pasture type is extensive in Nuntherungie, Katalpa, Pulchra, Cymbric, and Gap Hills land systems, but is also present to a lesser extent in many other land systems.

(ii) Black Bluebush Pastures. - These occur mainly along drainage lines and adjacent areas of alluvial texture-contrast soils. The pastures are characterised by *Kochia pyramidata* (black bluebush), a fairly large shrub growing to a height of 1 m and with a diameter to 2 m. Spacing and composition are variable depending on the condition of the range and the salinity of the soil. On texture-contrast soils which are not severely scalded the shrubs may be closely spaced with abundant grasses and forbs between them after rains; however where soils are saline *Enchylaena tomentosa* (ruby saltbush) and *Nitraria schoberi* (dillon bush) may also be present, or may even replace the bluebush, with little else growing. Along large channels with sandy floors or associated sand spreads *Rhagodia spinescens* (berry saltbush), with the same growth habit as black bluebush, is commonly present. Top-feed occurs locally, generally in frequently flooded areas or along the drainage channels, and mainly in the form of *Acacia victoriae* (prickly wattle).

These pastures are important because they stabilize texture-contrast soils which are highly susceptible to scalding, and also because of their capacity for sustaining moderate stocking rates for long periods.

No land system has large areas of this pasture type, but it is most common along drainage tracts in those land systems which support bladder saltbush pastures.

(iii) Pearl Bluebush Pastures. - These are confined to the southern part of the survey area, where they are restricted to calcareous soils. The dominant shrub is *Kochia sedifolia* (pearl bluebush), which has a tall habit, often exceeding 1 m in height, and which attains about 1 m in diameter. Spacing of pearl bluebush is variable, being rarely less than between 2 and 3 m and often sparser; where it is sparse, *Bassia longicuspis* (poverty bush) may be present, as in Nundooka land system.

On extremely calcareous soils, short grasses such as *Enneapogon avenaceus* (bottlewashers) and *Stipa variabilis* (speargrass), together with *Bassia* spp. (copperburrs), dominate the ground layer. Where this pasture occurs on hilly country, scattered mulga is also present as top-feed.

Pearl bluebush is unpalatable and is eaten only in times of extreme fodder shortage, most of the fodder of this pasture being supplied by the ephemeral ground-layer species.

This pasture type is most extensive on calcareous sandstone in Nundooka land system, but is also present in isolated areas in Nucha, Teamsters, and Floods Creek land systems.

(iv) Cottonbush Pastures. - These are found mainly on alluvial texture-contrast soils or on soils subject to occasional flooding. They are degraded pastures which appear once to have been characterised by bladder saltbush or by black bluebush. Cottonbush (*Kochia aphylla*) grows to a height and diameter of about 1 m and is generally widely spaced. It is of little forage value due to the small size of the leaves and the fibrous nature of the stems, and most of the forage in this pasture comes from the perennial grasses *Chloris truncata* (windmill grass), *Eragrostis dielsii* (mallee love grass) and *Eragrostis eriopoda* woollybutt), which grow in depressions and on sandy rises, and from other forbs and grasses which grow during favourable seasons. Top-feed is usually lacking.

This pasture is able to withstand low to moderate stocking rates in favourable seasons, but if stocking rates are maintained during drought the highly erodible soils will be subject to wind erosion, namely sand drifting and scalding.

Cottonbush pastures are found in Conservation and Fowlers land systems and on higher-lying parts of Caloola land system with lighter-textured soils.

(b) *Pastures Characterised by Perennial Drought-Evading Plants*

In the survey area plants of this class are confined to the perennial grasses, most of which are summer-growing species. These survive drought as dormant butts of dry material and respond to summer rains by shooting from basal buds. They supply nutritious feed while young, but become fibrous and less nutritious as the plant ages. They are particularly valuable as feed to the pastoral industry because of their ability to respond to summer rains.

(i) Mitchell Grass Pastures. - These pastures occur on small areas of fine-textured soils subject to flooding. These generally include the floodouts of major creeks, particularly in the south of the area, but also comprise gilgai depressions in degraded saltbush pastures. The latter habitat is most common in the central part of the survey area, where saltbush has been depleted by heavy grazing. *Astrebla lappacea* and *A. pectinata* (Mitchell grass) pastures are treeless

grasslands in which the grasses grow to about 1 m high. Butt diameters are about 20 cm and spacing of the grasses is usually close, in many instances forming pure stands. Few other species in Mitchell grass pastures respond to summer rain except *Chloris acicularis* (curly windmill grass) and other minor grasses, but during the winter months, when Mitchell grass is dormant, annuals such as *Atriplex* spp., and composites are abundant.

