THE SURVEY

Methodology (H.J.R. Pringle')
Geomorphology (H.J.R. Pringle')
Soils (A.M.E. Van Vreeswyk')
Vegetation (H.J.R. Pringle')
Ecological assessment (H.J.R. Pringle')
Land systems (H.J.R. Pringle', A.M.E. Van Vreeswyk' and S.A. Gilligan')
Resource condition (H.J.R. Pringle')

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Methodology

H.J.R. Pringle

General approach

This survey adopted an integrated survey method (McKenzie 1991) involving the land system approach to rangeland description and evaluation. Land system mapping was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Christian and Stewart 1953, 1968) and has been widely used in previous rangeland surveys in Western Australia by CSIRO (Speck et al. 1960, Mabbutt et al. 1963, Speck et al. 1964 and Stewart et al. 1970) and in joint Department of Agriculture, Western Australia (DAWA) - Department of Land Administration, Western Australia (DOLA) rangeland surveys which are commissioned by the Pastoral Board of Western Australia (Wilcox and McKinnon 1972, Payne et al. 1979, Payne et al. 1987, Payne et al. 1988, Payne and Tille 1992, and Curry et al. 1994).

Christian and Stewart (1953) define a land system as 'an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation'. Land systems consist of smaller land units, each of which has a distinctive aerial photo pattern. The relative proportions of constituent land units and their spatial arrangement relative to each other form characteristic patterns on aerial photography and may also be recognisable on remotely sensed satellite imagery.

Initial research of available information

A broad appreciation of the land types to be surveyed was gained from collected information on the geology, geomorphology, soils and vegetation of the survey area. Many sources of information were used including Beard's 1:1,000,000 Vegetation Series (1974, 1975, 1976), the 1:250,000 map series produced by the Geological Survey of Western Australia (Bunting and Williams 1974, Bunting and Chin 1979, Gower 1976, Kriewaldt 1970, Thom and Barnes 1977, Williams et al. 1976), the Atlas of Australian Soils series (Northcote et al. 1988), CSIRO Land Research Series reports (e.g. Mabbutt et al. 1963, Churchward 1977), the Biological Survey of the Eastern Goldfields of Western Australia series (e.g. Dell et al. 1988, Dell et al. 1992) and much unpublished data held within the records of DOLA and DAWA.

Based on information gained from the sources mentioned above, broad land classifications were derived and tentative land types/systems were mapped on black and white aerial photographs. Most of the aerial photography was at 1:50,000 scale with some at 1:86,000 scale. All photography had been flown more recently than 1983, with most being flown in 1988 or 1989.

Reconnaissance field work

Two reconnaissance field trips, undertaken in June and July 1988, were planned so as to visit as many as possible of the major land types identified during the initial research phase. During these trips, extensive traverse notes on vegetation and landforms were recorded and 107 inventory sites were selected, at which detailed information on soils, landform and vegetation were recorded. Land system descriptions were gradually developed as the survey team became more familiar with the survey area.

After the reconnaissance field work was completed, an ecological classification ('site type') was developed, based on the classification and ordination of floristic as well as limited soil and landform data collected at inventory sites during the reconnaissance trips. The classification was used in subsequent field classification of sites and became the basis of resource condition assessment and analysis. New site types were added to the classification as they were encountered. Furthermore, sampling techniques, reviewed and modified after the reconnaissance trips, were evaluated and finalised in readiness for the first main field trip.

Many plant specimens were collected during the reconnaissance trips. Following identification by Herbarium staff at the Department of Conservation and Land Management, a field herbarium was prepared. It was maintained and updated with new identified specimens throughout the main survey field work.

Main field work

The main field work component was carried out between September 1988 and June 1990 and consisted of 11 trips of three weeks duration in which the survey team operated on a daily basis out of one or two bases (generally shearers' quarters) per trip.

The survey team typically consisted of two advisers and a technician from the Department of Agriculture and a surveyor, a draftsman/navigator and a senior survey hand from the Department of Land Administration. A botanist from the Department of Conservation and Land Management accompanied the team on the first reconnaissance trip and first main trip.

Before each field trip, the broad land types initially identified in the office were re-interpreted as land systems onto 1:50,000 black and white aerial photographs covering the area to be visited. The traverse routes, with condition and inventory sites selected along them, were pre-planned for pastoral leases to be covered in any one trip. This allowed the survey team to notify pastoralists in advance of our arrival, thus providing them time to set aside at least one day to accompany the team in the field.

Traverses

Traverses were generally planned on a station basis, firstly trying to cover all land systems in proportion to their extent, and secondly to ensure that any areas of particular interest, such as areas with unusual photo
patterns or suspected severe degradation and erosion were visited. Traverse routes are presented in Figure 1. They reveal less intense traversing of areas characterised by spinifex hummock grasslands and other associations not generally well developed for pastoralism. Access is typically poorer than in more pastorally valued country.

Individual pastoralists accompanied the survey team along traverses on their stations. This provided a very useful opportunity for the survey team to explain the methods and purpose of the survey and to take advantage of the pastoralists' often extensive local knowledge of the area.

Each day, about 80 km of traverse were completed and about seven preselected sites (inventory and condition sites), were visited. During traversing, the land system boundaries, previously interpreted on aerial photographs in the office, were verified and amended as necessary. Minor detours from the traverse route were made frequently to check the position of station improvements (for mapping purposes) and land system boundaries.

The resource condition of an area of approximately 50 m radius around the vehicle was visually assessed at kilometre intervals. Station, paddock, land system and land unit were recorded, along with comments.
relating to subjects such as resource condition, vegetation, soil and evidence of the presence of feral animals.

The resource condition was recorded as a three-digit assessment according to the criteria detailed in Table 1. The soil erosion type/intensity scale used was adapted from the Western Australian Rangeland Monitoring System (WARMS) for arid shrublands (Hacker 1988).

### Table 1. Resource condition criteria for visual traverse assessments

1. **Measure of area affected by erosion**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No accelerated erosion present</td>
</tr>
<tr>
<td>1</td>
<td>Slight erosion (&lt; 10% of site affected)</td>
</tr>
<tr>
<td>2</td>
<td>Minor erosion (10-25% of site affected)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate erosion (25-50% of site affected)</td>
</tr>
<tr>
<td>4</td>
<td>Severe erosion (50-75% of site affected)</td>
</tr>
<tr>
<td>5</td>
<td>Extreme erosion (75-100% of site affected)</td>
</tr>
</tbody>
</table>

2. **Type of erosion present (dominant type recorded)**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Erosion characteristics present</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No erosion</td>
</tr>
<tr>
<td>A</td>
<td>Microterracing/sheeting</td>
</tr>
<tr>
<td>B</td>
<td>Scalding/capping</td>
</tr>
<tr>
<td>C</td>
<td>Pedestalling</td>
</tr>
<tr>
<td>D</td>
<td>Rilling/guttering</td>
</tr>
<tr>
<td>E</td>
<td>Guttering/gullying</td>
</tr>
<tr>
<td>F</td>
<td>Accelerated accretion of soil material</td>
</tr>
<tr>
<td>M</td>
<td>Mining (mention type of disturbance in notes)</td>
</tr>
</tbody>
</table>

3. **Vegetation condition rating**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Condition indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent or very good For the land unit-vegetation type (site type), the site's cover and composition of shrubs, perennial herbs and grasses is near optimal, free of obvious reductions in palatable species or increases in unpalatable species liable to reduce production potential.</td>
</tr>
<tr>
<td>2</td>
<td>Good Perennials present include all or most of the palatable species expected; some less palatable or unpalatable species may have increased, but total perennial cover is not very different from the optimal.</td>
</tr>
<tr>
<td>3</td>
<td>Fair Moderate losses of palatable perennials and/or increases in unpalatable shrubs or grasses, but most palatable species and stability desirables still present; foliar cover is less than on comparable sites rated 1 or 2 unless unpalatable species have increased.</td>
</tr>
<tr>
<td>4</td>
<td>Poor Conspicuous losses of palatable perennials; foliar cover is either decreased through a general loss of perennials or is increased by invasion of unpalatable species.</td>
</tr>
<tr>
<td>5</td>
<td>Very poor Few palatable perennials remain; cover is either greatly reduced, with much bare ground arising from loss of stability desirables, or has become dominated by a proliferation of unpalatable species.</td>
</tr>
</tbody>
</table>

The extent of soil erosion and vegetation condition indices have been integrated to form a single resource condition index. The slight (class 1) and minor (class 2), and the severe (class 4) and extreme (class 5) erosion classes were amalgamated for simplicity. Thus only four classes of soil erosion were considered: nil, minor, moderate and severe. The combinations and their resultant resource condition classes are displayed in Table 2. (The resource condition scores are summarised by land system in the 'Resource condition' chapter of this report.)

### Inventory sites

Inventory sites were selected to sample each land unit of each land system and to accommodate inherent variation according to the following criteria:

- Aerial photo pattern and associated land system and unit.
- Progressive coverage of all land systems' units; and
- The relative extent of the land system and unit.

The locations of inventory sites across the survey area are presented in Figure 2.

A total of 742 inventory sites were conducted. At each site information was collected on general surface geology, landform characteristics, soil surface characteristics, the extent of any accelerated erosional features, soil profile and vegetation cover and composition. These characteristics were entered on a standard record sheet derived from those used by Curry et al. (1994). More specifically, the following features were recorded.

**General:**
- aerial photograph - year, run and number;
- site number;
- land system and unit;
- station;
- 1:250,000 map sheet name;
- date;
- compass bearing in the direction of ground photograph;
- resource condition.

**Physical environment:**
- slope (in per cent);
- geology (according to 1:250,000 Geological Survey series);
- site geology - if different to the above;
- surface mantle abundance, shape, size and type;
- outcrop abundance and type;
- accelerated erosional features and their extent;
- extent and type of surface crusting;
- unit relief.
Vegetation:
- evidence of fire disturbance;
- site type;
- projected foliar cover class of perennial shrubs (see Curry et al. 1983);
- the dominant species and relative dominance of each stratum;
- basal cover class for perennial grasses;
- list of perennial plant species.

Soil:
- Principal Profile Form (Northcote 1979);
- total soil depth;
- soil substrate;
- soil surface condition;
- details of pans; type and structure;
- soil reaction trend;
- observation method;
- details of each soil horizon; horizon designation, depth, texture and texture group, moist colour (according to Munsell Soil Color Charts 1954), soil moisture status, consistence, porosity, fabric, structure, ped shape, boundary distinctness, effervescence with concentrated hydrochloric acid, pH (using the Raupach and Tucker (1959) method) and coarse fragments and segregations (abundance, shape, size and type).

Furthermore, notes and landscape sketches were made on an ad hoc basis with regard to such subjects as recent recruitments, changes in the vegetation, evidence of disturbance, management impacts and pressures, ephemeral growth and surrounding terrain.

Inventory site data were relied upon heavily in developing detailed land system descriptions including characteristics such as susceptibility to erosion and variation in soil and vegetation characteristics within land units of a particular land system.

Condition sites
Condition sites (643) were selected according to a stratified sampling by the following criteria:
- Distances from permanent stock water (1, 2, 4 or > 5 km).
- Land system representativeness on the station and in the paddock being traversed; and
- Adequate landform development of the unit to be sampled to enable the consistent selection of sites without noticeable internal environmental gradients.

Their distribution across the survey area is presented in Figure 3.

Two main techniques were applied at condition sites, depending on the type of vegetation being sampled. At succulent shrub sites and wanderrie grass sites, the plants were generally too dense to count in the limited time available; the species were listed and their relative dominance by cover (basal cover with grasses) were ranked. At sparse shrubland sites, perennial shrub species were counted, usually in two 500 m² quadrats. At most sparse shrubby grassland sites, the shrubs were counted and the grasses ranked by species according to visually assessed basal area.

