II Physical Environment

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Climate

The Kurnalpi-Kalgoorlie Study Area has hot, dry summers and cool winters. Rain falls during both winter and summer (Figure 4). The climate of the Study Area has been classified as Hot Arid Desert (BWh) according to the Koppen scheme (Dick 1975). Alternatively, the climate is Sub-desert (attenuated) (UNESCO-FAO 1963), using the system of Bagnouls and Gaussen (1957). Beard (1972) regards the Study Area as "non-seasonal desert" in recognition of the mean distribution of rain through the year. Details of the annual variation of rainfall and temperature are given in Figure 4.

Meteorological data have been collected at several weather stations in the Kurnalpi-Kalgoorlie Study Area. The Study Area is well known climatically relative to the rest of the Eastern Goldfields (Bureau of Meteorology, Australia 1975).

Rainfall

Average annual rainfall in the Kurnalpi-Kalgoorlie Study Area grades from about 270 mm in the southwest to about 220 mm in the northeast. Kalgoorlie-Boulder receives a mean of 256 mm per annum. Although the mean rainfall is fairly evenly distributed through the year (slightly greater in winter than in summer), precipitation is unreliable and some years are much drier than others. Extremes recorded annually in Kalgoorlie are 123 mm and 488 mm, while those for Zanthus (to the southeast of the Study Area) are 44 mm and 543 mm.

During the cool time of year, rain falls lightly, associated with the passage of atmospheric depressions and their cold fronts arriving from the southwest. This type of precipitation decreases in amount and reliability towards the northeastern corner of the Study Area. Unreliable and sporadic rainfall is associated with thunderstorms at the warm time of year. In addition, heavy rains (50 - 150 mm) fall occasionally when tropical cyclones degenerate into rain-bearing depressions and cross the Study Area from the north. As an illustration of variability, the ratio of mean to median rainfall in January to April at Kalgoorlie varies from 2 to 4 (mean 2.5 for this four-month block). The importance of this type of deep-wetting albeit sporadic rainfall for the vegetation should not be underestimated. Associated with rainfall is the "growing period" which is approximately 0.2 months in the southwest and absent over the rest of the Study Area (Anon 1981).

An examination of monthly rainfall totals for the Kurnalpi-Kalgoorlie Study Area during 1978-1983 show that the Study Area received good rainfall during the present survey and the year preceding it (Figure 4). May, June and July are the months in which most winter rain falls. In 1980, Kalgoorlie received 251 mm during these months, a value 3.1 times higher than the mean of 81 mm.

