PHYSICAL ENVIRONMENT

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Climate

The main features of the Study Area's climate are cool winters, hot summers and irregular rainfall. According to the classification of Koppen (Dick 1975) the south-western half is Hot Dry Continental (BSh) and the north-western half Hot Arid Desert (BWh). Alternatively, most of the Study Area is Sub-desert (attenuated). The exception is a narrow strip of Xerothermomediterranean along the western boundary (UNESCO-FAO 1963).

Southern Cross is the only major climatic recording station in the Study Area. Minor towns, such as Westonia and Marvel Loch, record daily rainfall. Stations on the now abandoned narrow gauge railway line from Southern Cross to Coolgardie, had recorded daily rainfall on an irregular basis while the railway line was operational. Additional climatic data are provided by Coolgardie and Kalgoorlie, just to the north-west of the Study Area, and by Hyden to the south-west (Bureau of Meteorology, Australia 1988a).

Temperature

The average monthly temperatures for 1977-81 and the long-term means for the Study Area are shown in Figure 3. Average monthly maximum temperatures range from 16°C (July) to 37°C (January), and average monthly minima range from 5°C to 18°C. Kalgoorlie has a slightly higher summer maxima than the other stations. Extremes recorded were Southern Cross (47.2°C and -5.0°C), Kalgoorlie (45.2°C and -3.0°C) and Hyden (44.6°C and -2.6°C). Closely correlated with temperature is the average annual evaporation which generally increases from 2450 mm on the southern boundary to 2700 mm on the northern boundary (Anon 1981). The only records of snow were light falls at Southern Cross on 5 August 1897 and 26 July 1964, and at Karalee on 10 August 1911.

Rainfall

Mean monthly rainfall for 1977-81 and the long-term means for the Study Area are shown in Figure 3. Most rain falls during the period of May to August. The average annual rainfall for Southern Cross is 284 mm. Both average annual rainfall and reliability decreases from south-west (Hyden 334 mm) to north-east (Coolgardie 263 mm and Kalgoorlie 252 mm). Annual rainfall varies as follows: Southern Cross (117-577 mm), Kalgoorlie (123-488 mm) and Hyden (216-572 mm). There is a general south to north decline in minimum monthly rainfall.

Winter rains are mainly from cold fronts associated with sub-Antarctic lows, sometimes supplemented by a stream of moist tropical air. Falls from cold fronts rarely exceed 10 mm but may reach 40 mm if supplemented by moist tropical air. Summer falls (to 50 mm) are highly erratic and occur from thunderstorms sometimes associated with troughs. Heaviest falls (to 160 mm) occur from tropical cyclones which have degenerated into rain-bearing depressions.

During the survey of the Study Area, above average rainfall was recorded in 1978 and 1980 while well below average rainfall occurred in 1977 and 1979. Monthly rainfall that exceeded