This pasture type is capable of supporting heavy stocking rates after summer rains, as the feed is best utilized when green. However it should not be overgrazed, as it has been shown that the response of Mitchell grass to rain is determined by the length of culm. Leaf buds on the culm respond to lighter falls of rain than do the basal buds, which need heavy rainfalls or floods to respond (Jozwik, Nicholls, and Perry, 1970). Hence it is recommended that Mitchell grass should not be grazed to within 15-20 cm of the ground.

Mitchell grass pastures are found in Caloola and Oakvale land systems, in areas which are frequently flooded; small areas also exist in gilgai in parts of Katalpa, Nuntherungie, and Nundora land systems which are now devoid of saltbush.

(ii) Neverfail Pastures. - This pasture type is not extensive, being mainly confined to fine-textured soils in small depressions in sandy country and to some gilgai areas in floodout country. It has a similar habitat to Mitchell grass but is able to withstand flooding for longer periods. Tussocks of *Eragrostis setifolia* (neverfail) grow to 30-40 cm tall and persist for long periods into drought; they are not palatable and are eaten only when green or when there is little other fodder. Grasses and forbs similar to those found in Mitchell grass pastures grow during the cool season and supply the bulk of the palatable forage.

These pastures occur principally as small areas in Allandy, Conservation, and Gumpopla land systems.

(iii) Woollybutt-Kerosene Grass Pastures. - This pasture type is found on sandplain and sand dunes. Neither *Eragrostis eriopoda* (woollybutt) nor *Aristida contorta* (kerosene grass) is extensive in pure stands, but mainly occur in pastures dominated by either or both species. Woolybutt grows to 50 cm tall with a butt diameter of 20 cm, whilst kerosene grass rarely exceeds 30 cm in height and 15 cm butt diameter. Top-feed consists of scattered *Acacia aneura* (mulga), *Atalaya hemiglauca* (whitewood), and *Heterodendrum oleifolium* (rosewood).

The two grass species which characterise this pasture type are not palatable when dry and are mainly eaten only when green. The ephemerals associated with them supply most of the fodder after suitable rains. They are important pastures since they protect highly erodible soils from wind sheeting and drifting, which otherwise result in the burial of available feed.

This pasture type is found on sandy units in Nucha, Rodges, Gumpopla, and Allandy land systems.

(iv) Warrego Summer Grass-Native Millet Pastures. - In the northeast of the survey area, along the sandy tract of Yancannia Creek, are pastures characterised by *Paspalidium jubiflorum* (Warrego summer grass) and *Panicum decompositum* (native millet), which grow to about 1 m tall and have a butt diameter of 30 cm. They respond to summer rains or floods and although they are fibrous in nature and of little value as sheep feed they are excellent for cattle forage. When dry they have a low nutritive value. Numerous short grasses and forbs supply feed in the cool months following favourable rains. These pastures are timbered with the inedible *Eucalyptus microtheca* (coolibah), but some top-feed is supplied by scattered *Acacia* spp. which grow along the channels. Their main occurrence is in Yancannia land system.

(v) Bottlewasher-Copperburr Pastures. - These pastures are found on highly calcareous saline loamy soils in the southwest of the survey area, and on shallow soils to the west of the Koonenberry Range in the centre of the region. They are characterised by *Enneapogon avenaceus* (bottle-washers) and by *Bassia ericantha*, *B. limbata*, *B. biflora*, and *B. patenticuspis* (copperburrs) and are included in this section because the bottlewashers and copperburrs act as perennials and the bottlewashers, which dominate the pastures, respond to summer rains. Bottlewashers rarely exceed 30 cm in height, with butt diameter about 7-10 cm; the copperburrs may grow to 45 cm in height and canopy diameter. Summer rains favour the dominance of bottlewashers and winter rains favour the copper-burrs and *Stipa variabilis* (speargrass), all of which are nutritious and palatable.

To the west of the Koonenberry Range some top-feed is supplied by scattered mulga and black bluebush; elsewhere this pasture type has no top-feed. Being herbaceous, this pasture does not persist into drought and little feed is available during long dry periods. This pasture type is widespread in Wonaminta land system; Teamsters and Floods Creek land systems are the other main areas of occurrence, with smaller areas in Nuntherungie and Nucha land systems.

(c) *Pastures Characterised by Ephemeral Drought Evaders*

The plants which characterise these pastures grow only during the short favourable periods of adequate moisture and survive the longer drought periods as seeds. Most of the plants lack morphological or physiological attributes which favour drought survival, but they do possess the capability of early seed setting which continues while the plant grows. Favourable long periods of growth result in heavy seed setting.

Many species are represented in these pastures, the families most commonly represented being *Gramineae*, *Chenopodiaceae*, *Compositae* and *Leguminosae*.