Table 2. Combined extent of erosion/vegetation condition scores and their resultant resource condition scores

<table>
<thead>
<tr>
<th>Extent of soil erosion</th>
<th>Very Good (1)</th>
<th>Good (2)</th>
<th>Fair (3)</th>
<th>Poor (4)</th>
<th>Very poor (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil (0)</td>
<td>Good 1</td>
<td>Good 1</td>
<td>Fair 2</td>
<td>Poor 3</td>
<td>Poor 3</td>
</tr>
<tr>
<td>Minor (1, 2)</td>
<td>Good 1</td>
<td>Good 1</td>
<td>Fair 2</td>
<td>Poor 3</td>
<td>Very poor 4</td>
</tr>
<tr>
<td>Moderate (3)</td>
<td>Fair 2</td>
<td>Fair 2</td>
<td>Poor 3</td>
<td>Very poor 4</td>
<td>Very poor 4</td>
</tr>
<tr>
<td>Severe (4, 5)</td>
<td>Poor 3</td>
<td>Poor 3</td>
<td>Very poor 4</td>
<td>Very poor 4</td>
<td>Very poor 4</td>
</tr>
</tbody>
</table>
Figure 2. The distribution of inventory sites across the survey area.
Figure 3. The distribution of condition sites across the survey area.
Other site characteristics recorded at condition sites were:

- aerial photograph - year, run and number;
- site and traverse number;
- land system and unit;
- station;
- site technique(s);
- 1:250,000 map sheet name;
- date;
- paddock and quadrant;
- site type;
- quadrat area (where applicable);
- type and extent of erosion features;
- visual vegetation condition assessment (Table 2);
- extent and types of cryptogamic crusting;
- evidence of the influence of fire;
- distance from water;
- projected foliar cover class of perennial shrubs (see Curry et al. 1983);
- basal cover class for perennial grasses;
- vegetation strata, their dominant species and relative dominance with respect to foliar cover.

For each species listed and then ranked or counted, the following additional information was also recorded:

- indicator value (Table 3);
- recent and historic grazing levels;
- population structure.

### Table 3. Species indicator values

<table>
<thead>
<tr>
<th>Indicator Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>D - Decreaser</td>
<td>Highly palatable species whose cover and density decline under excessive grazing pressure. A high proportion of decreaser species in the stand indicates good resource condition.</td>
</tr>
<tr>
<td>N - No Indicator Value</td>
<td>Species which are generally not grazed and hence are not affected by grazing pressure except in extreme situations.</td>
</tr>
<tr>
<td>I - Intermediate</td>
<td>Moderately palatable species which, under grazing, initially increase relative to decreaser species or increase in absolute terms as they utilise niches vacated by (more palatable) decreasers. Intermediate species may dominate the stand. They decline under extreme grazing pressure, and are common plants in areas regenerating from severe degradation.</td>
</tr>
<tr>
<td>U - increaser</td>
<td>Generally unpalatable species which increase in number and cover as decreaser species decline under excessive grazing. Also common in disturbed (e.g. fire) areas. A high proportion of unpalatable increaser species in the stand indicates poor resource condition or a recently disturbed site.</td>
</tr>
</tbody>
</table>

There was also provision for the recording of notes, particularly those providing some interpretation of the resource condition data collected.

### Analysis of field data

The collation, summarising and further analysis of the data involved data processing using WARIS (Rosenthal et al. 1988), pattern analysis using PATN (Belbin 1989) and statistical testing using SYSTAT (Hill 1990) and ParaStat (Financial Modelling Services 1990).

The traverse, inventory site and condition site data were used to describe land systems, land units and patterns of resource condition.

#### Traverse data

The primary analytical use of the traverse data was the derivation of resource condition statements for each land system, land unit, station and for the whole survey area. This process involved sorting the data by these attributes.

Traverse data were also relied upon heavily in developing descriptions for lightly sampled land systems such as some of those restricted to the extreme south-west of the survey area. When summarised, the land unit recordings at each kilometre provided some insight into the proportional area of each land unit in land systems. The recording of the presence of mining and mining exploration activities allowed for some quantification of the extent and pattern of mining impacts in the survey area. Whether the mining impact was benign or detrimental to the environment was not assessed, rather it was seen as a reason not to evaluate resource condition at that particular traverse point.

#### Inventory site data

Detailed description of land systems, landforms, vegetation and soil was the major use of these data. The soil classification and descriptions used in this report were derived by summarising and sorting of soil data. The land system descriptions were produced by the development of detailed land unit descriptions based largely upon the inventory site data.

#### Condition site data

Condition site sampling, conceived by P.J. Curry and first implemented in the rangeland survey of the Murchison River Catchment (Curry et al. 1994) provided a means of quantitatively calibrating visual resource condition assessments within the major site types sampled at condition sites. Furthermore, the extensive data collected according to paddock quadrant, distance from water and site type, allowed for the testing of widely held, but sometimes not thoroughly tested, perceptions of resource condition dynamics. For some site types, classification and trend analysis was conducted using modules of PATN analysis package.
The approach to analysing range dynamics has been to select attributes shown to be sensitive to grazing and use them to classify condition sites within selected site types. The approach is fundamentally ecological in that some of the variables reflect ecological processes rather than standing forage availability. There are several instances, however, where palatable density has been used, which reflects this attribute's sensitivity to grazing rather than an attempt to include a measure of current pastoral value in the analyses.

The classification of sites results in range classes based largely on quantitative data selected by objective methods. The resultant classes are not necessarily real condition states (Westoby et al. 1989) of their site types, however, they do provide information on how grazing sensitive attributes are distributed together. The classification process reduces the variation across all sites, within a site type, into a small number of classes whose attributes whose attributes can be usefully compared to reveal how grazing affects the various site types for which there were sufficient data to conduct analysis.

The method of analysis was kept as objective as possible; first, by equally weighting all selected attributes and standardising their values down to a scale of 0 to 1, and second, by picking thresholds on classification dendrograms at which there were no agglomerations and a practicable number (4 to 6) of classes were generated. Summaries of these classes' attributes are presented for 10 major site types in the 'Ecological assessment' chapter.

Resource mapping

The survey area was covered by an extensive mapping program to produce two separate map products, i.e. 1:100,000 station plans (not presented here) and 1:250,000 coloured land system resource maps which accompany this report.

Existing aerial photography flown in October 1984 was available for the Menzies 1:250,000 map sheet and new photography was obtained in 1988/89 for the Leonora, Laverton, Edjudina, Duketon and Sir Samuel sheets.

Topography data capture

Aerial photography at the scale of 1:50,000, and produced in matt finish, was used for interpreting and delineating land systems, and was then used in the field to validate these boundaries, and to check the position of station infrastructure such as water points and fences. The Topographic Service Branch and Cartographic Services Branch of the Department of Land Administration worked together with the Rangeland Survey Team to produce the two mapping products for the survey.

Pastoral lease boundaries

In 1989 and 1990 a separate field survey was organised by the Geodetic Branch of DOLA, to locate and precisely position, using Global Positioning Satellite (GPS) technology, many of the original boundary surveys and starting points for pastoral lease definition within the survey area. In the early days of development of this State, the explorers/surveyors were instructed during the course of their surveys to mark ('blaze') trees at waterholes, pools, wells, springs or river junctions. Some surveyors placed large wooden posts near these features or rock cairns on hills, and many of these still exist today in remote areas of the State. These old marks were then used as starting points for boundary lease surveys so that new surveyed positions on the map were known relative to topographic features.

The GPS Survey Team located as many as possible of these survey marks and original boundary marks within the survey area. At the completion of the boundary validation process, precise geographic coordinates on the Australian map grid (AMG) were defined using GPS methods. The coordinates were integrated into the Spatial Cadastral Database (SCDB) and provided to the mapping group within DOLA's Cartographic Services Branch. The coordinates have now allowed for very accurate definition of legal boundaries (and pastoral lease infrastructure) on station plans.

Map sheet validation

A validation program for the 1:100,000 station plan and the 1:250,000 land system maps began with the first reconnaissance trip and finished with the conclusion of field work by the survey team. Although not every track, fenceline or watering point was visited, pastoralists were given the opportunity to discuss any anomalies or features and infrastructure detail with the team. Topographic Service Branch finalised and digitised the data. An updated, digital map series was produced which became the base from which new station plans and land system maps were produced.

Map products

Two map series have been produced to present the spatial relationship of the resource data. Station plans (1:100,000 scale), specifically for individual pastoral leases, have been produced in colour and have the option of displaying whatever data the pastoralists may require. This facility is available as all the topographic, cultural, cadastral and resource data is in a multi-layered and geographically referenced, digital format. Six maps conforming to the State mapping format for the 1:250,000 scale covering Leonora, Laverton, Menzies, Edjudina, Duketon and Sir Samuel, have been prepared as an appendix to this report. These coloured maps display land systems, inventory and condition sites with some of their attributes and traverse assessments. Area statements, calculated for individual land systems within pastoral leases, are published separately (Pringle 1994).

Not all of the data collected are presented in this report. More detailed information is available on request from the Department of Agriculture Western Australia.
The current methodology in perspective

The evolving methodology used by successive rangeland surveys reflects the broadening range of users of the reports and the emerging requirement for more scientifically rigorous approaches (Curry and Payne 1989, Pringle 1991). The early survey reports, however, are still widely used and the envy of many areas yet to be covered by rangeland surveys.

Methodology will be further improved following this survey. For subsequent rangeland surveys it is anticipated that the field inventory and analysis methodologies will be further refined, to take advantage of emergent technology and to present more comprehensive and useful reports to the community.

Black and white aerial photographs, geological maps and station plans are used to plan traverse routes. When available, LANDSAT images are also very useful.

Pastoralists generally accompanied the team on traverses of their stations, providing opportunities for the team to explain the work and gain valuable local knowledge.

References


Geomorphology

H.J.R. Pringle

Introduction

The geomorphology of the survey area is described in terms of the morphotectonic setting at a continental and regional scale. Land surface types are described with reference to their component land systems. Landscape evolution is briefly discussed in terms of Cenozoic alteration of the morphotectonic setting and the interactions between land use and landscape processes are considered.

The morphotectonic setting

The survey area falls largely within the Eastern Goldfields Province of the Yilgarn craton with minor incursions of Officer and Nabberu Basin sediments in the north-east (Myers and Hocking 1988). This corresponds physiographically to the Salinaland Plateau of the Yilgarn Plateau Province and the Leemans Sandplain and the Great Victoria Desert Dunefield of the Sandland Province, all of which fall into the Western Plateau Division (Jennings and Mabbutt 1986) (Figure 1).

The regional geology is characterised by arcuate to linearly arranged greenstone belts separated by expanses of granitoid rocks. Associated with the predominantly mafic and ultra mafic sequences of greenstone belts are areas of clastic sedimentary rocks and felsic volcanics, all of which are of Archaean age. McCulloch et al. (1983) suggested that the greenstone-granite terrain formed between 2800 and 2600 Ma (1 Ma = 10⁶ years ago). The terrain has formed as a result of vertical tectonic processes interacting with considerable forces of subhorizontal deformation and pre-dates the development of the major fault lineaments with which they are spatially associated (Griffin 1990, Gee et al. 1981).

The rocks of the greenstone-granite terrain pre-date the current cratonic structure of Australasia; the greenstone belts may have originated as submarine lava flows. Subsequent episodic deformations have resulted in widespread metamorphism within the greenstone belts.

Griffin's (1990) review of geological research in the Eastern Goldfields Province identifies three major deformation events, of which the third, involving both wrench faulting and vertical folding influenced by the north, north-west trending lineaments, had the most profound effect on the present structure of the greenstone belts. The tectonic history (based on limited intensive studies) has been interpreted and summarised as follows:

(a) The formation of greenstone belts occurred at 2.7 Ga (x 10⁶ years ago). These greenstone belts consisted of mafic, ultramafic, intermediate and felsic volcanic rocks; psammitic, pelitic and cherty sedimentary rocks with minor banded ironstone formation; and mafic-ultramafic sills. They formed on, or adjacent to, an unknown crust. Zircons, as old as 3.5 Ga, in the greenstones, indicate the presence of an older, probably sialic, crust during the formation of the greenstones.

(b) Deformation, involving early recumbent folding and thrusting followed by upright folding, faulting, metamorphism, and intrusion of granitoids, affected the greenstones. Granitoid activity probably began deep in the crust during extrusion of the felsic volcanics in the greenstone belts.

(c) The erosional products of greenstones and granitoids were deposited as polymictic conglomeratic sediments in restricted basins.

(d) Deformation, peak of metamorphism, and further granitoid intrusion, occurred during the brief but complex period of tectonic activity. A strong, steeply dipping north-north-west trending fabric, together with major transcurrent faults, developed at this stage.

(e) Late, small granitic and syenitic stocks and dykes intruded deformed greenstones and granitoids.

(f) This granite-greenstone terrain was cratoniised by the time that undeformed, and unmetamorphosed, mafic dykes were intruded at 2.4 Ga.

The Archaean granites are generally expressed surficially as low, rounded tors surrounded by gritty surfaced plains. The greenstone hills are of two common forms. The first are low, rounded, deeply weathered hills such as those near Menzies. They frequently have broad, stony, calcareous lower slopes. The second form consists of, higher, steeper, less weathered linear hills with narrow incised drainages. This form is common in the Laverton area.

Banded ironstone ridges are commonly associated with greenstone belts and represent different depositional layers that have been chemically and hydrothermally altered and tilted to near vertical. Their prominence in the landscape reflects their relatively high resistance to weathering and erosion.