Temperatures

Summers are hot with warm nights while winters are mild with cold nights and

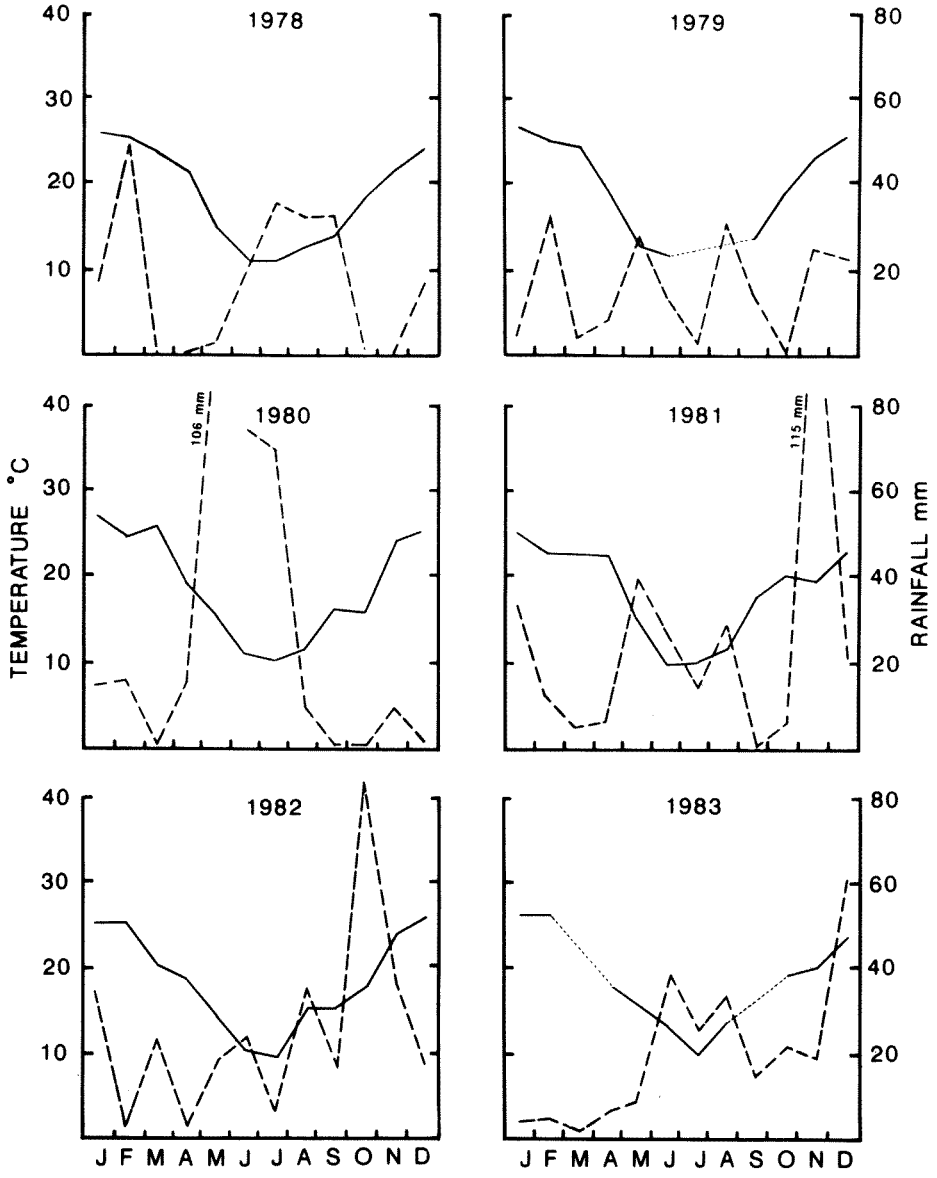

Figure 4 Ombrothermic diagrams showing the mean monthly rainfall and average monthly temperatures for the years 1978-1983 (Australian Bureau of Meteorology data).

frequent light frosts. Average annual temperature is about 18°C. Average maximum temperatures for each month range from 37°C (January) to 16°C (July). Average minima are 18°C and 5°C respectively. Recorded extremes of temperature for Kalgoorlie are 45°C and -3°C. Mean annual evaporation is 2400-2700 mm, increasing northwards within the Study Area (Anon 1981).

Winds

Wind in the Kurnalpi-Kalgoorlie Study Area blows mainly from the northeast or southeast, irrespective of the seasons. Average wind speeds at both 0900 hrs and 1500 hrs are 11 - 30 km/hr. Maximum monthly wind speeds at Kalgoorlie (1939-1980) are about 60-80 km/hour. Winds faster than 50 km/hour seldom last long. However, some squalls associated with thunderstorms may be capable of damaging the vegetation. The greatest speeds recorded were 138 km/hour (November 1979), 132 km/hour (October 1955) and 121 km/hour (May 1975). No evidence of trees broken by wind was seen during the survey.

Radiation

The average solar radiation at Kalgoorlie is about 800 mWh.cm^{-2} in July (Anon. 1975, Fitzpatrick 1979).