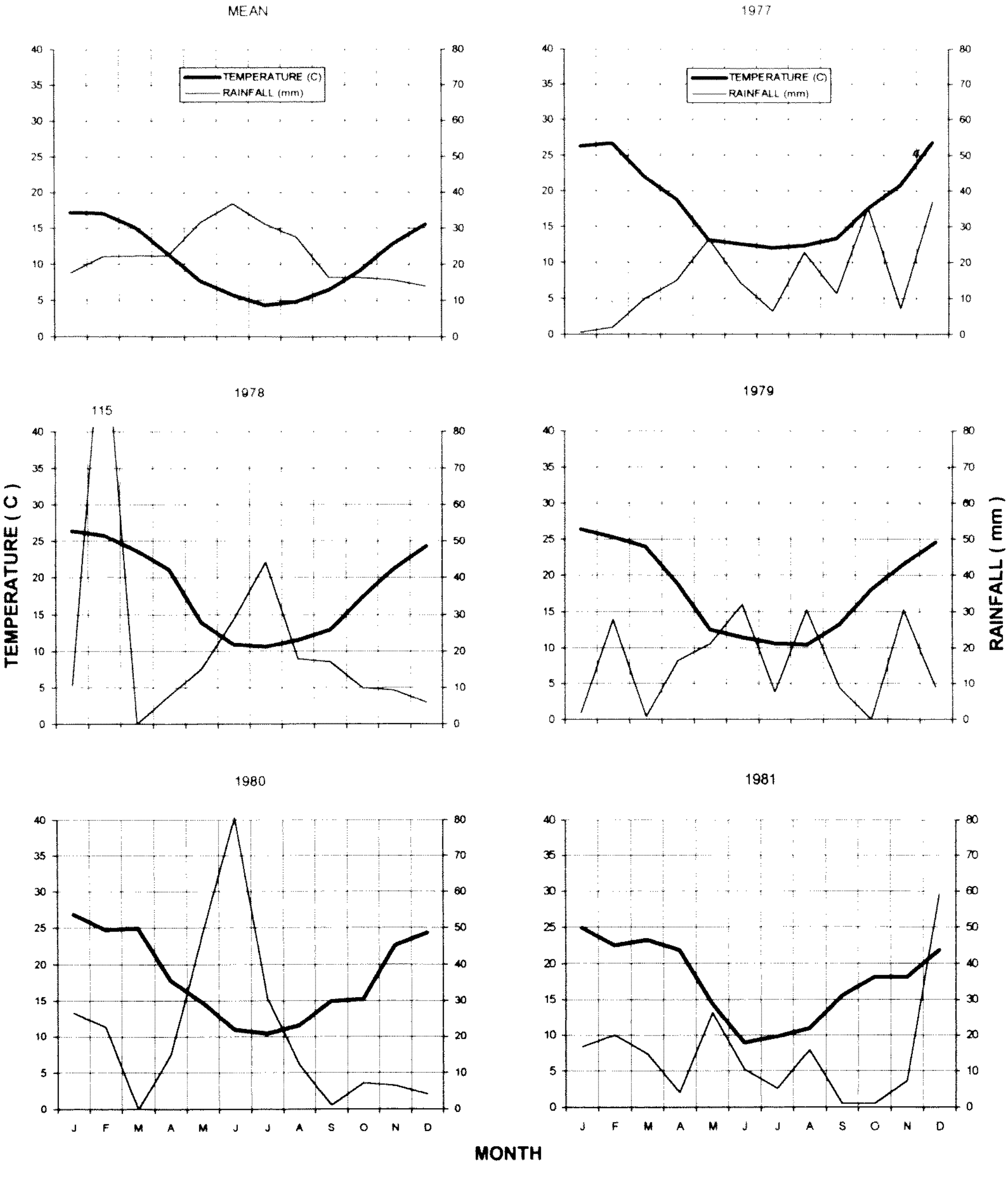

Figure 3 Ombrothermic diagrams showing the mean monthly rainfall and average monthly temperatures for the Boorabin-Southern Cross Study Area from 1977-1981 and the long term mean.

40 mm was recorded during December (1981), July (1978), May (1980) and June (1980). Substantial summer rain falls were recorded in February 1978 (115 mm).

Winds

Average wind speeds at both 0900 and 1500 are higher at Kalgoorlie (11-30 km/hour) than at Southern Cross (6-20 km/hour). The main directions are northerly during spring and summer, and variable during autumn and winter. Maximum wind speeds each month at Kalgoorlie (1939-1980) are about 60-80 km/hour. The highest speeds recorded were 138 km/hour (November 1979), 132 km/hour (October 1955) and 121 km/hour (May 1975). There were no sightings during field work of physical damage to the vegetation caused by strong winds.

Radiation

The average daily radiation during January grades from south (770 mWh. cm^{-2}) to north (800 mWh. cm^{-2}). During July the gradient is similar in direction (340-360 mWh. cm^{-2}) (Bureau of Meteorology, Australia 1988b).

Geology

The geology of the Study Area has been mapped and described in detail for Boorabbin (Sofoulis 1963) and Southern Cross (Gee 1979). The Study Area has been tectonically stable since the Proterozoic. The following elements are fundamental to landscape development and their associated vegetation:

(a) Most of the Study Area is underlain by Archaean or Proterozoic granites, and associated rocks. They have been eroded into gentle undulating plains and broad valleys covered with Tertiary soils. Exposures of bedrock are uncommon except north-east of Norseman.

(b) Much smaller in size are three areas of Archaean greenstone: south of Coolgardie, a north-south belt through Southern Cross and Marvel Loch, and the northern section of the Bremer Range. An important geological feature is the cap of concentrated iron minerals that forms the crest of Mt Caudan in the Parker Range. The feature, known as a gossanous cap, is rare and restricted to the vicinity of Mt Caudan (Gee 1979).