 Portions of the Nabberu Basin overlies the Yilgarn craton in the north-eastern corner of the survey area. The Farquharson Tableland consists of the Frere and Yelma Formations of the Tooloo subgroup within the Earaheedy Group. The sedimentation of the Earaheedy Group occurred around 1.6 to 1.7 Ga (Horwitz 1975, Bunting 1986) and consists of a marine-cover of clastics, carbonate and cherty iron formation (Gee 1990) whose distribution reflects marine transgression and subsequent regression to the north-east. Prominent surficial rocks associated with this setting are sandstones, siltstones, quartzite, dolomite and conglomerates.
Figure 1. Physiographic regions of Western Australia.

Key to Figure 1

203 Salinaland Plateau: sandplains and laterite breakaways; granitic and alluvial plains; ridges of metamorphic rocks and granite hills and rises; calcrites, large salt lakes and dunes along valleys.

180 Leemans Sandplain: sandplain with small salt lakes.

181 Great Victoria Desert Dunefield
   a. Main Dunefield: west-east longitudinal dunes;
   b. North-west dunes and hills: west-east longitudinal dunes broken by low tablelands and ridges.
The Paterson formation of the Officer Basin Permian sequences consist of glacial to subglacial lacustrine and fluvial deposits (Bunting and Chin 1973). They are distributed in the north-east of the survey area where they extend eastwards into the Officer Basin. There are minor outlier outcrops of Paterson sedimentary surfaces within the Yilgarn craton such as around Laverton Downs homestead. The lithology is characterised by diamicite, sandstone, siltstone and claystone formed by deposition from ice caps to the west (lasky 1990).

Table 1. Land surface types of the north-eastern Goldfields

<table>
<thead>
<tr>
<th>Land surface type</th>
<th>Land system</th>
<th>Predominant surface geology</th>
<th>Characteristic landform(s)</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Hills and ridges</td>
<td>Bevon</td>
<td>Limonite over greenstone</td>
<td>Low hills and strongly undulating plains</td>
<td>Wide, common</td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>Banded iron formation</td>
<td>Strike ridges</td>
<td>Wide, common</td>
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<tr>
<td></td>
<td>Graves</td>
<td>Greenstone</td>
<td>Low rounded hills</td>
<td>South-west, uncommon</td>
</tr>
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<td></td>
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<td>Wide, common</td>
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Land surface types (groups of land systems)

Nine land surface types were defined within the survey area.

The land systems comprising land surface types are primarily grouped on relief and landform, and secondly on soil and drainage features (Table 1). Colloquialisms are used to maintain brevity in descriptions.
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<td>Campsite Alluvium/colluvium</td>
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<td>Kirgella Sand, granite, minor alluvium</td>
<td>Irregular granite outcrops and undulating sandplain</td>
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<td></td>
<td>Pan Alluvium, sand</td>
<td>Narrow concentrated drainage tracts</td>
<td>Wide, uncommon</td>
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</tr>
</tbody>
</table>
Hills and ridges

The major geological groups associated with hills and ridges are greenstones, banded ironstone, granite, quartz and felsic volcanic rocks. Land systems of this land surface type are:

Bevon: irregular low hills, plateaux and occasional minor breakaways with limonite, very stony lower colluvial slopes, undulating gravelly plains with sandy soil profiles and narrow drainage tracts.

Brooking: conspicuous banded ironstone and jaspilite ridges with hillslopes of variable country rock. Generally shallow stony acidic to neutral soils are common on hill slopes.

Graves: very similar to Leonora system, differing mainly in the vegetation it supports. It is restricted to the south-west of the survey area.

Hospital: large granite domes surrounded by drainage foci and gritty surfaced plains. Drainage lines are well defined, narrow and incised. This system occurs in the south.

Laminar: flat-crested hills and mesas of lower Permian sedimentary rocks with steep, benched, stony hillslopes and narrow, incised, drainage lines. This system occurs in the north-east and is associated with the Nabburu Basin.

Laverton: generally linearly trending greenstone hills with strike ridges related to banded iron formation, and narrow, incised, rectangular drainage pattern. Soils are generally shallow red stony earth.

Lawrence: low greenstone hills and banded ironstone and jaspilite strike ridges. Similar to Brooking system, however, relief is generally more subdued and soils are highly calcareous. Occurs in the south-west of the region.

Leonora: low rounded hills with extensive, deeply weathered, parent rock which produce extensively calcareous soils, and wide, unincised, drainage tracts (which have heavier soil textures than those in Laverton land system).

Mulline: greenstone hill system very similar to Laverton system but supporting extensive eucalypt and Casuarina cristata woodlands. Occurs in the south-west of the region.

Teutonic: hills of felsic extrusive rock (occasionally intrusive) with narrow, sometimes incised, drainage lines and occasional lower rises with limonite rubble mantles. This system is generally associated with greenstone belts.

Wyarri: low hills and tor fields of granitic rocks with narrow plains of gritty or stony lag. Major quartz dykes such as the Dingo Range have been included in this system.

Greenstone hills such as at Mt Percy provide a change in an otherwise characteristically subdued landscape.

Breakaways and lower plains

Breakaways are most extensive and best developed in the granite domain where they consist of a duricrust of silcrete or indurated granite over deeply weathered granite. Duricrusts in the greenstone domain are generally ferricrete. There are usually saline foot-slopes downslope of breakaway scree slopes with variable plains further downslope, which often characterise the component land systems of this land surface type. The land systems of this land surface type are:

Crot: breakaways (often calcareous), low rises and gently undulating narrow plains and remnant plateaux surfaces on weathered granites.

Cumbreak: breakaways on granite and extensive lower alluvial plains with duplex soils which locally have a mantle of stone.

Hootanui: breakaways and low hills based on weathered greenstone and felsic extrusive rocks with extensive saline, gravelly, lower alluvial plains and drainage floors.

Sherwood: breakaways on granite, often silcrete duricrusted, with tributary drainage patterns on breakaway footslopes and extensive lower pediments.

Tuoloo: breakaways on lower Permian sedimentary rocks, with extensive lower, pebbly, saline, alluvial plains.

Waguin: irregular, poorly developed, breakaways based on weathered granite, distributed as small isolates within sandplain land systems.

Yilgangi: breakaways on greenstone above saline footslopes and gravelly alluvial plains with integrated drainage into ancient drainage systems (lake country).

Erosional surfaces of low relief (usually < 20 m)

Low erosional surfaces are characterised by mantles of lag and colluvium. Quartz is widespread, whilst ironstone and greenstone characterise the greenstone domain and silcrete and decomposed granite are
found below granite outcrops. Land systems of this surface type are:

Bandy: irregular low granite outcrops and tors to 15 m relief surrounded by narrow, very gently inclined plains with skeletal soils on granite.

Challenge: extensive plains with skeletal soils on granite, stony plains, occasional low tors, and breakaways.

Felix: very gently undulating plains with quartz lag based on felsic volcanic rocks, deeply weathered locally, and hardpan on lower plains. Occasional narrow, unincised drainage tracts.

Gransal: stony plains, low rises, occasional incipient breakaways, and alluvial floors based on deeply weathered granites (with conspicuously calcareous upper units in the south-east).

Gundockerta: extensive gently undulating plains on deeply weathered greenstone with stony lag, less extensive alluvial plains with duplex soil profiles and occasional rises of greenstone.

Moriarty: low rises, with local pockets of lateritic duricrust on weathered greenstone, very gently undulating plains with stony lag and extensive alluvial plains with duplex soils. This system is found in the south of the survey area.

Nubev: rises with lateritic duricrust, undulating plains with stone mantles and wide (> 500 m) drainage floors with duplex soils.

Sunrise: gently sloping stony interfluves on greenstone with poorly developed loam soils between sub-parallel drainage lines which are incised in higher areas.

Violet: undulating plains with mantles of ironstone, rises with ironstone gravel, occasional incipient breakaways with alluvial drainage tracts; drainage is generally sparse and unincorporated. Relief to 15 metres.

Windarra: quartz mantled colluvial plains based on granite with a thin veneer of hardpan in lower areas. Drainage patterns are approximately parallel and generally unincised. There are also occasional low hills or rises.

Plains receiving weak sheet flow and with extensive deep sandy loams to sand

These plains are often found on the lower margins of sandplains where they are subject to weak sheet flow following rain. The land systems of this land surface type are:

Ararak: broad sandy plains with ironstone lag, poorly developed drainage patterns and occasional low rises with lateritic profiles.
Desdemona: plains with negligible surface drainage features, often occurring adjacent to sandplain in areas receiving weak run-on.

Illara: very gently undulating plains with ironstone lag over loamy soils and local, slightly elevated plains with finer textured soils and calcrete rubble mantles; occasional irregular and unchannelled narrow drainages. This system is confined to the south-west.

Yowie: a southern equivalent of Desdemona system, principally differing by supporting different vegetation (a denser acacia tall shrub stratum, occasional eucalypt mallees and sparser wanderrie grass communities).

**Alluvial plains with extensive duplex and/or clay soils**

These plains are found in depositional areas, usually distributary fans. They are associated with alluvial plains downslope of substantial greenstone subcatchments and major creeks. The land systems of this land surface type are:

- **Bunyip**: wide drainage tracts receiving run-on from greenstone hills; cracking clays grading to calcareous loams on margins. This system occurs only in the south of the survey area.

- **Campsite**: very gently inclined alluvial plains receiving sheet wash from mafic hills with calcareous stony upper tracts (erosional) and occasional narrow concentrated drainages. This system occurs only in the south-west of the survey area.

- **Cyclops**: saline alluvial plains receiving distributary flow from creek lines; numerous small circular drainage foci, playas, ephemeral swamps and low sandy banks.

- **Monitor**: distributary alluvial fan system based on hardpan frequently receiving drainage off greenstones; consisting of minor upper channels, extensive alluvial plains with gradational to duplex alluvial soils and broad drainage tracts and sump areas occasionally with clay soils.

- **Steer**: saline alluvial plains with a ferruginous gravel veneer, and occasional gravelly rises, scattered circular drainage foci and central drainage tracts carrying concentrated flow.

- **Sturt**: saline alluvial plains receiving distributary flow from major creeks, and characterised by irregularly shaped drainage foci and minor sandy banks.

- **Wilson**: major creek system with distributary fans consisting of sandy bedload deposits adjacent to channels and extensive lower alluvial plains with duplex soils.

**Plains with deep calcareous red earths flanking salt lakes**

These plains are characteristic of the southern part of the survey area where they occur between salt lakes and erosional terrain. They differ markedly from the more extensive alluvial plains on red brown hardpan to the north in having deeper, sandier, calcareous soils, with calcrete inclusions and frequently calcrete, rather than silicaceous, soil pans. They are also subject to considerably less sheet flow and have very poorly developed drainage features. The land systems of this land surface type are:

- **Deadman**: nearly flat to gently undulating plains mostly with no defined drainage, based on calcrete. Calcrete nodules occur through the soil and calcrete rubble characterises higher areas with shallower soil.

- **Doney**: drainage plains often with a calcareous subsoil pan carrying weak unchannelised flow and with scattered drainage foci. Vegetation of eucalypt woodlands distinguishes Doney from predominantly black oak (Casuarina cristata) woodlands on coarser textured soils in Deadman land system.

**Salt lakes and other former more active drainage axes**

The drainage pattern of the area is characterised by previously integrated river systems which have become networks of variably connected salt lakes. Deposition of marine and terrestrial sediments effectively choked these drainage networks, which have been variably subjected to aeolian deposition of sand and groundwater precipitation of calcrete. The land systems of this land surface type are:

- **Carnegie**: lake beds with fringing kopi dunes and sand lunettes and banks generally surrounded by extensive alluvial plains with duplex soils.

- **Cosmo**: calcrete platforms and plains with calcrete rubble in ancient drainage axes which have been extensively overlain by red aeolian sands.

- **Cunyu**: calcrete platforms in ancient drainage valleys with shallow poorly developed soils above alluvial plains with saline duplex and more extensive non-saline loamy soils.

- **Darlot**: lake beds as in Carnegie land system, but with regular sandy banks and frequently interconnected claypans through more extensive fringing alluvial plains.

- **Melaleuca**: swamps, densely vegetated drainage foci and extensive sandy banks generally overlying calcrete, often between extensive sandplains and Carnegie land system.