Geology

The rock types of the Kurnalpi-Kalgoorlie Study Area have been described and mapped in detail at a scale of 1:250 000 by Kriewaldt (1969) and Williams (1973), and jointly at a scale of 1:1 000 000 by Williams (1976). The area, tectonically stable since the Proterozoic, consists of several elements important in any study of landforms and vegetation. Much of the Study Area is underlain by Archaean "greenstone" (metabasalt, metadolerite, some ultramafics) consisting of relatively hard, resistant rocks varying considerably in mineral composition but all highly modified by heat and pressure (Bartram & McCall 1971, Hallberg 1972, Hallberg & Williams 1972, Williams & Hallberg 1973). Broad belts in the Study Area are underlain by Archaean or Proterozoic gneisses and granites deeply weathered in the Cainozoic (Tertiary) and partly replaced by lateritic materials and sand (Sofoulis 1966). The mainly north-northwest to south-southeast alignment of the metamorphic suites is cut across by two salt lakes representing the remnants of ancient major drainage lines (van de Graaff *et al.* 1977). The term granite as used here refers to all granitoid rocks, which weather into similar soils and support vegetation of similar structure and composition. Granite does not form hills in the Study Area although breakaways are present.

The Kurnalpi-Kalgoorlie Study Area, falling within Salinaland of Jutson (1950), is gently undulating. Altitude is about 400 m in the west sloping gradually to 150 m in the east, but a few individual hills of greenstone in the general vicinity of salt lakes rise more than 100 m above the surrounding countryside. The highest points in the Study Area are about 500 m above sea level (Kriewaldt 1969, Williams 1973). Surface drainage in the Study Area is mainly by short, abrupt creeklines running less than 10 km and diffuse areas where ephemeral water flows into the larger salt lakes on the rare occasions when

rainfall is enough to saturate the soil. The salt lakes in the broad flat bottoms of the valleys are 50-125 m below the level of a distinguishable upland plain (Brewer & Bettenay 1973, Gower & Bunting 1976). During past arid periods, ending about 15 000 years ago (Bowler 1976, Glassford & Killigrew 1979), material on the bottomlands was blown into extensive sheet deposits. These include some small dunes, the full expression of which is three concentric dune arcs, one of quartz sand, one of sandy clay and one of gypsum (calcium sulphate), not necessarily in that order (Glassford, pers. comm.). Salt lakes vary in size from less than 100 hectares to several thousand hectares, e.g. Lake Yindarlgooda. Their floors may be bare, or covered with up to 30 cm of water for short periods following abnormally heavy rains. High rates of evaporation maintain the high salt content of the bottomlands. The origin of the salt is partly the parent rocks and partly the atmosphere (F.J. Hingston, pers. comm.).

Landform Units

Newbey and Milewski have developed a classification of ten geomorphological units to describe the Eastern Goldfields (unpublished). The distribution of these landforms in the Kurnalpi-Kalgoorlie Study Area is shown in Figure 2.

Breakaways (B): Bluffs 3-4 m high with a free face, and scree slopes of 12-15°, are formed in lateritic deposits, generally over deeply weathered granitic rocks. Breakaways occur particularly in the east-central parts of the Study Area and generally form the southwestern edge of Sandplains, associated with Granite Exposures. The soil is gritty loam of variable depth, limited to shallow pockets in exposures of duricrust, or soil sheets on scree slopes. Colluvial soil at the foot of the bluff is relatively deep and may be waterlogged by run-off from above during rain events.

Dunefields (D): The disjunct areas of this landform distinguished in the Kurnalpi-Kalgoorlie Study Area are too small to be mapped (Figure 2). The isolated Dunefields marginally constitute a separate landform in sandy parts of Sandplains and Salt Lake Features. The deep sandy soils mainly form salt lake lunettes and contain variable amounts of gypsum (calcium sulphate). Extensive dunes of pure kopi with their extremely specialized vegetation are absent in the Study Area although they are present further north in the Eastern Goldfields.