The term "granite", as used in this report, refers to all granitoid rocks. They all weather into similar soil types supporting similar types of vegetation without marked differences in species composition. "Gravel" refers to concentric concretions of iron oxides developed in the A horizon of soils during laterization of their profiles over deeply weathered granite. "Ironstone gravel" has developed during the laterization of greenstone.

The Study Area consists almost entirely of gentle undulating uplands dissected by broad valleys with chains of salt lakes, and occurs within the Salinaland of Jutson (1950). There is a very gentle regional slope from west (390 m) to east (450 m) near the northern boundary while the southern boundary has little variation (330-340 m). The whole landscape is very subdued with only a few chains of low hills i.e. Parker Range. The Study Area has not experienced marine transgression nor glaciation since the Permian (van de Graaff *et al.* 1977).

Drainage lines, only sighted occasionally west of Yellowdine, are indistinct on the flat floors of broad valleys. Thin deposits of alluvial sand indicate that flows only occur following very heavy rain. The chains of salt lakes in broad valleys are remnants of drainage lines that flowed during wetter periods in the geological past (van de Graaff *et al.* 1977). Some of the aeolian features of broad valleys have developed during the last major arid period, i.e. about 15,000 years ago (Bowler 1976).

Widespread laterization of deeply weathered granite is believed to have occurred during the Cainozoic (Mulcahy 1973). The widespread occurrence of gravel ridges and occasional small breakaways are evidence of laterization.

Landform Units

Newbey & Milewski (unpublished) have developed a classification of 10 landform units to describe the landscapes of the Eastern Goldfields. Six of these were present in the Study Area (Figure 2) and they are briefly described below. The units not present in the Study Area were Drainage Lines, Dunefields, Hills and Calcareous Plains.

The stratigraphic units distinguished by Sofoulis (1963) and Gee (1979) for the Boorabbin and Southern Cross map sheets (respectively) were too coarse to be useful in characterising the plant and vertebrate quadrats, so we have adopted the lithological classification used on an adjacent map sheet (Williams 1970) (see Tables 1 and 2).

Breakaways (B)

Breakaways occur where the deeply weathered granite that underlies the Sandplains is exposed. The exposure is truncated by a free and vertical face of bare rock 1-3 m high. Skeletal deposits of Gritty Loams occur on the rim, either filling small pockets or as sheets that grade into soils of the Sandplains. A pediment of colluvium has developed at the base of the exposure. Run-off from the exposure increases the moisture content of the pediment. Breakaways were rarely seen during field work. A feature, seen twice in the Study Area, was a rubble slope of *ca.* 5° on an exposed bedrock that underlies Breakaways. The rubble slope supported the same vegetation types as Breakaways.

Granite Exposure (G)

Exposures of granite range in topography and size from flat and a few metres across, to the domed of Cave Hill which rises about 90 m above the surrounding plain, and covers about 60 ha. The surfaces of exposures are mainly bare with scattered small pieces of exfoliated flat stone. Sheet deposits of skeletal soil have developed in the low-lying areas of the exposure. Due to the thinness of deposits (up to 30 cm), the soil becomes waterlogged and dries out more rapidly than the thicker soil profiles of surrounding plains. Run-off also increases the rate of waterlogging. Peripheral to the bedrock exposures are aprons of soils, to 1.5 m thick, that have primarily weathered *in situ* from the underlying granite. The rate of change in soil moisture content decreases as soil depth increases. Large exposures usually have 1-3 faint drainage lines where the soil is damp to waterlogged during winter. Others lack drainage lines and the run-off is shed evenly around the perimeter resulting in a narrow zone of soil (3-6 m) that may be damp or waterlogged for long periods during winter. Ephemeral pools, up to a few metres across and rarely more than 30 cm deep, occur on the exposures. Granite exposures are scattered throughout the Study Area with the highest concentration in the south-eastern section.

Table 1 Relationship between landforms, lithology, soils, vegetation structure and floristic composition at sites sampled or visited in the Boorabbin–Southern Cross Study Area.