- **Mileura**: calcrete valley fills with calcrete platforms to 3 m relief above extensive alluvial plains with duplex soils (supporting halophytic shrublands).
Sandplains

Sandplains are very extensive away from greenstone belts and are found in a number of positions in the landscape. They are the dominant land surface in the north, east and south-west of the survey area, where they occur as extensive plains with occasional sand ridges or granite outcrops. In more dissected terrain they occur on the backsteps of breakaways in the granite domain. They are also common adjacent to salt lakes. Most of the sandplains have red sand, there are areas with buff sand in the south-west. The land systems of this sand surface type are:

Bullimore: generally very gently sloping to broadly undulating plains of red sand with occasional incidence of near parallel sand ridges.

Kirgella: sandplain with extensive very gently undulating areas containing granite outcrop frequently with thin calcrete pans. This land system is found in the south-east.

Marmion: very gently undulating sandplain with occasional very low rises with laterite profiles, minor granite outcrop. This land system is found in the south.

Pan: narrow (<300 m wide) meandering drainage tracts and clay pans in sandplain.

Deep weathering

Warmer and wetter climates than exist today during the Tertiary (e.g. Bowler 1976) were the prevailing conditions in which deep weathering occurred (Wyrwoll and Glover 1988). That deep weathering occurred prior to the Tertiary should not be discounted (Wyrwoll 1988 and Milnes et al. 1985), however, it was during the Tertiary that Western Australia attained its modern form (Beckman 1983 in Wyrwoll 1988). The relevance of this deep weathering is twofold: first it altered rocks, making them more susceptible to subsequent erosion, and second it produced laterites or ‘Wallah’ profiles (see Wallah 1915). In effect, deep weathering prepared the landscape for erosion events.

Geomorphologists such as Jutson (1934) and Woolnough (1927) perceived a duricrusted peneplain of continental extent, a model which has been used by subsequent workers to describe current landforms in terms of the extent of back stripping of this Old Plateau. Mabbott (1963a) relied extensively on a ‘New Plateau’ /‘Old Plateau’ model to interpret landform evolution in the Wiluna-Meekatharra area, which bounds the northern limit of this survey area.

While advances in understanding of geomorphological processes - quite closely linked with technological advances not available to earlier workers - have rendered this model of a weathered profile of continental extent untenable, the fundamental concept of etchplanation, operating by retreat at breakaway faces reducing the extent of in situ deeply weathered rock and exposing fresh rock, is still relevant.

The formation of ferricretes remains a contentious issue, one stream of opinion views its formation (and that of silcrete) as involving in situ vertical mobilisation of iron (and silica in the case of silcrete) and its precipitation near the surface. This infers that duricrusts form in areas of higher relief (e.g. Churchward 1977) whilst others, such as Ollier et al. (1988) envisage duricrust formation by lateral transport of ions in groundwaters and cementation in areas of lower relief, the duricrust attaining positive relief by subsequent inversion. There is much still to be learnt about duricrust formation, as there are contradictory observations to all models proposed to date (as acknowledged by Ollier et al. 1988). Thus, whilst the processes are not well understood, there are duricrusts in areas of higher relief overlying a variety of deeply weathered materials including granitoid and greenstone rocks. The main types of duricrust in the survey area are silcrete and indurated weathered granite in the granitic domain, and ferricrete in the greenstone domain. Silcrete also overlies sediments of the Paterson formation in the north-east of the survey area. Once again, this mineralogical correspondence between duricrusts and underlying bedrock invites a genetic inference, however, Ollier et al. (1988) observed cases in mine shafts that indicate that duricrusts often overlie weathered alluvium and hence are unconformable with the bedrock. Further research is needed to explain these regolith patterns and anomalies.

The evolution of landforms in the Cenozoic

The morphotectonic stability experienced by the Yilgarn block since before the Tertiary provides the setting upon which climatic and landscape forces have interacted to develop the various types of land surfaces described above. Rates of erosion of over 5 m per million years over parts of the Mesozoic have probably obliterated the geomorphological impact of Permian glaciation (Wyrwoll 1988). This section discusses Cenozoic surfaces evolved by weathering, erosion and deposition.
The onset of aridity

Following the extensive deep weathering of a landscape of predominantly low relief during warmer and wetter periods, another major influence on the landscape emerged in the Late Tertiary: the onset of more fluctuating and arid climatic conditions in central Australia.

Bowler (1976) suggests that the onset of aridity occurred in the Pliocene. The Quaternary has been characterised by fluctuations between warmer and wetter (Interglacials) and cooler and drier (Glacials) periods. The degree of coincidence of glacial/interglacial fluctuations and climatic fluctuations has not been rigorously evaluated in Western Australia (Wyrwoll 1988).

The impact of a more arid climate in the Late Cenozoic, and in particular in the Quaternary has been on the effectiveness of weathering, erosional and depositional processes. Whilst Finkl (1982) proposed a 'catastrophic erosion rate' for the Late Cenozoic, Wyrwoll claims that Finkl's hypothesis lacks field evidence, involves rates of erosion of orders of magnitude greater than those estimated in the eastern States (e.g. Young and McDougall 1985) and in north-western Australia (Spaeth 1987 in Wyrwoll 1988) and lacks chronological or stratigraphical control.

It would appear that a considerably less punctuated erosional history at considerably lower rates has occurred since the Tertiary (see Van de Graaf 1981). This being the case, the major impact of the onset of aridity has been to preserve much of the landscape; erosion and deposition undoubtedly having occurred since then, but producing minor alterations rather than substantial modification of Late Tertiary landforms. Thus, the current landscape may be viewed in terms of its continental and regional morphotectonic setting, which was subjected to extensive deep weathering in the Tertiary, and perhaps Late Cretaceous, and has been somewhat modified in subsequent more arid climatic conditions in the Late Cenozoic (mainly Quaternary) by etchplanation and local alluvial and aeolian deposition.

Erosional landforms and processes

The most striking of erosional landforms in the survey area are breakaway scarps. Breakaways represent regional erosion fronts in which highly weathered saprolite, capped by a duricrust of indurated saprolite, silcrete or ferricrete, is eroding by lateral retreat. Breakaways are generally best developed on granitic rocks such as the Barr-Smith and Sholl ranges in the north of the survey area (Sherwood land system). Breakaways in the greenstone domain are conspicuous to the west of Lake Carey (e.g. Yilgangi land system).

Further examples of erosional landforms are considerably more difficult to recognise. Exfoliation of granite domes was observed regularly and depositional plains in upland areas of both the greenstone and granite domain indicate that erosion is still occurring (see Leonora land system). Churchward (pers. comm.) found an area on Perrinvale station he interpreted to consist of alluvial deposits, enriched with iron, that are currently being eroded. This indicates a more complex model of landscape evolution than (Late Cenozoic) etchplanation of deeply weathered Tertiary lateritic profiles, involving multiple planation surfaces. Consideration of patterns at this scale, whilst very important to unravelling the landform-process story, are beyond the scope of this report.

Depositional landforms and processes

(a) The broad, nearly level salt lake systems contain basal sediments that have been dated back to the Eocene and include terrestrial sediments overlain by marine sediments. Hocking and Cockbain (1990) claim that these drainage systems were active in the Early Tertiary and that significant flow ceased before the Late Miocene. When active, these drainage systems drained towards the Eucla basin. Today most drainage is internal, however, the very large rainfall events in the mid 1970s saw flow from Lake Raeside reach Lake Boonderoo via Ponton Creek. Lake Boonderoo lies approximately 250 km south-east of the survey area.

(b) Sandplains are extensive throughout the survey area, but are most noticeably absent or of limited extent near the major greenstone belts which trend NNW-SSE through the centre of the survey area. Churchward’s (1977) observation in the north of the survey that sand particle size declined down the backslope of a breakaway is consistent with the fluvial sedimentological explanations of sandplain distribution and formation supported by Betteray and Hingston (1964) and Mulcahy (1967) (cf. Glassford 1980). Further observations by Churchward indicate that sandplain overlies a variety of materials including alluvium. Aeolian deposition of sand such as over calcrite platforms in Cosmo land system in the north-east of the survey area, and in sand ridges found in generally near parallel sequences, indicates the considerable role of wind in determining the current distribution of sands in the survey area. Limited observations indicate that both fluvial and aeolian processes have influenced the distribution of sandplain, quite possibly including some aeolian reworking during previous arid periods in the Quaternary.

(c) Calcreted valley fills are common in palaeodrainage axes and represent old valley floors whose alluvium has become replaced by carbonate. Hocking and Cockbain (1990) suggest that groundwater calcrite formation requires conditions of 'low, irregular rainfall, high evaporation, little surface drainage or run-off, and a shallow water table with sluggish groundwater movement'. They thus indicate that the precipitation of these calcrite bodies post-date the onset of aridity in the Pliocene.
(d) Plains with a ferruginous-siliceous hardpan are extensive throughout the survey area and are likely to have formed by accumulation of iron and silicates derived by weathering upslope and transported in groundwater to the zone of precipitation. Olhier et al. (1988) view hardpan as incipient duricrust, attaining its relief by subsequent inversion.

(e) Distributary alluvial fans are uncommon in the survey area, being restricted to flood out areas of creeks emerging from relatively large (often greenstone dominated) stony catchment areas such as the alluvial plains west of Sturt Meadows homestead, the Bummers Creek flats on Minara and Glenorn stations and the Monitor Flats on Erlistoun station. These plains contain variable sedimentary sequences including old bedload deposits from prior stream channels, and often overlie hardpan. Occasionally, within these alluvial fans are drainage foci representing areas of lowest relative relief which are characterised by heavier soils, including cracking clays, than in adjacent areas.

(f) Piedmont tracts adjacent to greenstone hills often consist of granite rock overlain by alluvium, including stones derived from the greenstone domain (Sunrise land system or the Hanson unit of Churchward 1977). Pediments in the granitic domain consist of shallow alluvium including quartz pebbles and stones of irregular depth over granite.

(g) Wanderrie banks are characteristically found in the lower portions of alluvial plains on hardpan and vary in form according to the relationship between winds that transported the sediments and sheetflood direction (Mabbutt 1963 a, b). The best examples of wanderrie banks in the granitoid domain are in areas where there is a substantial breakaway system with extensive lower pediment and might indicate that fluvial processes are involved in transporting sediment into the area of wanderrie bank formation from immediately upslope. Further research is needed to conclusively describe processes involved in wanderrie bank formation. Wanderrie banks in the survey area are quite poorly defined relative to those of the tributary plains of the upper Murchison catchment (see Curry et al. 1994), rarely attaining a unit relief of 30 cm above adjacent plains.

In summary, the current landform patterns in the survey area comprise extensive sandplain, (locally with near parallel sand ridges), sub-parallel greenstone belts, breakaways with often extensive lower pediments which give way to level to very gently inclined sheetflood plains draining into salt lakes. Relief is subdued, and drainage is generally disorganised and endoreic. This regional characterisation reflects a very old landscape that has not experienced the rejuvenation of glacial events in the Pleistocene that have overwhelmingly influenced current landforms in the northern hemisphere. Here, the landform patterns are best appreciated in terms of a morphotectonic setting of greenstone belts surrounded by extensive granitoid expanses that have undergone deep weathering in the Mid to Early Cenozoic and have been largely preserved with the onset of aridity in the Late Cenozoic, with some modification by erosion and deposition.

Land use impacts and landscape processes

The first research on this topic in Western Australia's rangelands was conducted by Wilcox and McKinnon (1972) in the Gascoyne catchment, in an effort to evaluate pastoral grazing impacts on flooding of the Carnarvon townsite. Since then, little investigation of interactions between land use and landscape processes has been attempted.

Hills and adjacent undulating plains

The scattered to very scattered nature of perennial vegetation and very shallow stony soils in hilly greenstone areas and adjacent undulating plains (e.g. Laverton and Sunrise land systems) results in little infiltration and high levels of run-off. Erosion in this terrain is not generally a concern as the soil is protected by extensive stony mantles. In areas of Gundockerta land system, in which a mantle of quartz is sparse or absent, microterracing was noticeable on the gentle tributary concavities in degraded areas and rilling and guttering occurred locally in areas receiving more concentrated run-on.

Breakaway footslopes

The breakaway footslopes in both granite and greenstone domains were generally unrestable and had tributary rills even in ungrazed situations. Where degradation had occurred there was generally a variety of erosion types including scalding, sheeting, microterracing, rilling, guttering and occasionally gullying. The extensive loss of soil in these fragile areas clearly illustrates the importance of minimising grazing activity. These areas warrant further research to investigate cover thresholds and trampling impacts on soil stability.