(i) Short Grass-Forb Pastures. - This is the most extensive pasture type in the survey area and is found throughout, on all types of soils. Variation in composition is large, and soil type, seasonal conditions, as well as past grazing history are all important in determining species composition. Greatest response to rain occurs in the cooler months when the growth of forbs is stimulated rather than of grasses, which respond more to summer rains.

Species of *Helipterum*, *Helichrysum*, and *Craspedia* among the *Compositae*, *Swainsona* and *Medicago* from the *Leguminosae*, and *Bassia*, *Atriplex*, and *Babbagia* among the *Chenopodiaceae* are most common in winter growth, and *Enneapogon*, *Dactyloctenium* and *Tripogon* among the *Gramineae* are commoner in the warmer months. A large number of the species are aromatic and therefore relatively unpalatable to stock; this applies to numerous species from the *Compositae* and *Cruciferae*. The majority of the plants do not exceed 30 cm in height, but there are a few erect growers such as *Lavatera plebeia* (Australian hollyhock) which may exceed 2 m height in favourable seasons. Plant density varies from place to place, but after adequate rains all but the most seriously eroded country responds with some growth. On coarse-textured soils, where this pasture type is most extensive, there is usually some top-feed, mainly supplied by *Acacia aneura* (mulga), *Acacia cana* (cabbage tree), *Heterodendrum oleifolium* (rosewood), or *Atalaya hemiglauca* (whitewood). There is very little top-feed on fine-textured soils.

Grazing rates on these pastures are low to moderate due to their non-persistence and consequent failure to supply fodder during drought periods except where top-feed is present.

These pastures occur extensively in Gumpopla, Rodges, Nucha, Allandy, Fowlers, Conservation, Marrapina, Oakvale, Nundora, Tekum, Kayrunnera, Ravendale, Kara Hill, Barrier, and Faraway land systems, and to a lesser extent in most other land systems in the area.

III. PASTURE LANDS

By combining land systems which have the same dominant pastures, related groups of pasture lands have been defined. These are further differentiated by local factors such as geology, landforms, or soils into individual pasture lands which usually have characteristic grazing capacity and erosion hazards and which require a single overall management technique. The distribution of pasture lands is shown on an accompanying map.

(a) Saltbush-Bluebush Pasture Lands

This group of pasture lands can be divided into hill country with a tree storey of mulga and belah, and lowland country lacking trees, comprising undulating stony lowlands with medium-textured soils and plains with texture-contrast soils.

(i) Hilly Shrubland Country

(1) *Area.* - 47,900 ha.

(2) *Distribution.* - Comprises Nundooka and Quarry View land systems and parts of Faraway and Flat Top land systems.

(3) *Environment.* - Steep ranges and plateaux of sandstone, quartzite, or silcrete with much rock outcrop and incised valleys.

(4) *Pastures.* - Dense pearl bluebush and bladder saltbush pastures occur beneath stands of moderate mulga and belah in Nundooka land system. Elsewhere the pastures are not as dense and have only scattered mulga and dead finish generally, and cabbage tree in Quarry View land system. Grasses and forbs occur in season beneath the shrubs.

(5) *Productivity.* - Productivity is moderate, based on grasses and forbs, but this pasture land is capable of being grazed continuously due to the drought reserve supplied by shrubs and trees. Although the country is steep, most of this pasture land is accessible to stock.

(6) *Water Supplies.* - There is ample surface water for stock from runoff. This is generally trapped on the adjacent plains, and stock must walk some distance to water. Temporary waters exist locally after rain in the form of rock pools. Adequate supplies of ground water are available in the southwest of the area.

(7) *Present Land Use and Condition.* - This pasture land is mainly suited to dry sheep, for it is too stony for cattle. Due to abundant stock water, most of this country can be developed to its maximum potential. Soil is trapped by rock outcrops and the condition of the country will not deteriorate provided the bush is not removed.

(ii) Lowland Shrubland Country

(1) *Area.* - 403,175 ha.

(2) *Distribution.* - Nuntherungie, Katalpa, Sandstone Tank, Gap Hills, Pulgamurtie, Cymbric, Kayrunnera, and Pulchra land systems and parts of Caloola, Flat Top, Oakvale and Fowlers land systems.

(3) *Environment.* - Footslopes and undulating lowlands with prominent contour bands of alternate bare stony and vegetated less stony strips. In some strongly undulating areas, as in Cymbric and parts of Nuntherungie land systems, the banding pattern may be absent. The country also includes plains which are subject to sporadic flooding and generally characterised by gilgai.