Landform	Lithological Surface Boorabbin	Lithological Surface Southern Cross*	Soil	Vegetation Type	Vegetation Sites (Appendix 1)[a]
BREAKAWAY (B)					
Slopes and summits	Ts	Tl	Gritty Loams	*Eucalyptus capillosa* Low Woodland	BS1
	Tl, Ts, Tg	(K)**		*Eucalyptus loxophleba* Malllee	
GRANITE EXPOSURE (G)					
Skeletal soil sheets and inner aprons	Agu[b]	Agg[b]	Granitic Soils	Granite Complex	BS4a
Outer aprons	Agu[b]	Agg[b]	Granitic Soils	*Allocasuarina huegeliana* Low Woodland	
				Eucalyptus loxophleba Mallee	BS43a,BS43b
				Acacia acuminata Tall Shrubland	BS3,BS3a
				Acacia coolgardiensis Tall Shrubland	
SALT LAKE FEATURES (L)					
Lake floors	Qa, Ql	Ql	Saline Soils	*Halosarcia* Low Shrubland	BS11,BS11a
	Qrm (K)				
Lake slopes and dunes	Qa	Qd, Qa	Aeolian Sands	*Eucalyptus salicola* Low Woodland	BS7
	Qrs (K)			*Eucalyptus hypochlamydea* Mallee	
				Acacia lineolata Tall Shrubland	
				Dodonaea angustissima Tall Shrubland	BS10
	Qpk (K)		Gypsum Soils	*Callitris columellaris* Low Woodland	BS5
				Casuarina obesa Low Woodland	BS6
Aeolian sheet deposits and well-drained flats	Qrs (K)		Aeolian Sands	*Eucalyptus myriadena* Low Woodland	
				Eucalyptus gracilis Low Woodland	

SANDPLAIN (S)					
Plains	Ts	Ts	Deep Sands	*Eucalyptus burracoppinensis* Mallee	BS12
	Ts (K)			*Eucalyptus hypochlamydea* Mallee	
				Eucalyptus leptopoda Mallee	BS14
				Acacia beauverdiana Tall Shrubland	BS18,BS18b
				Acacia coolgardiensis Tall Shrubland	
				Allocasuarina corniculata Tall Shrubland	BS22
				Callitris preissii Tall Shrubland	BS23
				Grevillea excelsior Tall Shrubland	BS24
				Melaleuca uncinata Tall Shrubland	BS25
				Mixed *Grevillea* spp. Open Shrubland	BS26
			Shallow Sands	*Eucalyptus platycorys* Mallee	BS15
				Eucalyptus scyphocalyx Mallee	
				Eucalyptus transcontinentalis Mallee	
	Ts	Tl	Gravelly Sands	*Acacia beauverdiana* Tall Shrubland	BS18a
	Tg (K)			*Eucalyptus scyphocalyx* Mallee	BS16
UNDULATING PLAIN, GREENSTONE (UN)					
Colluvial flats	Qa^c	Qa, Qe^c	Shallow Calcareous	*Eucalyptus salmonophloia* Woodland	
	Qqz, Qqs	(K)	Earths	*Eucalyptus campaspe* Low Woodland	
				Eucalyptus dundasii Low Woodland	
				Eucalyptus flocktoniae Low Woodland	
				Eucalyptus lesouefii Low Woodland	BS30
				Eucalyptus longicornis Low Woodland	
				Eucalyptus melanoxylon Low Woodland	BS31
				Eucalyptus salubris Low Woodland	
Low rises and ridges	Ac, Af^c	Ac^c	Deep Calcareous	*Eucalyptus clelandii* Low Woodland	
			Earths	*Eucalyptus conglobata* Low Woodland	
				Eucalyptus corrugata Low Woodland	BS29
				Eucalyptus longicornis Low Woodland	
				Eucalyptus torquata Low Woodland	BS32
		Gossan Cap	Gritty Loams	*Hakea pendula* Tall Shrubland	BS33

Table 1 (cont.)