Pediments

Pediments below both greenstone and granite hills, rises and breakaways are usually level to very gently undulating, have a protective cover of stone, low vegetation cover (usually less than 15%) and poor infiltration characteristics, but are generally not susceptible to erosion, even when plant cover is reduced. This is largely a result of the protection provided by the stony mantle. Narrow drainage areas in this terrain characteristically support moderately close mulga tall shrublands, are unincised and not usually susceptible to soil erosion. Thus, the majority of run-off areas in the survey area are relatively free of obviously accelerated soil erosion.
Distributary alluvial fans

Where substantial drainage tracts emerge from upland terrain onto alluvial plains they generally form extensive distributary fan systems (Monitor and Wilson land systems). Here, slopes are low (usually less than 3%) but the soil surface is without the protective cover of the stony pediments found upslope. A compounding factor is that the vegetation on these areas often includes palatable succulent chenopod shrubs favoured by stock and has generally been severely degraded by overgrazing earlier this century. Thus, with reduced plant cover and high levels of run-off from adjacent uplands, the fans are susceptible to soil erosion (which is often extensive and severe). Hardpan is often exposed where soil removal has been complete, elsewhere there are often microterraces and scalds, with gullies or gullying in areas receiving more concentrated flow. Fortunately these distributary fans are not extensive in the survey area. Similar terrain is in undegraded condition on the north-east of Glenorna station west of Mt Margaret Mission. Examples of historically severely degraded areas are the Bummers Creek Flats and the Monitor Flats. (See photo below)

The Monitor Flats on Erliston station have become severely degraded and eroded by inappropriate management in the earlier years of the pastoral industry in this region. The dotted line outlines the area of accelerated soil erosion.

Sheetflood (hardpan) plains

Most of the extensive alluvial plains in the area are subject to intermittent sheet flow, are level to very gently inclined and support scattered mulga tall shrublands whose plant cover is only very locally subject to reduction by overgrazing. These conditions render the extensive plains fairly immune to soil erosion. Cryptogamic crusting is extensive on these plains and may infer additional stability to the soil surface against wind and water erosion.

These plains are susceptible to ‘water starvation’ caused by inappropriately located and constructed tracks and roads. In such cases vegetation may decline downslope of the impendence to flow and expose the soil to wind erosion. Tracks should allow for the regular and frequent passage of water downslope so as to reduce the risk of water build-up and high energy discharge where it breaks through the track. Similarly spoon drains should be used to disperse water moving along tracks so as to minimise track erosion and downslope water starvation. Construction of tracks in the same direction as sheet flow should be avoided as this can cause water starvation problems and track erosion which may spread laterally by microterracing away from the track.

Wanderrie banks

Historical overgrazing of wanderrie banks has sometimes lead to a reduction in ground cover and the breakdown of the bank by both wind and water erosion. However, unpalatable species often invade in such circumstances and serve to stabilise these areas.

Alluvial plains adjacent to salt lakes

Broad alluvial plains with duplex soils are found adjacent to salt lakes and are level to very gently inclined. They have a sandy surface horizon which enhances infiltration, usually have extensive cryptogamic crusts on the soil and are subject to sheet flow from adjacent plains with shallow loamy soils on hardpan. They are fairly resistant to water erosion, although they may become wind scalded if plant cover is reduced (for example by overgrazing).

Sandplains

Theoretically, the widespread use of fire in spinifex hummock grassland communities could lead to accelerated wind erosion, particularly if the fire burns with, rather than perpendicular to, the direction of prevailing winds. No such areas of concern were observed during fieldwork.

In summary, the north-eastern Goldfields has several natural features which help protect the landscape from the impacts of inappropriate land use practices. These include widespread stony mantles on pediments, extensive nearly level plains subject to sheetflow with tall-shrub strata largely unaffected by sheep grazing, and historical difficulties in obtaining adequately fresh stock drinking water on extensive alluvial plains with sandy-surfaced duplex soils. Soil depth also limits the extent of erosion in many areas.

The local areas in which the landscape is most susceptible to inappropriate land use are breakaway footslopes and distributary fans in the upper sectors of alluvial plains, particularly below greenstone terrain. The impact of land use in these areas has not been quantified in terms of increased run-off velocities, soil loss rates, sediment yields, vegetation cover thresholds and other such variables inherently reflective of landscape processes and ecosystem health.

References


Soils

A.M.E. Van Vreeswyk

Background

The Atlas of Australian Soils (Northcote et al. 1968) provides a soil map of Australia at a scale of 1:2,000,000. The survey area is covered by Sheet 10 of the Atlas. The following soil units, that are listed in the Atlas of Australian Soils, occur within the survey area:

- **BY7** Firm siliceous sandy soils, gravelly (K-Uc1.4)
- **AB6, AB14, AB50** Earthy sands (red forms - Uc5.21)
- **AC24** Earthy sands (yellow forms - Uc5.22)
- **SV4, SV5, SV15** Calcareous and siliceous loamy soils (Um1.1, Um1.2)
- **Fa32** Shallow dense loamy soils (Um1.4)
- **BB5, BB9** Shallow calcareous loamy soils (Um5.11)
- **BE2, BE3, BE6, BE8, BE15** Shallow earthy loams with red-brown hardpan (Um5.3)
- **Fa4, Fa7** Shallow, coherent and porous loamy soils (Um5.51)
- **DD33** Brown calcareous earths (Gc)
- **My50, My153** Neutral reaction trend through profile (Gn2.12)
- **Mx40, Mx42** Alkaline reaction trend through profile (Gn2.13)

Methods

During the course of the survey, soils were described at 640 of the 742 inventory sites using the terminology of the ‘Australian Soil and Land Survey Field Handbook’ (McDonald et al. 1984, 1990). The methodology used is described in the ‘Methodology’ chapter.

The soil profiles described were ranked according to the Northcote key (Northcote 1979) and Northcote Principal Profile Forms (PPFs) are provided in the soil descriptions.

Soil features

Aridity dominates the land mass of Australia; approximately 75% of Australia is arid according to Meig’s (1953) definition of arid lands. Much of Australia’s arid region consists of ancient highly weathered land surfaces which are distinctive for the extreme age of their soils. These soils have retained characteristics developed when the climate was much wetter than it is today. During the last million years, the climate has become increasingly arid and the old soils are gradually changing as a result. This change, together with widespread redistribution (mainly by water) of soil parent materials during the Quaternary, followed by slower rates of weathering associated with the increasing aridity, has resulted in the great variety of soils now present (Dregne 1976).

The soils of the survey area possess features which are characteristic of the arid regions of Australia. The dominant soil colour is some shade of red, owing to coatings of oxides of iron on the coarser particles. Soil structure is often only weakly developed, being mainly single-grain, or massive to weakly pedal. The main reason for the lack of soil structural development in the A horizon is low organic matter content which is typical of Australian soils (Hubble et al. 1983). Many of the massive and weakly structured A1 horizons are hardsetting when dry. Other soils possess a thin (usually less than 1 cm) crust which can be readily separated from the soil below. The lower part often has a strong vesicular appearance (Hubble et al. 1983). Vesicle formation is attributed to entrapment of air in dry soils during rain. As the entrapped air escapes, it leaves behind voids (Dregne 1976). Most B horizons have strong coherence but, although massive, are often porous, i.e., they have an earthy fabric.

Red-brown hardpans occur extensively in the central west of Western Australia, covering some 300,000 km² (Bettenay and Churchward 1974). These red-brown hardpans may have a porous appearance, but are massive and very hard. They are impermeable to water and therefore resistant to weathering although they may break into irregular pieces along laminar cleavages or vertical fissures (Hubble et al. 1983). The hardpan may range in thickness from a few centimetres to 30 metres.

The hardpans were formed possibly by silicification interspersed with episodes of clay illuviation. Teakle (1936) put forward the following explanation for the formation of the hardpan: episodic flooding and saturation of the soil on smooth slopes and plains caused leaching and acidification of the upper soil horizons, the leached silica was deposited as a hardpan during subsequent drying. Evidence presented by Litchfield and Mabbutt (1962) and Bettenay and Churchward (1974) tends to support this view.

In the survey area the red-brown hardpan occurs below a variety of soils (but predominantly red earths) at varying depth (usually at less than 1 metre). It is not known to what extent, if at all, the current overlying soil has had an effect on the formation of the hardpan or if hardpan formation is still continuing.

Relict soils in arid regions of Australia commonly have acidic reaction trends (Dregne 1976) and low contents of soluble salts. However, many other soils are alkaline and contain significant amounts of calcium and magnesium carbonates, calcium sulphate (gypsum) and sodium chloride (Hubble et al. 1983). Cochrane et al. (1994) estimate that saline-sodic soils comprise up to 10% of the soils in the arid shrublands of Western Australia. These are generally red duplex soils which occur on alluvial plains associated with salt lakes and on footslopes below granite breakaways and greenstone rises.
Saline sediments occur in ephemeral shallow salt lakes, which are widespread throughout Australia’s arid region (Hubble et al. 1983). Gypsiferous sediments occur within the salt lake beds and as fringing dunes along their margins.

Indurated horizons cemented by calcium carbonate are commonly referred to as calcrete. Calcrete normally occurs as a subsurface horizon, but may be exposed on the surface through erosion processes. Calcrete horizons are pedogenic; they occur at shallow depths, are relatively thin (up to 1 to 2 m thick) and occur over different substrate materials.

The soils frequently have a layer of lag gravels of fragments of laterite and silcrete, commonly 2-60 mm in diameter. The lag gravels are usually fairly tightly packed on the soil surface, but are only one layer thick. Lag gravels may have darkened and polished surfaces, known as desert varnish, owing to surface precipitation of iron and manganese oxides (Dregne 1976). The stony mantle may form through the removal of fine material by wind or water erosion, by upward movement of gravel through alternate expansion and contraction of the fine material between the coarse fragments, deposition by water, or may be formed in situ (on the surface) from the weathering of an exposed indurated soil layer (Dregne 1976, Hubble et al. 1983). Many areas in arid Australia would be severely affected by wind or water erosion if they did not have this protective cover of gravels and stones (Hubble et al. 1983). The coarse fragments also increase moisture retention and reduce moisture losses. The gravel slows down water movement across the surface, which increases infiltration, and also reduces the amount of soil surface exposed to evaporation (Dregne 1976).

Within the survey area there are tracts of land where a continuous or nearly continuous layer of sand covers the underlying rock or sediments. This sandplain is characterised by siliceous sand dunes which are up to 20 m high and are generally stabilised by vegetation.

Soils present in the survey area

Soils within the survey area have been divided into six groups based on morphological characteristics, in particular pedological organisation, field texture and presence or absence of carbonates. The six groups have been given generalised soil names as follows:

1. Red sands
2. Lithosols
3. Calcareous red earths
4. Red earths
5. Duplex soils
6. Clays

Soils within the groups are further distinguished by depth, substrate, fabric and presence or absence of a stony mantle. The descriptions that follow include the description of a representative profile for each soil. Horizon notations are according to McDonald et al. (1990).

In Table 1 (p. 100) the soil classification used in this report is compared with current Australian soil classification systems.

Description of groups and their component soils

Group 1 - Red sands (202 sites)

These soils have uniform, coarse-textured profiles which show weak to no pedological organisation, with no A2 horizon or structure. Textures range from sands to sandy loams; most common are clayey sand, loamy sand, sandy loam and fine sandy loam. These soils are usually red; mostly 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red), however, some of the deep sands of the sandplain and dunes in the south-west of the survey area are yellowish red (5YR 4/6 or 5YR 5/8). The soils in terms of Northcote (1979) are Uel and Uc5.

Eight soils are recognised in this group:

a) red sand on calcrete (25 sites) - uniform, coarse textured soils overlying calcrete, they occur on calcrete platforms, plains with rubbly calcrete mantle and on sandy banks over a calcrete pan. They are very shallow with calcrete at 30 cm or less, commonly with 10-50% calcrete rubble (6-20 mm) throughout the profile.

These soils have an alkaline soil reaction trend with pH of 8.0 or higher. The soil is usually calcareous, but may not be. The surface is firm. The textures are fine sandy loams and sandy loams with earthy fabric and massive structure, except on sandy banks where they are clayey sands and loamy sands, with single-grain structure.

Principal Profile Forms: Uel.13, Uel.33, Uel.43, Uc5.12, Uc5.21.

Representative profile

Site details
Site number: 616, Yakabindie station
Land system: Mileura
Land unit: level calcrete platform with 2 m relief (CAP)
Site type: calcrete platform woodland / shrubland (CAPW)
Surface condition: soft, algal crust
Surface mantle: many (20-50%) large (20-60 mm) angular calcrete fragments, minor (< 10 %) calcrete exposed
Principal Profile Form: Uc1.13

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Table 1. Grouping of soils and their relationship with the Great Soil Groups of the Handbook of Australian Soils*, the Principal Profile Forms of the Factual Key† and the classes of the Australian Classification System++.  