Granite Exposures (G): Outcrops of bedrock, flat to low-domed, vary in size from a few square metres to 0.5 km^2. Gritty soils are directly weathered from the granite surface and form a peripheral apron. Granite Exposures are mainly bare although skeletal sheets of soil accumulate in slight depressions on the exposures of the rock or along faint washlines. Shallow aprons, consisting of soil profiles up to 2 m thick, weather *in situ*, and suffer alternate waterlogging and desiccation. Some subsurface areas of granite are not exposed but bear the distinctive vegetation of deep aprons. Granite Exposures are scattered throughout the Study Area and small Breakaways are associated with some of them (see above).

Hills (H): Features rising more than 30 m above the surrounding plains are regarded as Hills. Slopes are 5-15° and soil is largely skeletal and excessively drained with numerous small areas of bare rock. Hills are considered separately depending on the type of bedrock, including granite. The main Hills in the Study Area are located by Lake Yindarlgooda, north of Lake Rebecca and in the northwest (Wongi Hill). All are surrounded by Undulating Plains.

Salt Lake Features (L): Salt lakes are flat-floored with ephemeral water up to 30 cm after rain. Peripheral dunes, 1-4 m high, occur mainly on the southeastern margins. Most salt lakes represent former major drainage courses reduced to disjunct closed basins with extensive subsaline flats at a level slightly above the salt lake floor. The soil of Salt Lake Features has a complex history including colluvial, alluvial and aeolian influences and intermittent reworking, especially by wind during recent arid periods (Bowler 1976). Lake dunes, of fine and loose sand to clayey loam, are generally stabilised by vegetation. Sandy deposits are interrupted on the western margins of some salt lakes formed over greenstone. The lakes appear to be eroding the rock at this edge to produce an abrupt boundary with limited influence of salinity up to 1 m above the lake floor. The main salt lakes in the Kurnalpi-Kalgoorlie Study Area are Lake Yindarlgooda (south-central), Lake Rebecca (northeast) and the Black Flag-White Flag group (west-central), while Lake Goongarrie straddles the northern border.

Calcareous Plains (P): Flat areas with Deep Calcareous Earths of colluvial and alluvial origin, well-drained, are referred to as Calcareous Plains. Sandy soil is limited to small areas only. Deep soils on Undulating Plains are similar to Calcareous Plains although the topography is diagnostic: local relief on Calcareous Plains rarely exceeds 4 m. Calcareous Plains and Broad Valleys are distinguished with difficulty in the Kurnalpi-Kalgoorlie Study Area. The limits of the transgression by an Eocene sea are arbitrarily taken as the criterion, following Newbey (1984). As a result, Calcareous Plains are confined to the southeastern part within the Kurnalpi-Kalgoorlie Study Area.

Sandplains (S): Relatively pale, yellowish sandy deposits reworked relatively little since the Tertiary, derived by deep weathering and lateritisation, are regarded as Sandplains. Sheets or dunes of sand of recent origin, for example in Salt Lake Features, are not considered part of this landform. Texture varies; in places ferricrete, pisolitic gravel or lime hardpan are prominent in the subsoil. However, the soil is freely drained and extremely poor in all nutrients throughout. Sandplains are usually associated with granite bedrock and grade into Broad Valleys and Granite Exposures, or are abruptly bounded by Breakaways. Dunes are generally absent from Sandplains in the Kurnalpi-Kalgoorlie Study Area although Dunefields are commonly found within this landform further north in the Eastern Goldfields. Deep, relatively yellow, purely siliceous earthy or loamy sands, slightly loamier and redder at depth than at the surface, are found on some gentle slopes. Sandplains occur in several separate parts of the Study Area; mainly the east-central part, but also the north and east, and the northwest and southwest corners.