(4) *Composition.* - Bladder saltbush pastures, mostly treeless, but with scattered belah and cabbage tree in steeper areas lacking banding patterns. The pastures range from pure stands of dense bladder saltbush, through combinations of bladder saltbush and Mitchell grass, and Mitchell grass alone, to bottlewasher-copperburr or short grass-forb pastures, depending on the stage of degradation through overgrazing. For this reason it is not uncommon to see all stages concentrically zoned around watering points, with the bladder saltbush being furthest from water. In the north of the area Mitchell grass has entirely replaced the bladder saltbush over large tracts. This is probably mainly due to overgrazing, but may also reflect an increasing amount of summer rainfall northwards, which favours the growth of Mitchell grass. Unpalatable species of copperburr are frequently present in

such situations. These areas are depicted separately on the accompanying map of pasture lands, as lowland shrubland country with Mitchell grass.

(5) *Productivity.* - Variable according to the relative proportions of saltbush and other species. The pasture land is highly productive and stable where there remains sufficient bladder saltbush to maintain a ground cover, and is then able to support moderate numbers of sheep for long periods. Where the saltbush has been replaced by Mitchell grass the country is highly productive in wet summers and moderately productive in other favourable periods, but in this degraded state the pasture land is not able to support constant stocking rates through a drought. Where Mitchell grass has in turn been replaced by bottlewasher-copperburr pastures or by short grass-forb pastures, productivity is further reduced.

(6) *Water Supplies.* - Surface water is adequate due to the high runoff from the undulating country with its high drainage density. The moderate slopes are generally favourable for the location of surface storages.

(7) *Present Land Use and Condition.* - This country is used extensively for breeding sheep since it is totally accessible and supplies good quality feed for long periods. Grazing rates vary with density of saltbush but range from 12 to 21 sheep per 100 ha. During good seasons sheep do not fare as well on this country as on the short grass-forb pastures of sandy country because of the high salinity of the feed, but this is compensated by the ability of this pasture land to carry moderate numbers of stock consistently for long periods.

Surface water is preferable for this country, as saline ground water calls for more frequent drinking and hence limits the area which can be utilised by stock.

(b) *Mitchell Grass Pasture Lands*

(i) Mitchell Grass Country

(1) *Area.* - 85,575 ha.

(2) *Distribution.* - Comprises parts of Caloola and Oakvale land systems, mainly in the south and east of the survey area.

(3) *Environment.* - Treeless alluvial plains of fine-textured soils, self-mulching and with swelling clays, in terminal floodouts with small but continuous drainage channels.

(4) *Composition.* - Chiefly Mitchell grass pastures, with small areas of other pastures including perennial drought evaders such as neverfail in the lower and better-watered areas. Bladder saltbush, berry saltbush and cottonbush pastures occur in less frequently flooded tracts. All these pastures are characterised by abundant short grass-forb pasture elements following adequate winter or spring rains.

(5) *Productivity.* - Flooding or heavy rains produce an abundance of feed, either of Mitchell grass in the summer or of ephemerals in the cooler months. This pasture land does not respond to light rain unless the plants are already growing. High stocking rates can be maintained after good rains, but the Mitchell grass pastures should

not be grazed too severely as this will reduce their ability to respond to subsequent lighter falls. Soils are not prone to erosion by wind or water unless there is excessive grazing, when higher-lying tracts are subject to scalding.

(6) *Water Supplies.* - Surface water is the most common source of supply for stock grazing on this pasture land, although ground water of reasonable quality is available in the south of the area. As this pasture land is not extensive, the water supply will often be located on an adjacent pasture land.

(7) *Present Use and Condition.* - Both sheep and cattle use this country, it being particularly suited to cattle in favourable years when the grass is tall. Stock may bog during short periods following heavy rains.

(c) *Perennial Short Grass Pasture Lands*

(i) Limestone Country

(1) *Area.* - 16,450 ha.

(2) *Distribution.* - Comprises Teamsters and Floods Creek land systems, in the south of the survey area.

(3) *Environment.* - Rolling plains and hills and limestone ridges with slightly incised closely-branching valleys. The soils are saline highly calcareous sandy loams, with areas of less calcareous saline red sandy loams with stony topsoils.

(4) *Composition.* - This pasture land is characterised by a lack of trees and shrubs generally and by bottlewasher-copperburr pastures. Speargrass, which responds to winter rains, is sometimes prominent. Local areas of bladder saltbush pasture occur on some of the more stable slopes.

(5) *Productivity.* - This is a moderately productive pasture land capable of responding to summer showers and supplying nutritious feed. However the feed does not persist and hence the stocking capacity is only low to moderate.

(6) *Water Supplies.* - There are sufficient slopes to produce ample runoff for surface storages.