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>North-eastern Goldfields Survey</th>
<th>Great Soil Groups</th>
<th>Principal Profile Forms</th>
<th>Australian Classification System</th>
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<td>1 Red sands</td>
<td></td>
<td>Calcareous Sands (where calcareous throughout)</td>
<td>Uc1, Uc5</td>
<td>Hyperbasic Petrocalcic Leptic Calcargosol</td>
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<td>1a Red sand on calcrete</td>
<td></td>
<td>Earthy Sands</td>
<td>Uc1.43, Uc5.21</td>
<td>Lithic Leptic Rudosol</td>
</tr>
<tr>
<td>1b shallow red sand on granite</td>
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<td>Siliceous Sands, Earthy Sands</td>
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<td>Calcareous Soils</td>
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<td>3b calcareous red earth on greenstone</td>
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<td>Calcareous Red Earths</td>
<td>Um5.51, Um1.43</td>
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<td>Solonchaks</td>
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<tr>
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<td>Basic Hypergypsic Rudosol</td>
</tr>
<tr>
<td>Gypserous sediments</td>
<td></td>
<td>Solonchaks</td>
<td>-</td>
<td>Basic Hypergypsic Rudosol</td>
</tr>
</tbody>
</table>

* Stace et al. (1968).
† Northcote (1979).
++ Isbell (unpublished).
Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>A</td>
<td>dark reddish brown (2.5YR3/4) sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) subangular and few (5-10%) fine (2-6 mm) angular calcareous (carbonate) fragments; highly calcareous; pH 9.5, on calcrete.</td>
</tr>
<tr>
<td>20+</td>
<td>Cmk</td>
<td>calcrite.</td>
</tr>
</tbody>
</table>

b) shallow red sand on granite (33 sites) - uniform, coarse textured soils on granite at 60 cm or less, frequently with 'gritty' surfaces - that is many small pebbles (2-6 mm), usually quartz, on the surface. They occur mainly around granite outcrops.

Textures are very light, often clayey sand or clayey coarse sand with a sandy fabric. All have a massive structure, and firm surface condition. Most profiles contain few to common (5-20%) fine quartz gravel (2-6 mm). They have neutral or acidic soil reaction trends with pH between 5.0 and 7.5.

Principal Profile Forms: Uc1.43, Uc5.21.

Representative profile

Site details

Site number: 217, Perrinvale station
Land system: Gransal
Land unit: gently undulating plain with a stony mantle (PLG)
Site type: sandy granitic acacia shrubland (SGRS)
Surface condition: hardsetting
Surface mantle: common (10-20%), medium (6-20 mm) subangular quartz pebbles, 10-50% granite bedrock exposed

Principal Profile Form: Uc1.43

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-22</td>
<td>A</td>
<td>red (2.5YR4/6) clayey coarse sand; massive; earthy fabric; few (5-10%) fine (2-6 mm) angular fragments of weathering material; pH 5.6, on granite.</td>
</tr>
<tr>
<td>22+</td>
<td>R</td>
<td>granite.</td>
</tr>
</tbody>
</table>

d) red sand with ferruginous gravel (15 sites) - uniform, coarse textured soils with a common to abundant (10-90%) mantle of small to medium (2-20 mm) ferruginous gravel. They occur on plains subject to diffuse run-on and on low rises in greenstone terrain. The soils may be shallow or deep, and are underlain by ferruginous material or greenstone.

Textures are fine sandy loam or sandy loam, with earthy fabric and massive structure. They contain 5-20% rounded fine to medium (2-10 mm) coarse fragments in the profile which are generally ferruginous. They have acidic soil reaction trends with pH between 4.5 and 6.0, except where they are associated with calcareous rises where they have alkaline soil reaction trends with pH around 8.5.

Principal Profile Forms: Uc5.11, Uc5.21.
Representative profile

Site details
Site number: 634, Lake Way station
Land system: Ararak
Land unit: level plain with ferruginous gravel (PLL)
Site type: 'lateritic' mulga wanderrie grassy shrubland (LMWS)
Surface condition: firm
Surface mantle: many (20-50%) small (2-6 mm) subangular ferruginous pebbles

Principal Profile Form: Uc5.21

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>A</td>
<td>red (2.5YR4/6) fine sandy loam; massive; earthy fabric; few (5-10%) fine (2-6 mm) rounded ferruginous gravel; pH 4.5; clear boundary to</td>
</tr>
<tr>
<td>25-70</td>
<td>AC</td>
<td>red (2.5YR4/6) fine sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) rounded ferruginous gravel; pH 5.0, on</td>
</tr>
<tr>
<td>70+</td>
<td>Cc</td>
<td>ferruginous gravel.</td>
</tr>
</tbody>
</table>

e) red sand on hardpan (40 sites) - uniform, coarse textured soils on hardpan at varying depth; between 25 and 100 cm. They occur mainly on sandy banks on sheet flood plains and in lake systems, and on sheet flood plains. Textures of sandy banks are loamy sand or clayey sand, occasionally over sandy loam, texture on the plains ranges from loamy sand to fine sandy loam. The soils generally have few (2-10%) fine (2-6 mm) quartz gravel, or occasionally medium (6-20 mm) ferruginous gravel in varying abundance. The soils have acidic or neutral soil reaction trends with pH values between 4.5 and 7.0.

Principal Profile Forms: Mostly Uc5.21, also Uc5.13.

f) deep siliceous red sand (19 sites) - uniform, coarse textured soils more than 100 cm deep. These soils occur on sand dunes and some sand sheets and sandy banks in sandplain or salt lake systems. Textures are sand, loamy sand or clayey sand with sandy fabric and single grain or massive structure. All have soft surface condition. Most have acidic or neutral soil reaction trends with pH between 5.0 and 7.0; dunes in lake country may have alkaline soil reaction trends with pH values around 8.5.

Principal Profile Forms: Uc1.23, Uc5.11.

g) deep earthy red sand (36 sites) - uniform, coarse textured soils, generally more than 100 cm deep or occasionally on granite at 75 cm or deeper. These soils occur extensively on sand sheets in sandplain systems and on plains receiving diffuse run-on. Textures are very light - loamy sand or clayey sand, sometimes grading into sandy loam on the plains. All have earthy fabric and massive structure. A soft
Lithosols (27 sites)

Site details

Site number: 166, Riverina station
Land system: Marmion
Land unit: gently undulating sand sheet (SSH)
Site type: sandplain spinifex hummock grassland (SASP)
Surface condition: soft
Surface mantle: 
Principal Profile Form: Uc5.21

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>A</td>
<td>red (2.5YR4/8) fine sand; massive; earthy fabric; pH 5.0; diffuse boundary to</td>
</tr>
<tr>
<td>20-100+</td>
<td>B</td>
<td>dark red (2.5YR2/6) clayey fine sand; massive; earthy fabric; pH 5.0.</td>
</tr>
</tbody>
</table>

Group 2 - Lithosols (27 sites)

These soils are characterised by their stoniness and their lack of pedological organisation. They are predominantly red (2.5YR 3/6 and 2.5YR 4/6), with an earthy fabric and massive structure. They contain common (10-20%) to abundant (> 50%) coarse fragments throughout the profile, mostly quartz, ferruginous fragments or weathered material. The size of the gravel ranges from 6-20 mm to > 60 mm. They are very shallow (less than or equal to 30 cm) over rock. They have uniform texture down the profile and can be divided into coarse textured soils (sands and sandy loams) and medium textured soils (loams and clay loams). They have firm or hardsetting surface conditions. Principle Profile Forms are Um1.43 and Uc1.43.

These soils occur on plateaux, low rises, hills and hillslopes, ridges and footslopes.

Representative profile

Site details

Site number: 676, Weebo station
Land system: Teutonic
Land unit: rounded crest of a low (20 m) sandstone hill (HIL)
Site type: stony plain acacia-eremophila shrubland (SAES)
Principal Profile Form: Uc5.21

Surface condition: firm
Surface mantle: very abundant (> 90%) mixed size, angular tabular sandstone pebbles and stones
Principal Profile Form: Um1.43

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>A</td>
<td>dark reddish brown (2.5YR3/4) fine sandy loam; massive; earthy fabric; many (20-50%) medium (6-20 mm) angular tabular fragments of weathered sandstone; pH 6.0; on</td>
</tr>
<tr>
<td>30+</td>
<td>R</td>
<td>sandstone.</td>
</tr>
</tbody>
</table>

These soils generally have uniform, medium textures but may have gradational texture profiles (showing gradually more clayey texture grades down the profile). Textures are mostly clay loams, sandy clay loam or fine sandy loam.

The soils are red; mostly 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red).

The soils are calcareous throughout the profile, they have alkaline soil reaction trends and pH values between 7.0 and 9.5. They are of variable depth, mostly over calcrete. The soil may contain coarse fragments, usually calcrete but also quartz. Principal Profile Forms include Um1.33, Um5, Gc1.12, Gn2.13 and Gn2.23.

Three soils are recognised in this group:

a) shallow calcareous red earth on calcrete (19 sites) - uniform, medium textured shallow soils, usually less than 30 cm deep, with common to many (10-50%) inclusions in the solum of calcrete fragments, over calcrete. They have varying amounts of calcrete fragments on the surface, occasionally with < 10% of calcrete exposed. These soils occur on calcrete platforms and plains in calcrete systems.

Textures are most commonly fine sandy loam, and are occasionally sandy clay loam or clay loam. The soils have earthy fabric and massive structure, and firm or hardsetting surface condition. Soil reaction trends are alkaline with pH values between 7.0 and 9.5 at the surface, and 8.5 and 9.5 at depth. Generally these soils are calcareous throughout, although occasionally they have non-calcareous topsoils.

Principal Profile Forms: Um1.33, also Um5.11, Um5.51 and Um5.61.

Representative profile

Site details

Site number: 424, Mt Weld station
Land system: Mileura
Land unit: level calcrete platform with 2 m relief (CAP)
Site type: calciphytic pearl bluebush shrubland (CPBS)
Surface condition: soft
Surface mantle: common (10-20%) medium (6-20 mm) subangular calcrete fragments, minor (<10%) calcareous
Principal Profile Form: Um1.33

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-17</td>
<td>A1k</td>
<td>red (2.5YR4/6) fine sandy loam; massive; earthy fabric; many (20-50%) very coarse (&gt;50 mm) rounded calcareous fragments; highly calcareous; pH 8.5, on firm, hardsetting. The soils generally have earthy fabric and massive structure; some profiles show weak pedality with rough faced peds. Profiles contain a range of coarse fragments; usually calcareous, ferruginous or siliceous, as well as weathering material; there are usually few to many (5-50%) coarse fragments. The soils have alkaline soil reaction trends with topsoil pH values between 6.5 and 9.0, and subsoil between 8.5 and 9.5, they may be calcareous throughout the solum. Principal Profile Forms: Um5.51, also Gc1.12, Gn2.23.</td>
</tr>
<tr>
<td>17+</td>
<td>Cmk</td>
<td>calcrete.</td>
</tr>
</tbody>
</table>

b) calcareous red earth on greenstone (13 sites) - uniform, medium and gradational textured soils underlain by greenstone with a calcrete veneer, most commonly very shallow (less than or equal to 30 cm deep) but may be up to 100 cm deep. They have a mantle of greenstone, quartz or ironstone pebbles (2-60 mm), and may have <10% bedrock exposed. They occur on hills and low rises and their footslopes, and plains on greenstone systems which are calcareous in part (in the south-west of the survey area).

Textures are most commonly fine sandy loam, sandy clay loam and clay loam, and may grade into light clay. Surface condition is firm or hardsetting. The soils generally have earthy fabric and massive structure; some profiles show weak pedality with rough faced peds. Profiles contain a range of coarse fragments, usually calcareous, ferruginous or siliceous, as well as weathering material; there are usually few to many (5-50%) coarse fragments. The soils have alkaline soil reaction trends with topsoil pH values between 6.5 and 9.0, and subsoil between 8.5 and 9.5, they may be calcareous throughout the solum. Principal Profile Forms: Um5.51, also Gc1.12, Gn2.23.

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>A1k</td>
<td>dark reddish brown (2.5YR3/4) clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) subangular calcrete fragments and few (2-10%) medium (6-20 mm) angular tabular weathering material; very highly calcareous; pH 6.0, on firm, algal crusting</td>
</tr>
<tr>
<td>15+</td>
<td>Cmk</td>
<td>calcrete veneer, on greenstone</td>
</tr>
</tbody>
</table>

c) deep calcareous red earth (13 sites) - uniform, medium and gradational textured soils, overlying calcrete at 60 cm or greater. These occur on plains and drainage tracts associated with groundwater calcretes and in calcareous sandplain systems.