Undulating Plains (U): Differential weathering of the greenstone bedrock has resulted in series of low rises with local relief of 2-30 m and shallow soil on slopes of 5-15°, separated by flats with deep calcareous earths and drained by frequent narrow creeklines. In the south of the Study Area, rises 2-3 m high are formed of relatively resistant metabasalt, while the intervening flats are formed of relatively easily eroded ultrabasics. Fairly steep slopes have shallow stony and gravelly loam with exposures of bedrock. There is generally some accumulation of calcium carbonate at the interface between soil and bedrock, particularly in the north of the Study Area. This is exposed as a hardpan over small areas. Soil derived from greenstone is generally rich in bases although poor in nitrogen, available phosphorus and exchangeable potassium. Undulating Plains dominate the western, south-central and southern parts of the Study Area and extend in broad tongues north-northwestwards, for example east and west of Lake Rebecca.

Broad Valleys (V): This landform consists of virtually flat areas with a largely rock-free, loamy soil, usually of mixed colluvial, aeolian and alluvial origin. Soil depth varies although lime nodules or hardpan are present throughout all but the sandiest Broad Valley soils in the Kurnalpi-Kalgoorlie Study Area. On relatively high-lying parts of Broad Valleys the soil may be shallow over hardpan. Overlying areas of granitic rocks are broad, saucer-shaped valleys, 3-5 km wide with internal relief usually less than 20 m and slopes rarely exceeding 2°. Broad Valleys are well-drained, mainly by sheet movement of water following heavy rainfall. Deep calcareous earths form the main soil in the south, in places covered with siliceous topsoil such as neutral loam or sand. The subsoil nodules of calcium carbonate found in the south give way to hardpan further north which becomes progressively less calcareous and more siliceous. Broad Valleys are widely distributed in the Kurnalpi-Kalgoorlie Study Area.

Soils

The soils of the Kurnalpi-Kalgoorlie Study Area have been described in general terms by Stace *et al.* (1968) and Campbell *et al.* (1975), and mapped by Northcote *et al.* (1968). Soils rich in magnesium and calcium are widespread in the Study Area, especially over greenstone. Soils are skeletal to shallow where either greenstone or granite break the surface. Saline and subsaline soils on the one hand, and deep sands on the other, are also fairly widespread.

The soils of the Study Area cannot be understood without a knowledge of their history. The land surface is substantially the same as it was under a far moister climate in the Tertiary, a time when fine particles and cations were leached out of soil profiles and lateritic podzols were formed. The Tertiary landform is preserved in the Sandplains (and Breakaways) found in the Study Area, and has left its mark on other landforms with respect to their nutrient poverty. However, present-day climate has modified all soils in the Study Area, including the lateritic sandy surfaces. They currently share the qualities of loaminess or earthiness, dark colour (generally red), neutral to alkaline reaction trend in the subsoil, and the lack of an eluvial (leached) horizon. Sands in the Study Area vary

Table 1 Relationship between landforms, stratigraphy, soils, vegetation structure and floristic composition in the Kurnalpi-Kalgoorlie Study Area. Stratigraphy follows Kriewaldt (1969) and Williams (1973). (p) = in part.