Landform	Lithological Surface Boorabbin	Southern Cross*	Soil	Vegetation Type	Vegetation Sites (Appendix 1)[a]
BROAD VALLEY (V)					
Drainage lines	Qa	Qa	Deep Calcareous Earths	*Eucalyptus loxophleba* Mallee	
	Qpv (K)				
Valley floors and slopes, and Aeolian sand sheets	Qc, Qe	Qc	Aeolian Sands	*Eucalyptus gracilis* Low Woodland	BS38
	Qqz, Qqs,			*Eucalyptus hypochlamydea* Mallee	BS13a
	Qpv, Qrs	(K)	Deep Calcareous Earths	*Eucalyptus salmonophloia* Woodland	BS35a,BS46,BS47
				Eucalyptus longicornis Woodland	
				Eucalyptus campaspe Low Woodland	BS36
				Eucalyptus flocktoniae Low Woodland	
				Eucalyptus longicornis Low Woodland	BS34
				Eucalyptus salubris Low Woodland	BS40,BS40a,BS39
				Eucalyptus transcontinentalis Low Woodland	BS41
				Melaleuca spp. Tall Shrubland	
Valley slopes	Qc, Qe	Qc	Shallow Sands	*Eucalyptus gracilis* Mallee	BS42
	Qps (K)			*Eucalyptus pileata* Mallee	BS44

[a] A total of 130 vegetation sites were sampled, of which a representative set of 42 are presented in detail as Appendix 1. The balance of the sampled sites are held as data sheets in the library at the W.A. Wildlife Research Centre, Dept. CALM, Perth.

* Lithological surfaces follow: Boorabbin (Sofoulis 1963) and Southern Cross (Gee 1979).

** (K) = Kurnalpi map sheet (Williams 1970), a more refined classification of surface stratigraphy units, used in an adjacent Study Area (see text).

[b] Includes: Agn, Apo (Boorabbin); Agp, Apz, Agl, Agv, Agb, Ago, Am, Ang, Anl (Southern Cross).

[c] Includes: Au, Aud, Afl, Acu, Abu (Boorabbin); Aln, Alp, Anb, Aap, Aah, Aad, Aab, Aub, Aur, Aux, Aup (Southern Cross).

Salt Lake Feature (L)

Salt lakes have flat floors of saline loams that are rarely covered with more than 15 cm of water. Peripheral dunes are 1-5 m high and stabilised by vegetation. They are most common on the eastern and southern margins of lakes. The remainder of most lake margins consists of a gentle slope. The soil types of both dunes and gentle slopes are Aeolian Sands to Loams. Loam, rich in gypsum, is present on the margins of some lakes. Flats consisting of alluvial or aeolian material are often marginal to salt lakes. There are two distinct types of flats, but intergradations are frequent. The main distinguishing factor is height above the salt lake floor (and saline water-table), which controls salinity and waterlogging.

(a) Saline flats - up to 30 cm above the salt lake floor, highly saline and damp to waterlogged.

(b) Well-drained flats - 30-120 cm above the salt lake floor and primarily of aeolian origin.

Salt Lake Features occur throughout most of the Study Area, mainly as continuous belts on the floors of major Broad Valleys.

Sandplain (S)

The undulating uplands, including the upper and middle valley slopes, are referred to as Sandplain. The dividing line between Sandplain and Broad Valley is the change of slope from erosional to colluvial. Sandplain slopes rarely exceeded 2° and the soil profiles are thick and laterized. Areas of Sandplain high in the landscape are the result of *in situ* weathering and consist of Gravelly Sands or Shallow Sands. Sandplains low in the landscape (Deep Sands) have a thicker A-horizon with a colluvial component derived from areas up-slope. Run-off only occurs over short distances following heavy and intense falls of rain. Sandplains are the dominant landform unit of the Study Area.

Undulating Plain, greenstone (UN)

These plains have weathered from greenstone into a series of low rises, ridges and small hills interspersed with narrow colluvial flats 30-300 m wide. Most rises and ridges are less than 5 m above the flats, and the hills rarely exceed 25 m. Slopes range from 2° to 8°, and small exposures of bedrock are frequent on relatively steep slopes and crests. Shallow Calcareous Earths cover the remaining slopes and crests. Colluvial flats consist of Deep Calcareous Earths. Undulating Plains occur in three areas: south of Coolgardie, a N-S tending belt through Southern Cross, and a small area of the Bremer Range along the Study Area's central southern boundary. The last area was not studied during this survey.

Broad Valley (V)

The valleys of a previous landscape have been filled with colluvium and alluvium which has been frequently reworked - including by aeolian action. Valley floors are now almost flat and the same soils extend up the valley slopes from 5 m to 20 m above floor level. Internal slopes rarely exceed 2°. A range of soil types form a mosaic in most places but the B horizon is always calcareous. Deep Calcareous Earths are the major soil group on the Broad Valley unit. Aeolian sands form extensive sheet-deposits that sometimes contain subdued sand dunes which have been stabilised by vegetation. Broad Valleys are widespread within the Study Area.