(7) *Present Use and Condition.* - Sheep are grazed on this pasture land, the feed being too short for cattle most of the time. The grazing rate is about 12 sheep per 100 ha. Prolonged overgrazing leads to the death of the perennial grass butts, which are important as soil stabilisers, and serious gullying and sheet erosion of the slopes result. Where the pasture land is in a very deteriorated state the light calcareous soil powders on trampling and is very susceptible to wind erosion.

(ii) Shale Hill Country

(1) *Area.* - 28,250 ha.

(2) *Distribution.* - Comprises Wonaminta land system, in the central part of the survey area adjacent to the Koonenberry Range.

(3) *Environment.* - Low rounded and discontinuous ridges on phyllite with shallow loamy sand soils; closely spaced, incised dendritic valleys.

(4) *Composition*. - This pasture land is characterised by scattered mulga and black bluebush above widespread bottlewasher-copperburr pastures and abundant short grass-forb pastures. Minor areas of saline red loamy soil on the western side of the land system support bladder saltbush pastures.

(5) *Productivity*. - Good feed is supplied by the dominant grass pastures following summer rain; however this does not persist and only a small amount of drought feed is supplied by the sparse tree and shrub layers. The short grass-forb pastures respond to winter rain and supply nutritious feed in that period.

(6) *Water Supplies*. - Ample supplies of surface water can be obtained from runoff from the low hilly areas and stored on the flat adjacent land. This is the main water supply to stock grazing this pasture land, although there are several permanent springs which supply good quality water.

(7) *Present Use and Condition*. - Sheep are grazed on this country, which is good wool-growing country free of dust and providing protection for sheep from the hazards of climate; when the grasses die off however, stock tend to lose condition. The assessed grazing capacity is between 13 and 15 sheep per 100 ha. Due to the numerous low outcrops of rock, this country is stable, as soil is trapped between them; however sheet erosion may follow heavy rain. Overgrazing could lead to the removal of saltbush pastures on the stable slopes in the western section of this pasture land.

(d) *Short Grass-Forb Pasture Lands*

This is an extensive and complex group of pasture lands which, while dominated by short grass-forb pastures, show local differences according to soil type and the amount of upper-storey vegetation.

(i) Hill Country

(1) *Area*. - 33,250 ha.

(2) *Distribution*. - Kara Hill, Ravendale, and Barrier land systems and the eastern occurrences of Faraway land system.

(3) *Environment*. - Mainly steep hills and plateaux of sandstone with much rock outcrop and shallow sandy soils. Deeply incised drainage with little or no adjacent flats.

(4) *Composition*. - Moderate to dense tree cover of mulga or *Callitris columellaris* var. *glauca* (white pine) over sparse to moderately dense short grass-forb pastures.

(5) *Productivity*. - The pastures are ephemeral and grow in areas of trapped soil; they supply limited feed to stock. Grazing rates are generally low due to the paucity of feed, but these lands are valuable in drought, especially where there is dense mulga which supplies drought forage to stock through leaf fall. The grazing rate is about 10 sheep per 100 ha.

(6) *Water Supplies*. - High runoff from this pasture land provides adequate surface water to storages on adjacent flatter areas, the stock moving in and out of the hills for water. Rockholes and soaks, although rarely permanent, supply water of reasonable quality for stock over short periods.

(7) *Present Use and Condition.* - These lands are used for sheep grazing, mainly for wethers due to the difficulty of management in areas of broken relief. However, although the country is steep and rugged and hence difficult for men to muster, it is mostly accessible to stock. Tree cover and rock outcrops protect the country from extreme deterioration by water erosion. Stocking should be at low to moderate rates, but continuous stocking is possible where there is abundant top-feed.

(ii) Sandy Country with Open Mulga

(1) *Area.* - 355,125 ha.

(2) *Distribution.* - Gumpopla, Nucha, Allandy, Yancannia, and Tekum land systems, and parts of Rodges, Nundora, and Cobham land systems; extensive in the north of the survey area, with a smaller area in the south.

(3) *Environment.* - Level to slightly undulating sandplain, or low sand dunes with level and often scalded swales with sandy or finer-textured soils. Drainage is often in the form of through-drainage from adjacent or distant higher country and many small pans dot this country.

(4) *Composition.* - Sparse to moderately dense mulga scrub with isolated whitewood, rosewood, and beefwood trees, with or without areas of inedible shrubs over short grass-forb pastures. Small areas of woollybutt-kerosene grass pastures are present, mostly on stable sand-plain. The pans and the swales with finer-textured soils often carry neverfail pastures or inedible canegrass.