Landform	Stratigraphy		Position in landform	Soil	Vegetation Type
	Kalgoorlie	Kurnalpi			
BREAKAWAYS (B)	Qpz,Qpy	Ts(p),Tg(p), Qqz(p)	Whole feature	Shallow Calcareous Earths	Breakaways Complex
				Granitic Soils	*Acacia aneura* Tall Shrubland
DRAINAGE LINES (C)	DOES NOT OCCUR				
DUNEFIELDS (D)	Qas	Qrs(p),Qpk(p)	Peripheral lake dune	Aeolian Sands	*Acacia aneura* Low Woodland *Casuarina cristata* Low Woodland
				Aeolian Loams	*Callitris columellaris* Low Woodland
GRANITE EXPOSURES (G)	Ag	Ag	Skeletal soil sheet and inner apron	Granitic Soils	Granite Exposures Complex
	Ag	Agb	Outer apron	Granitic Soils	*Acacia* spp. Tall Shrubland *Eucalyptus* spp. Mallee
	Qqz(p)	Qpm(p),Ag	Colluvial/alluvial flat	Shallow Calcareous Earths	*Acacia* spp. Tall Shrubland over *Atriplex* spp. Low Shrubland
	Qpz(p)	Qpm(p)	Soil mantle over sub-exposures	Shallow Sands	*Eucalyptus* spp. Mallee over *Triodia scariosa* Hummock Grassland
HILLS (H)	Ats,Ab,Av,An, Ar,Ah	A1b,A1d,A1, A2h,A2m	Slopes and crest	Granitic Soils	*Acacia quadrimarginea* Tall Shrubland
				Shallow Calcareous Earths	*Casuarina cristata-Acacia aneura* Low Woodland
				Red Sands	*Acacia acuminata* Tall Shrubland
SALT LAKE FEATURES (L)	Qrb(p),Qra	Qrm,Qpv	Lake margins and floors, and saline flats	Saline Soils	*Halosarcia* spp. Low Shrublands
	Qrb,Qpv	Qpf	Damp flats or claypan	Red Cracking Clays	*Cratystylis subspinescens* Low Shrubland
			Outer lake edge	Aeolian Loams	*Atriplex* spp. Low Shrubland

Table 1 (cont).

Landform	Stratigraphy Kalgoorlie	Stratigraphy Kurnalpi	Position in landform	Soil	Vegetation Type
	Qas	Qrs	Well-drained flats	Aeolian Loams	*Casuarina cristata* Low Woodland
	As,Ak,Qqq,Qpv Avp,Qpa	A1v,A2b	Outer lake slope	Shallow Calcareous Earths/Subsaline Soils	*Eucalyptus lesouefii-E. clelandii* Low Woodland
	Qas	Qpk	Peripheral lake dune	Aeolian Sands	*Eucalyptus oleosa* Mallee over *Triodia scariosa* Hummock Grassland
CALCAREOUS PLAINS (P)	-	Qpz,Qpl	Plain	Deep Calcareous Earths	*Eucalyptus lesouefii-Casuarina cristata* Low Woodland *Eucalyptus longicornis-E. salmonophloia* Woodland *Eucalyptus salubris* Low Woodland
	-	Qpv	Plain	Shallow Calcareous Earths	*Eucalyptus longicornis* Low Woodland
	-	Qpz	Colluvial flat	Deep Calcareous Earths	*Eucalyptus salmonophloia* Woodland over *Maireana sedifolia* Low Shrubland
SANDPLAINS (S)	Qts,Qps	Qps,Qpa,Ts	Gentle slope	Deep Sands	*Eucalyptus oldfieldii* Mallee over *Triodia scariosa* Hummock Grassland
				Deep Calcareous Earths	*Eucalyptus transcontinentalis* Low Woodland
	Qtg	Tg,Ts	Level upland	Deep and Gravelly Sands	*Eucalyptus leptopoda - Acacia* spp Tall Shrubland *Allocasuarina* spp. Tall Shrubland

Table 1 (cont).