Table 2 Faunal survey areas of the Boorabbin–Southern Cross Study Area: sampling dates and methods*.

1. Jilbadgi survey area.

Fauna Code**	5–11 Feb, 1980	30 April– 5 May, 1981	18–23 Oct, 1981	20–21 Sep, 1993	Lithological Surface
7W01	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Qpv
7W02	Q (M,B,R)	Q (M,B,R) F	Q (M,B,R) F	R	Qpv/Agg
7W03	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Ts
7W04	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Tg
7W05	Q (M,B,R)	Q (M,B,R) F	Q (M,B,R) F	R	Qqz/Agg
7W06	–	F,B,R	F,B,R	R	Ts

2. Woolgangie survey area.

Fauna Code**	12–17 Feb, 1980	6–11 May, 1981	13–18 Oct, 1981	22–23 Sep, 1993	Lithological Surface
7E01	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	–	Qrm
7E01A	–	F,B,R	F,B,R	–	Qrm–Qrs
7E02	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Qqz
7E03	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Ts–Qrs
7E03A	–	F,B,R	F,B,R	–	Qrs–Ts
7E04	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Qqs–Qrs
7E05	Q (M,B,R)	Q (M,B,R)	Q (M,B,R)	R	Qpv
7E06	F,B,R	F,B,R	F,B,R	R	Ts
7E06A	–	F	F	–	Qrs

3. Boorabbin survey area.

Fauna Code**	13–18 July, 1980	24–29 March, 1981	24 Sep, 1993	Lithological Surface
BN1	Q (M,B,R)	Q (M,B,R)	R	Ts
BN2	Q (M,B,R)	Q (M,B,R)	R	Ts
BN4	Q (M,B,R)	Q (M,B,R)	R	Qqs
BN6	Q (M,B,R)	Q (M,B,R)	R	Qpv/Agu

* Q = Fauna quadrat (fenced pit lines and, adjacent, a 200 metre x 200 metre bird quadrat) that was sampled daily for five days as described in Biological Surveys Committee of Western Australia (1984).

M = Mammal trapline (9 Elliotts, 9 Break–backs, 3 Cages).

B = Bird searches.

R = Reptile searches.

F = Fenced pit line of six pits (4 shallow, 2 deep) with *ca.* 50 m drift fence. Set either in the quadrats as a second fence, or at sites other than quadrats.

** The inventory table at the beginning of Appendix 1 lists the vegetation site codes and corresponding fauna sites.

Soils

The soils of the Study Area have been discussed briefly by Northcote *et al.* (1968). The soil groups on the Sandplains are dominated by Deep Sands, Shallow Sands and Gravelly Sands. All have been largely formed by *in situ* weathering of granite. They are highly leached and well-drained with pH less than 6.5. Siliceous sands dominate their A horizons.

Well-drained Deep Calcareous Earths are common on the floors of Broad Valleys. The B horizon always has a pH of 8.0 or greater but the A horizon pH varies between 7.0 and 8.5. Even though the pH may exceed 8.0, and carbonate nodules may be present in either horizon, the soil is not always calcareous (i.e. effervesces when a few drops of HCl are added). Extensive thin sheets of Aeolian Sands are sometimes present.

The floors of salt lakes consist of Saline Soils of lacustrine origin, and any surrounding damp flats consist of Sub-saline Soils. Peripheral to most salt lakes are dunes and broad flats of Aeolian Sands and Loams.

Soils of the Undulating Plains on greenstone areas are calcareous and high in Mg and Ca. Colluvial flats consist of Deep Calcareous Earths while Shallow Calcareous Earths occur on the low ridges.

Granitic Soils, neutral to slightly acid, occur as skeletal or shallow deposits on or peripheral to exposures of granite bedrock. Somewhat similar Gritty Loams occur on Breakaways. The soil group present on gossanous caps is closest to Gritty Loams but has a higher loam content.

Freshwater

The only sources of permanent freshwater are dams of 2,000-10,000 m^2 capacity on farms, and a few small dams with catchments on exposed granite sheets near the old Merredin-Kalgoorlie railway line. South of Southern Cross, on a Broad Valley floor, are a few depressions that would contain water for 9-24 months after floods. The depressions are 80-200 m across and are in farmland.

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