(5) *Productivity.* - These lands have low to moderate carrying capacity, being capable of producing fair amounts of nutritious feed in favourable seasons but not of supporting stock for long periods of low rainfall. Where perennial grasses exist, with a quick response to summer rain and an ability to supply forage, although of poor quality, for longer periods into drought, this pasture land has a higher carrying capacity. A moderate tree cover supplies drought forage in some areas.

(6) *Water Supplies.* - Few suitable catchments for surface stock water exist except along watercourses which receive floods from adjacent country. Surface tanks with local catchments may go for considerable periods without intake of water and tend to be less reliable than tanks located on stony country. Areas of extensive scalding are suitable as catchments for tanks, provided there is sufficient slope. Ground-water supplies vary in quality but generally are more saline closer to the larger salt lakes; those in the Bancannia drainage system appear to be of better quality than in the Bulloo basin to the north. Because the forage of this pasture land is less saline than that from saltbush country, stock can tolerate more saline drinking water.

Where large creeks traverse this country, for example Yancannia and Pulgamurtie Creeks, there are usually waterholes in the channels, some of which give an almost permanent supply of good quality water. The more permanent waterholes, which may be more than a kilometre long, are characterised by adjacent areas of dense inedible shrubs including hopbush and turpentine, which are a reflection of past heavy stocking.

(7) *Present Use and Condition.* - Principally used for sheep, this pasture land is also capable of supporting cattle in favourable seasons, particularly if there are floodouts nearby to which the cattle can retreat when the local pastures deteriorate. Cattle are better able to utilise the perennial woollybutt-kerosene grass pastures. The assessed grazing capacity of this country varies greatly, but is between 7.4 and 14.5 sheep per 100 ha.

Overstocking leads to the removal of perennial grass butts and to the death of trees. There is then very little drought fodder available and the risk of sand drifting is greatly increased. Once drifting commences it is difficult to re-establish the pastures, and the usual result is encroachment of drifting sand on the nearby stable areas, or the establishment of inedible shrubs which compete for moisture with the grasses and forbs.

(iii) Sandy Country with Close Timber

(1) *Area.* - 40,100 ha.

(2) *Distribution.* - Rodges land system, constituting a small area in the eastern part of the region.

(3) *Environment.* - Sandplain and plains of coarse-textured alluvium combining hummocky sandy surfaces and scalded tracts. Broad flat drainage tracts pass through much of the country, with scattered pans and floodouts.

(4) *Composition.* - Moderate to dense timber, mainly belah, mulga, cabbage tree, and isolated leopardwood (*Flindersia maculosa*), and areas of inedible turpentine (*Eremophila sturtii*) over sparse to moderately dense short grass-forb pastures.

(5) *Productivity.* - This pasture land has moderate productivity through the growth of ephemerals after adequate rains or flooding, for large parts of it are inundated following heavy rains. The dominant trees are all edible and contribute to the drought forage, so giving stability to the carrying capacity. While the ephemeral pastures in general are not particularly nutritious because of the dominance of spiny copperburrs, there are areas of perennial woolybutt-kerosene grass pastures which are capable of maintaining stock for reasonable periods.

(6) *Water Supplies.* - Surface water is available along major drainage tracts, and some of the floodouts supply water for several months after extensive flooding.

(7) *Present Use and Condition.* - This country is used mainly for sheep, which are able to forage under and on the trees. The assessed grazing rate is 15.0 sheep per 100 ha. The country is generally stable, being protected mainly by the tree cover; however there are minor areas of sand drifting and scalding.

(iv) Sandy Country with Pine

(1) *Area.* - 11,150 ha.

(2) *Distribution.* - Marrapina land system, in the south of the area.

(3) *Environment.* - Dunes of deep sand with little surface drainage.

(4) *Composition.* - Dense stands of white pine on the dunes, with scattered pine and mulga elsewhere, over a ground vegetation consisting of sparse to abundant short grass-forb pastures.

(5) *Productivity.* - This country has low to moderate productivity and relies solely on the ephemeral pastures for feed. The sandy soils produce abundant but short-lived growth following rain.

(6) *Water Supplies.* - Water is usually available on the adjacent areas of Nucha land system. Nuntherungie Creek passes through or near this country, and temporary water holes along the channel provide limited supplies for stock.

(7) *Present Use and Condition.* - This pasture land is mainly used for sheep grazing, although cattle can also be grazed after good seasons. Its assessed safe grazing capacity is about 9 sheep per 100 ha. If overgrazed, the sand surface will become unstable and subject to drifting, with a resultant reduction in carrying capacity. At present, sand drifts are not common and are localised in open areas.

(v) Frontage Country

(1) *Area.* - 77,675 ha.

(2) *Distribution.* - Comprises Conservation and Fowlers land systems in the south of the area, and other tracts adjacent to major creeks.