The uniform, textured profiles are sandy clay loam and clay loam, the gradational soils may grade through sandy loam, sandy clay loam and clay loam to light clay. Soils have earthy fabric and massive structure, and firm surface condition. The profile has an alkaline soil reaction trend with topsoil pH between 6.0 and 8.0, and subsoil pH between 8.5 and 9.5. The profiles have non-calcareous topsols and highly calcareous subsoils which may contain common (10-20%) inclusions of medium (5-20 mm) calcrete fragments at depth. Principal Profile Forms: Um5.52, Gn2.13.

Representative profile

Site details

Site number: 179, Adelong station
Land system: Doney
Land unit: level plain with loamy soil (PLO)
Site type: calcareous plain eucalypt mallee/ acacia shrubland (CEAS)
Surface condition: firm, algal crusting
Principal Profile Form: Gn2.13.

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>A</td>
<td>dark red (2.5YR3/6) sandy loam; massive; earthy fabric; non calcareous; pH 6.5; gradall boundary to</td>
</tr>
<tr>
<td>25-45</td>
<td>B11</td>
<td>dark red (2.5YR3/6) sandy clay loam; massive; earthy fabric; non calcareous.</td>
</tr>
</tbody>
</table>
Group 4 - Red earths (199 sites)

These soils have uniform, medium textures or gradational texture profiles. Textures of the former are fine sandy loam, sandy clay loam and clay loam. The gradational profiles are loamy sand or sandy loam over sandy clay loam or clay loam. They most commonly have earthy fabric and massive structure.

The soils are red - 2.5YR, generally 2.5YR 3/6 (dark red) and occasionally 2.5YR 4/6 (red). The solum is commonly underlain by red-brown hardpan at variable depth. The cemented hardpan layer is treated as substrate. The soils are generally acidic, with pH values between 4.0 and 7.0, except where they are overlying calcrete and subsoil pH is between 7.5 and 9.5. Principal Profile Forms include Um1.43, Um5.51, Um5.51 and Gm2.11.

Eight soils are recognised in this group:

a) red earth on calcrete or calcrete veneer on bedrock (18 sites) - very shallow (less than or equal to 30 cm) uniform textured soils and deeper gradational textured soils (60-100 cm) on calcrete or calcrete veneer over granite or greenstone. The solum is carbonate free. These soils occur on plains associated with groundwater calcrites and in granite systems and on low rises and stony plains in greenstone terrain.

The soils have neutral or alkaline soil reaction trends with topsoil pH values between 6.0 and 7.5. The solum contains fine quartz gravel (2-6 mm), or may contain calcrete fragments becoming larger (6-20 mm) and more abundant immediately above the calcrete horizon.

Principal Profile Forms: Um1.43, Um5.51, Gm2.13, Gn1.12, Gm1.13.

Representative profile

Site details
Site number: 214, Kookynie station
Land system: Gundockerta
Land unit: gently undulating plain with a stony mantle (PGS)

Site type: calciphytic pearl bluebush shrubland (CPBS)
Surface condition: hardsetting and algal crust
Surface mantle: many (20-50%) large (20-60 mm) subangular tabular pebbles of mixed lithology; calcceous, quartz and siltstone with 10-50% exposed siltstone

Principal Profile Form: Um1.43

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>A</td>
<td>dark red (2.5YR3/6) fine sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.5, on</td>
</tr>
<tr>
<td>10+</td>
<td>CmK</td>
<td>calcrete.</td>
</tr>
</tbody>
</table>

b) shallow red earth on granite (30 sites) - shallow, uniform, medium textured and gradational textured soils on granite, usually very shallow (at less than 30 cm) or shallow (at less than 60 cm) in drainage tracts. These soils occur on the plateaux, plains and drainage tracts of granite systems. The plains have many to abundant (20-90%) granite cobbles (60-200 mm) and > 10% bedrock exposed. The plains may have common to abundant (10-90%) large pebbles (20-60 mm) or coarse fragments of mixed size, mostly quartz; they often have minor (< 10%) granite bedrock exposed. Lower plains have varying amounts of small to medium quartz or ironstone pebbles (2-20 mm) and the drainage tracts have nil or very few (<2%) surface coarse fragments.

The uniform textured profiles are generally sandy clay loam, often with a coarse sand fraction. The gradational profiles have lighter textures at the surface; loamy sand or sandy loam, over sandy clay loam, and occasionally over clay loam or coarse sandy clay. The surface condition is generally hardsetting. They have an earthy fabric and massive structure.

The solum contains few (2-10%) small to medium (2-20 mm) coarse fragments of quartz, weathered material or ferruginous material. The soils are acidic or neutral, with pH between 4.0 and 7.0.

Principal Profile Forms: Um1.43, Um5.51, Gm2.11, Gm2.12.
Site type: stony plain acacia-eremophila shrubland (SAES)

Surface condition: hardsetting, algal crust

Surface mantle: many (20-50%), mixed size subangular granite, silcrete and quartz pebbles, minor (<10%) granite exposed

Principal Profile Form: Um5.51

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12 &amp; 12-16</td>
<td>A</td>
<td>red (2.5YR4/6) sandy clay loam; massive; earthy fabric; few (2-10%) medium (6-20 mm) angular quartz gravel; pH 5.0; abrupt boundary to red (2.5YR4/6) clay loam; massive; earthy fabric; common (10-20%) medium (6-20 mm) angular platy fragments of weathered material; pH 5.0; on granite.</td>
</tr>
<tr>
<td>18+</td>
<td>R</td>
<td>Ferruginous gravel; pH 5.0, on granite.</td>
</tr>
</tbody>
</table>

**c)** shallow red earth with a stony mantle, on rocks associated with the greenstone domain (34 sites) - uniform, medium textured soils over greenstone or associated rocks at less than 60 cm depth. They have many to abundant (20-90%) surface coarse fragments, ranging in size from small pebbles (2-6 mm) to cobbles (60-200 mm), and in lithology through ironstone, laterite, quartz and sedimentary rocks. These soils occur on hillslopes, footslopes and plains associated with limonite and greenstone hills, slopes of hills composed of sedimentary rocks and banded ironstone, and on plains of felsic volcanic rock systems.

The textures are fine sandy loam, sandy clay loam and clay loam. Surface condition is firm or hardsetting. The soils have a massive structure and most have earthy fabrics. The solum contains varying amounts (between 2 and 20%) of fine to medium (2-20 mm) ferruginous fragments, quartz and weathering material. The soils are generally acidic with pH between 4.5 and 6.5

Principal Profile Forms: Um5.51, Um1.43.

**Representative profile**

**Site details**

Site number: 423, Mt Weld station

Land system: Brooking

Land unit: gently inclined (5%) hillslope (1ISL) below 10 m high banded ironstone ridge

Site type: stony ironstone mulga shrubland (SIMS)

Surface condition: soft

Surface mantle: abundant (50-90%), mixed size angular ironstone pebbles

Principal Profile Form: Um5.51
common to abundant (10-90%) medium to large (6-60 mm) pebbles. These soils occur on higher plains receiving sheet flow in greenstone and granite terrain. The hardpan commonly forms a thin, discontinuous crust over bedrock.

The textures are sandy clay loam and clay loam, with earthy fabric and massive structure, and hardsetting or firm surface condition. The soil pH ranges between 4.5 and 7.0. The solum may contain varying amounts of fine to medium (2-20 mm) quartz and/or ferruginous gravel.

Principal Profile Forms: Um5.31

**Representative profile**

**Site details**

- **Site number:** 613, Albion Downs station
- **Land system:** Hamilton
- **Land unit:** level plain with a stony mantle and underlain by hardpan (PHG)
- **Site type:** stony plain acacia-eremophila shrubland (SAES)
- **Surface condition:** hardsetting, algal crust
- **Surface mantle:** many (20-50%), large (20-60 mm) subangular quartz pebbles

**Principal Profile Form:** Um5.31

**Profile description**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>A</td>
<td>dark red (2.5YR3/6) sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.0; on</td>
</tr>
<tr>
<td>20+</td>
<td>Dm</td>
<td>hardpan.</td>
</tr>
</tbody>
</table>

**g) deep red earth** (40 sites) - deep (> 60 cm) uniform, medium textured soils with a surface horizon texture which is loamy rather than sandy (as with 4f). The solum may be underlain by hardpan at > 60 cm depth. These soils occur on plains subject to diffuse sheet flow and on drainage features such as drainage lines, groves and drainage foci on sheet flood plains.

The textures are fine sandy loam, sandy clay loam or clay loam. The solum has an earthy fabric and massive structure. Surface condition is firm or hardsetting. The profiles contain varying amounts of fine to medium (2-20 mm) quartz or ferruginous gravels. Soils are generally acidic with pH between 4.5 and 6.5.

**Principal Profile Forms:** Um5.52, Um5.31.

**Representative profile**

**Site details**

- **Site number:** 515, Erlistoun station
- **Land system:** Ararak
- **Land unit:** vegetation grove (GRO)
- **Site type:** mulga groves on hardpan plains (GRMU)
- **Surface condition:** firm

**Principal Profile Form:** Um5.52
Profile description

Depth (cm) | Horizon | Description
--- | --- | ---
0-30 | A | dark red (2.5YR3/6) fine sandy loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; pH 5.5; gradual boundary to
30-100+ | B2c | dark red (2.5YR3/6) clay fine sandy; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; pH 5.5.

Group 5 - Duplex soils

Duplex soils have a clear to sharp change in texture from a coarse or medium textured surface soil to a finer textured subsoil. The subsoil has a high clay content compared to the topsoil. Surface soil textures range from loamy sand through to clay loam; subsoils are light clay, sandy clay and clay loam. The topsoils are hardsetting. The soils are red (2.5YR), usually 2.5YR 3/6 (dark red) or 2.5YR 4/6 (red); the subsoils are very occasionally yellowish red (5YR 5/6 and 5YR 5/8). The subsoils are generally whole coloured. The soils have neutral or alkaline soil reaction trends, with surface soil pH values higher than 6.0 and subsoil pH values higher than 6.5. Principal Profile Forms include Dr2.12, Dr2.13, Dr2.52 and Dr2.53.

Five soils are recognised in this group:

a) shallow duplex with a stony mantle, on granite (26 sites) - very shallow (<35 cm) duplex soils over granite with a mantle of up to 50% large pebbles (20-60 mm) or of mixed size, generally quartz, and often with minor (<10%) granite outcrop. These soils occur on footslopes and stony plains of granite systems.

The surface soil is coarse textured; loamy sands, sandy loams and fine sandy loams, while the subsoils have finer textures of light clay, sandy clay and clay loam. The subsoil may have massive structure with an earthy fabric, or have weak to moderate pedality with smooth or rough faced peds. The subsoil is red and whole coloured. The topsoil horizons are hardsetting.

The soils most commonly have neutral soil reaction trends with pH values between 6.5 and 8.0, or occasionally alkaline soil reaction trends with subsoil pH values between 8.5 and 9.5.

The solum contains up to 10% fine (2-6 mm) quartz coarse fragments.

Principal Profile Forms: Dr2.12, Dr2.13, Dr2.52, Dr2.53.

b) shallow duplex on greenstone (22 sites) - shallow (<60 cm) duplex soils on rocks associated with the greenstone domain. These soils occur on footslopes and plains where they have an abundant (50-90%) mantle of ironstone or quartz fragments of mixed size, and on drainage tracts where they have a lighter mantle (2-10%) of mixed coarse fragments.

The surface soil textures are heavier than that of 5(a); fine sandy loam, sandy clay loam or loam. The subsoil textures are light clay and clay loam, they are moderately pedal with rough or smooth faced peds, or massive with earthy fabric. The subsoil is red and whole coloured.

The surface soil is hardsetting. The solum may contain up to 20% fine to medium (2-20 mm) quartz of ferruginous fragments.

The soil reaction trend is neutral or alkaline with pH values between 6.0 and 9.0.

Principal Profile Forms: Dr2.12, Dr2.13, Dr2.52, Dr2.53.

Representative profile

Site details
Site number: 087, Yerilla station
Land system: Gransal
Land unit: level plain with a stony mantle (PGS)
Surface mantle: many (20-50%) large (20-60 mm) subrounded ironstone pebbles

Principal Profile Form: Dr2.12

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>A1</td>
<td>red (2.5YR4/6) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 7.0; sharp boundary to</td>
</tr>
<tr>
<td>8-20</td>
<td>B2t</td>
<td>dark red (2.5YR3/6) light medium clay; moderate pedality with rough-faced peds; very few (&lt; 2%) fine (2-6 mm) angular tabular weathering material; pH 6.5 on</td>
</tr>
<tr>
<td>20+</td>
<td>R</td>
<td>felsic volcanic rock.</td>
</tr>
</tbody>
</table>

c) sandy-surfaced saline duplex (74 sites) - saline duplex soils with coarse textured topsoil. They are most commonly shallow (< 60 cm) underlain by hardpan or occasionally granite, but may be more than 1 m deep. These soils occur extensively on saline alluvial plains.