Landform	Stratigraphy Kalgoorlie	Stratigraphy Kurnalpi	Position in landform	Soil	Vegetation Type
UNDULATING PLAINS (U)	Qqq,Qqz	Qqf,Qqc	Colluvial flat/ faint creekline	Deep Calcareous Earths	*Eucalyptus lesouefii* - *Casuarina cristata* Low Woodland over *Maireana sedifolia* Low Shrubland
	An,At,Ah,Ab As,Au,Ar Qqq,Qqs	Abu,Alb Alo,A2b A3	Ridge and narrow valley	Shallow Calcareous Earths	*Eucalyptus clelandii* - *Eucalyptus lesouefii* Low Woodland *Eucalyptus torquata* - *Eucalyptus lesouefii* Low Woodland
				Granitic Soils	*Acacia aneura* - *Acacia brachystachya* Tall Shrubland *Acacia* spp. Tall Shrubland
	Qtl,As	Tl,Qqs	Ridge, slopes	Shallow Calcareous Earths	*Casuarina cristata-Acacia aneura* Low Woodland *Eucalyptus oleosa* - *Casuarina cristata* Low Woodland
	Qqq,Qqz	Qqc	Colluvial flat	Deep Calcareous Earths	*Eucalyptus salmonophloia* Woodland over *Maireana sedifolia* Low Shrubland
	Qpa,Qpy,Qpv	Qpv	Colluvial flat	Red Cracking Clays	*Eucalyptus salubris* Low Woodland over *Atriplex* spp. Low Shrubland *Maireana pyramidata* Low Shrubland
BROAD VALLEYS (V)	Qpv,Qqs	Qpv	Alluvial flat	Deep Calcareous Earths	*Eucalyptus salubris* Low Woodland
	-	Qqz	Gentle slope	Red Earths	*Eucalyptus oleosa* - *Casuarina cristata* Low Woodland
	Qqs	Qqs,Qpl	Alluvial flat	Deep Calcareous Earths	*Eucalyptus salmonophloia* Woodland over *Maireana sedifolia* Low Shrubland *Eucalyptus longicornis* Woodland *Eucalyptus transcontinentalis* - *Eucalyptus flocktoniae* Low Woodland
	Qqz	Qqz,Qpm	Gentle slope	Red Earths Deep Calcareous Earths	*Acacia aneura* Low Woodland *Eucalyptus concinna* - *Eucalyptus oleosa* Low Woodland

from neutral to alkaline depending on the concentration of calcium and other bases recently acceded by aeolian action under an arid climate.

The soils of the Kurnalpi-Kalgoorlie Study Area may be summarized in terms of the classification of Northcote *et al.* (1968). On Salt Lake Features there is a variety of types of loamy or sandy soil of minimal profile development. Bottomlands are gypsous and saline loams (Uml.1, Uml.2, Uml.3), changing to Gn on the lake bed itself. Sands present as aeolian dunes peripheral to salt lakes are classed as sandy red earths (Gn 2.13). Plains surrounding the salt lakes have gradational soil profiles (Gcl.22), becoming duplex on "eroded plains" (Drl.33). Scattered small clay pans are classed as Uf soils. Proceeding upslope to Broad Valleys, we find red earths (Gn2.13) differing slightly in the moister southern and drier northern parts of the Study Area. The former have a neutral reaction trend and give way in places to alkaline non-calcareous massive earths. The latter are alkaline and neutral red earths, often with a surface scatter of gravel and a red-brown hardpan (Gn2.12). Pediments with areas of Broad Valleys have a similar red-brown hardpan but are regarded as Um5.3. Undulating Plains and Sandplains form the higher lying landforms.

Concave surfaces on Undulating Plains adjacent to Broad Valleys have alkaline red earths with limestone or lime nodules at shallow depths (less than 60 cm) (Gn2.13). These grade to shallow brown and grey-brown calcareous earths with weathered rock at shallow depths on rises (Gcl.12), and to shallow calcareous loamy soils (or powdery calcareous loams less than 60 cm deep) (Um5.11) on exposed ridges. Narrow valleys and clay plains flanking outcrops of ultrabasic rocks are heavy in texture (Ug5.38). The steepest slopes on Undulating Plains we classed as Um5.41, and the highest points on this landform, constituting Hills of basic rocks, have soils similar to those on the rises and ridges referred to above but including examples of Gcl.12 and Uml.43. Finally, Sandplains have red or yellow sands with an earthy fabric (or earthy sands) classed as Uc5.2.

Table 1 shows the relationship between landforms, stratigraphy, soils, vegetation structure and floristic composition in the Kurnalpi-Kalgoorlie Study Area.

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