(3) *Environment.* - Alluvial plains and floodplains, extensively scalded and with sandy hummocks and isolated gravelly rises, traversed by incised channels or by shallow drainage depressions. Some areas with gilgai and minor floodouts.

(4) *Composition.* - The plains are treeless and have a few inedible shrubs such as punty bush (*Cassia eremophila*) on the sandy rises. River red gums occur along the main channels and prickly wattle along the minor drainage channels.

Perennial shrub pastures such as cottonbush and bladder saltbush pastures may be present in small depressions in the plain, with black bluebush pastures usually confined to the scalded levees along the major drainage lines. However, short grass-forb pastures are the principal type, with scattered areas of perennial grass pastures including woollybutt-kerosene grass pastures on sandy areas and Mitchell grass and neverfail pastures in lower-lying areas with gilgai.

(5) *Productivity.* - This country has a low to moderate productivity, depending upon the degree of scalding which has occurred. Where areas of perennial grass pastures or shrubs exist, some drought fodder is available; otherwise this country is not able to support continuous stocking. The soils are highly erodible by wind, particularly under heavy stocking, and wool can then become very dusty. Where tanks are located along the channels there is usually an area around them which is severely eroded and dusty; it is indeed unfortunate that the best locations for tanks in most of the survey area are on land that is highly susceptible to erosion. The only way to overcome this is to pipe the water to adjacent pasture lands, but this is rarely economic.

(6) *Water Supplies.* - Away from the channels, lack of slope makes surface water difficult to catch, since heavy downpours are required to yield sufficient runoff. Ground water from bores is plentiful and of reasonable quality on the plains in the south of the area. However, the main channels in this country provide the most important locations in the survey area for tanks.

(7) *Present Use and Condition.* - This land is used mainly for sheep, cattle being grazed only where there are adjacent areas of Mitchell grass or other tall grass pastures. The assessed safe grazing capacity is approximately 10 sheep per 100 ha. The condition varies greatly from place to place; usually there is moderate scalding and sheet erosion, but this often becomes severe near water points.

(e) *Desert Lake Pasture Lands*

(i) Desert Lake Country

(1) *Area.* - 18,050 ha.

(2) *Distribution.* - Comprises Cobham land system, mainly in the northwest of the survey area.

(3) *Environment.* - Claypans, swamps, and salt lakes, together with fringing sandy country.

(4) *Composition.* - Varies with soil type, particularly soil salinity, and with frequency and duration of flooding. Relatively unpalatable shrubs such as nitre goosefoot (*Chenopodium nitrariaceum*), lignum, and the inedible perennial canegrass dominate.

(5) *Productivity.* - The large salt lakes, for example The Salt Lake, are unproductive and of no pastoral value because of salinity. The more numerous claypans supply limited feed only after flooding and do not generally respond to rain. The extensive open bare surfaces are subject to wind erosion, particularly where saline and puffy.

(6) *Water Supplies.* - Surface supplies are provided by tanks set in the less saline claypans below sloping lake margins or near stream intakes.

(7) *Present Use and Condition.* - Grazed extensively by sheep, together with adjacent sandy country with open mulga. The carrying capacity is variable but is usually extremely low, and this pasture land is of little significance for grazing.

IV. HISTORY OF LAND USE

(a) *Exploration and Settlement of the West Darling Region*

The survey area occupies about 10 per cent of the West Darling Region and is located in the central northern portion of it.

Sturt was the first European in the area when during his 1844-45 expedition he explored part of the southwest corner of the area near the present Fowlers Gap and Sturts Meadows Stations and ventured across the Bancannia Plains to a point close to Marrapina in search of water. In the north of the area he also penetrated into the sandy country east of The Salt Lake and noted the Yancannia Range further to the east.

The next report is that of the ill-fated Burke and Wills expedition of 1860. Their route passed Mootwingee, followed Nuntherungie and Wonaminta Creeks, and crossed to Yancannia Creek and eventually to Torowoto Swamp in the north of the survey area. Here they set up a base camp. It is of particular note that W.H. Wright from Menindee was engaged by Burke as third-in-command due to his knowledge of the country, suggesting that unrecorded local expeditions into parts of the northwest had taken place prior to 1860.

Settlement quickly followed after 1860, for records show that A. Wallace settled on Sturts Meadows in 1864, that Depot Glen northwest of the survey area was taken up in that year, that Land Commissioner Woore had established a base camp at Wonominta by 1863, and that W.H. Wright held leases on land near Wonominta in 1865. It would be safe to assume that all the easily-watered country in the survey area had been taken up by 1870.

(b) *Early Development*

Wells were developed as the main sources of stock water initially, though by 1880 the first bores were being sunk, adding to reliability of water supplies. Stock numbers no doubt increased with the buoyant wool prices of the 1870s; however, the 1880's heralded a decline in wool prices and saw the introduction of the rabbit into the survey area, probably during the mid-eighties. Rabbiters were employed on Mt. Wood Station to the north of the area in 1886. The first plague of rabbits occurred in 1889, though it is not certain whether this was confined mainly along the Darling River or whether it was widespread.

Despite the financial recession of 1890, stocking rates reached a peak in this area in 1894, when the average stocking rate was about 32 sheep per 100 ha as shown by records of the Milparinka and Menindee Pasture Protection Boards. Stocking rates rapidly declined to 10 sheep per 100 ha by 1902.

Most of the early holdings were large, but in 1884 the government intervened with legislation to provide small blocks of land or "homestead leases" for settlers. These were not more than 4140 ha and were far too small. After the Royal Commission of 1901 into the condition of Crown tenants in the Western Division, further attempts were made to build holdings up to 8280 ha. However land within the survey area still largely remained in the hands of the big landholders, for example Kidman held more than a third of the West Darling area in 1920, mainly in the northwest of the region.

The year 1934 saw the introduction of a new Act by Buttenshaw, the N.S.W. Minister of Lands, its intention being to build up leases to a minimum carrying capacity of 3000 sheep, with up to 10,000 sheep in remote areas. The Act provided for leases which were due to expire in 1946 to be given a further 25 years if they surrendered one quarter of their land immediately, an eighth in 1943, and a further eighth in 1948. Those who failed to comply with the Act lost the whole lease in 1946. The surrendered areas were used to build up smaller areas to economic size and to establish new leases, and this subdivision and build-up of leases was completed in the survey area by 1950.

Also in 1934 came the introduction of Local Land Boards into the Western Division to decide land allocations on the merits of the applicants. Each Land Board was to be under the chairmanship of the Western Lands Commissioner or one of two appointees of the Commission. Later the structure of the Board was changed so that today a Land Board consists of an Assistant Western Lands Commissioner as chairman, and two local pastoralists.

Today 36 leases held by individual landholders have more than half their extent within the survey area. Their sizes vary from 17,000 ha to 74,000 ha, with the majority being approximately 40,000 ha. The size of lease is largely governed by the type of country, the larger properties being mostly on the sandy or hilly country.

(c) *Present Development*

All leases are now well developed with fences and watering points. By far the most common type of watering facility is the surface earth tank, and this is found extensively in all but the most sandy country, where there are no catchments. Bores and wells are important, although not as abundant as tanks; their water is permanent but may not always be of good quality. The southwest and the north of the survey area are the areas of greatest concentration of bores.

In the hilly country there are isolated soakages which supply either temporary or permanent water to stock. Such soakages and rock pools are found mainly in the shale country west of the Koonenberry Range or in the sandstone hills of Kara and Ravendale land systems. The most famous rock pools are those at Mootwingee to the southeast of the survey area, which have been used by aborigines for centuries.

Sheep are the main pastoral animals, with cattle being run in small numbers only, mainly during good seasons and on properties that have areas of flooded country or tall grass pastures. Holdings with a high percentage of stony country usually have low cattle numbers. Cattle and horses make up about 1 per cent of the total stock numbers of the area in any year.

Average carrying capacities of properties range from about 3000 to 7000 sheep equivalents, with the mean for the area being 4500 sheep equivalents.

Although generally well-watered, about 10 per cent of the area is more than 5 km from reasonably permanent water and can hence be considered inadequately watered. Those areas are nevertheless grazed by stock occasionally, although in many cases it would probably be uneconomic to provide water to them. Inadequately watered country is generally indicated by the gross deterioration of the range near the watering points which supposedly serve it, for in hot dry periods stock are forced to remain concentrated about the watering point due to their inability to utilise the distant country. Other areas of deterioration are evident along old stock routes, which carried large numbers of stock during the early days of pastoral settlement; this is especially so near old-established permanent watering places. Areas around old tanks sunk by early settlers in the area also display marked evidence of overgrazing.

V. REFERENCES

BEADLE, N.C.W. (1948). - *The Vegetation and Pastures of Western New South Wales with special reference to Soil Erosion.* N.S.W.Govt Printer, Sydney.

HARDY, B. (1969). - *West of the Darling.* Jacaranda, Brisbane.

JOZWIK, F.X., NICHOLLS, A., and PERRY, R.A. (1970). - Studies on the Mitchell Grasses. *Proc.Int.Grasslands Cong. Surfers Paradise Qld,* 48-51.

KING, C.J. (1957). - *An Outline of Closer Settlement in New South Wales. Part 1. The Sequence of the Land Laws 1788-1956.* N.S.W.Govt Printer, Sydney.