The topsoils are hardsetting and coarse textured; loamy sand, clayey sand and sandy loam and may have a surface crust. The subsoils range from clay loam to sandy clay and light clay. They most commonly have a massive structure and earthy fabric, occasionally they are pedal with smooth-faced peds. They are red and whole coloured.

They have a neutral or alkaline soil reaction trend with pH values between 6.5 and 9.0. The solum may contain up to 10% fine (2-6 mm) quartz or ferruginous fragments. These soils do not have a stony mantle.

Principal Profile Forms: Dr2.52, Dr2.53, occasionally Dr2.12, Dr2.13.

d) shallow duplex on granite (8 sites) - duplex soils with medium textured topsoils, on granite at < 60 cm depth. These soils occur on lower footslopes, alluvial plains and drainage lines in granite terrain.

The surface soils are hardsetting or may have a surface crust; they are loam or sandy clay loam. The subsoils are light clay or sandy clay, with massive structure and earthy fabric. They are red and whole coloured.

The soil reaction trend is neutral or alkaline. The solum contains up to 10% fine (2-6 mm) quartz gravel.

Principal Profile Forms: Dr1.52, Dr2.52, Dr2.53.

Representative profile

Site details

Site number: 590, Vacant Crown Land
Land system: Sherwood
Land unit: very gently inclined narrow (< 500 m wide) drainage floor (DRN) on a gently undulating plain with a stony mantle
Site type: bladder saltbush low shrubland (BLSS)
Surface condition: hardsetting
Surface mantle:

Principal Profile Form: Dr2.52

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>A</td>
<td>reddish brown (2.5YR4/4) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular quartz gravel; pH 6.5; clear boundary to</td>
</tr>
<tr>
<td>30-50</td>
<td>B2</td>
<td>red (2.5YR4/8) light clay; very few (&lt; 2%) medium (6-20 mm) angular tabular silcrete pebbles; pH 7.0; on granite.</td>
</tr>
<tr>
<td>50+</td>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>
The surface soil textures range from fine sandy loam to clay loam, and are firm or hardsetting. The subsoils are light clay, and may increase in texture to medium clay at depth. They commonly have massive structure and an earthy fabric, but may have weak to moderate pedality with rough-faced peds. They are red or yellow, and may have mottling. They have alkaline soil reaction trends with pH between 8.0 and 9.5 at depth.

Principal Profile Forms: Dr2.53, Dr3.53, Dy5.53.

Representative profile

Site details
Site number: 203, Jeedamya station
Land system: Gundockerta
Land unit: gently undulating plain with a stony mantle (PGS)
Site type: calyphytic pearl bluebush shrubland (CPBS)
Surface condition: firm
Surface mantle: many (20-50%) small (2-6 mm) subrounded quartz pebbles

Principal Profile Form: Dy5.53

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>A</td>
<td>red (2.5YR4/6) sandy clay loam; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular ferruginous gravel and few (2-10%) fine (2-6 mm) angular quartz gravel; highly calcareous; pH 8.5; clear boundary to</td>
</tr>
<tr>
<td>25-80</td>
<td>B2k</td>
<td>mottled red (2.5YR6/8) light clay; massive; earthy fabric; few (2-10%) fine (2-6 mm) rounded ferruginous gravel; very highly calcareous; pH 8.5; clear boundary to</td>
</tr>
<tr>
<td>25-100+</td>
<td>Ck</td>
<td>red (2.5YR4/6) medium clay; massive; earthy fabric; few (2-10%) fine (2-6 mm) angular ferruginous gravel; highly calcareous; pH 8.5</td>
</tr>
</tbody>
</table>

Group 6 - Clays
(50 sites)

Clay soils have uniform, fine-textured profiles. Textures are light clay to medium heavy clay. The clays may be earthy or pedal. The layer below the surface horizon is red, except in some cracking clays where it is brown. Soil reaction trends are neutral or alkaline. Principal Profile Forms are Ug5.3, Ufl43 and Ufl6.

Three soils are recognised in this group:

a) cracking clay (7 sites) - uniform, fine-textured soils which show seasonal cracking. The soils swell and shrink on wetting and drying, causing them to crack widely during dry periods. The cracks are greater than or equal to 6 mm wide and penetrate at least 30 cm into the solum. Cracking clays occur on gilgai plains and swamps.

The solum are deep (> 80 cm), and are characterised by smooth-faced peds throughout and a brown or red clay horizon below the surface horizon. The textures are light clay or medium clay which may grade to medium heavy clay at depth.

The solum have alkaline soil reaction trends, with pH between 8.0 and 9.5

Principal Profile Form: Ug5.3.

Representative profile

Site details
Site number: 176, Riverina station
Land system: Bunyip
Land unit: gilgai on a level saline alluvial plain (PLI)
Site type: eucalypt chenopod woodland (PECW)
Surface condition: periodic cracking
Surface mantle: common (10-20%) small (2-6 mm) angular ironstone pebbles

Principal Profile Form: Ug5.3

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>Ak</td>
<td>dark red (2.5YR3/6) medium clay; moderate pedality with smooth-faced polyhedral peds; moderately calcareous; pH 9.5; clear boundary to</td>
</tr>
<tr>
<td>30-100+</td>
<td>Bk</td>
<td>dark red (2.5YR3/6) medium heavy clay; moderate pedality with smooth-faced polyhedral peds; moderately calcareous; pH 8.0</td>
</tr>
</tbody>
</table>

b) red clay (31 sites) - uniform fine-textured soils. These soils occur on alluvial plains and drainage foci on a range of land systems, particularly on highly saline alluvial plains in salt lake systems, drainage lines in granite terrain, and in drainage foci.

The surface soil texture is most commonly light clay, the subsoils may become more clayey; light medium clay or medium clay. The solum may be earthy or dense, or be pedal with smooth or rough faced peds. The solum, below the surface horizon, is whole coloured and red (5YR or redder).

The depth of the solum may vary from 30 cm to greater than 100 cm, underlain by a range of substrates: hardpan, calcrite, metamorphic rock, and granite. It may have a neutral or alkaline soil reaction trend.

Representative profile

Site details

Site number: 651, Barwidgee station
Land system: Cunyu
Land unit: drainage focus (DRF) on a level plain with calcrete rubble
Site type: drainage tract mulga tall shrubland (DRMS)
Surface condition: hardsetting, algal crust
Principal Profile Form: Uf6.12.

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-55</td>
<td>AB</td>
<td>red (2.5YR4/8) light clay; moderate pedality with rough-faced polyhedral peds; pH 7.0; increasing to 8.5 at 45 cm; on</td>
</tr>
<tr>
<td>55</td>
<td>DmK</td>
<td>calcrete.</td>
</tr>
</tbody>
</table>

c) red clay with a stony mantle (12 sites) - uniform, fine-textured soils with common to many (10-50%) medium to large (6-60 mm) pebbles on the surface. These soils occur on stony plains in greenstone terrain.

The soils are shallow, often very shallow with substrate at less than 30 cm. Substrate may be hardpan, metamorphic rock or calcrete.

The textures range from light clay to medium heavy clay, and may increase slightly with depth. The surface condition is hardsetting or firm. The subsoils may be earthy or have smooth or rough faced peds. The solum, below the surface horizon, is whole colored and red (5YR or redder). It has a neutral or alkaline soil reaction trend.

Principal Profile Forms: Uf6.12, Uf6.21, Uf6.71.

Gypsiferous sediments

Gypsiferous sediments occur on salt lake beds and as kopi dunes adjacent to salt lakes. They may be unconsolidated to full depth or consist of a layer of unconsolidated sediments over solid gypsum at less than 100 cm depth. The sediments range in colour from pink (5YR 7/3 or 8/3) to reddish yellow (7.5YR 6/6 or 6/8). They have a pH range between 7.5 and 9.5 and are not commonly calcareous. The sediments form a surface crust which may be up to 4 cm thick. The gypsiferous sediments may be overlain by a layer of aeolian deposited sand.

Representative profile

Site details

Site number: 498, Erlistoun station
Land system: Carnegie
Land unit: gently inclined crest of a large (3 m relief) arcuate kopi dune (KOP) on a level saline alluvial plain
Site type: kopi dune woodland (KOP)
Surface condition: crusted

Profile description

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>ACy</td>
<td>pink (5YR7/3) gypsiferous powder; non calcareous; pH 7.5 on</td>
</tr>
<tr>
<td>50+</td>
<td>Cmy</td>
<td>consolidated gypsiferous sediment.</td>
</tr>
</tbody>
</table>

Soil distribution

The soils described are often associated with a particular part of the landscape. Table 2 lists land units and the soils which occur in them. In the 'Land systems' chapter soils found on each land unit within land systems are identified. The land system maps can then be used to provide a picture of the distribution of soils in the survey area.
Table 2. Land units, associated soils, and their occurrence in land systems

<table>
<thead>
<tr>
<th>Land unit code</th>
<th>Land unit</th>
<th>Dominant soil</th>
<th>Associated soil</th>
<th>Land systems in which soil association is dominant or characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAP</td>
<td>calcrete platforms in trunk valleys</td>
<td>1a</td>
<td>3a</td>
<td>Cosmo, Cunyu, Mileura</td>
</tr>
<tr>
<td>PLU</td>
<td>plains at the foot of granite rises</td>
<td>1b</td>
<td></td>
<td>Bandy, Challenge</td>
</tr>
<tr>
<td>PLL/RIL</td>
<td>plains and low rises with ferruginous lag</td>
<td>1d, 4g</td>
<td></td>
<td>Ararat, Illara, Moriarty</td>
</tr>
<tr>
<td>BAS</td>
<td>wanderie banks</td>
<td>1e</td>
<td>1g, 4f</td>
<td>Duketon, Tiger</td>
</tr>
<tr>
<td>DJN</td>
<td>sand dunes</td>
<td>1f</td>
<td></td>
<td>Bullimore, Marmion</td>
</tr>
<tr>
<td>SSH</td>
<td>sandplain</td>
<td>1g</td>
<td></td>
<td>Bullimore, Marmion, Yowie</td>
</tr>
<tr>
<td>DOM/TOR</td>
<td>granite domes and tors</td>
<td>rock outcrop</td>
<td>pockets of detrital sand</td>
<td>Hospital, Wyarri</td>
</tr>
<tr>
<td>PTX, HSL, HIL, RDG</td>
<td>plateaux, hills, hill slopes and ridges with exposed rock</td>
<td>2</td>
<td>rock outcrop</td>
<td>Brooking, Laminar, Lawrence, Teutonic</td>
</tr>
<tr>
<td>PLC</td>
<td>plains with underlying calcrete</td>
<td>3a</td>
<td>1a</td>
<td>Cunyu, Deadman</td>
</tr>
<tr>
<td>HIL/RIL/FOL/PGS</td>
<td>low hills and rises, footslopes and plains on calcareous greenstones</td>
<td>3b</td>
<td>5b</td>
<td>Graves, Gundockerta</td>
</tr>
<tr>
<td>PLO/DRN</td>
<td>plains and drainage tracts in calcareous systems</td>
<td>3c</td>
<td>1a</td>
<td>Deedman, Doney, Kirgeila</td>
</tr>
<tr>
<td>PLC</td>
<td>plains with underlying calcrete veneer on granite or greenstones</td>
<td>4a</td>
<td></td>
<td>Gransel</td>
</tr>
<tr>
<td>PLG</td>
<td>stony plains on granite</td>
<td>4b and 1c</td>
<td></td>
<td>Sherwood, Wagin, Windarra</td>
</tr>
<tr>
<td>PLG</td>
<td>stony plains on greenstones</td>
<td>4c</td>
<td></td>
<td>Felix, Violet</td>
</tr>
<tr>
<td>PLH</td>
<td>sheet flood plains underlain by massive hardpan</td>
<td>4d</td>
<td>1e</td>
<td>Monk, Rainbow, Tiger, Wilson</td>
</tr>
<tr>
<td>PHG</td>
<td>stony upper plains with underlying hardpan</td>
<td>4a</td>
<td></td>
<td>Duketon, Hamilton, Sunrise</td>
</tr>
<tr>
<td>DRN</td>
<td>drainage zones in sandplains</td>
<td>4f</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRO</td>
<td>vegetation groves on sheet flood plains</td>
<td>4g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLO</td>
<td>plains with loamy soils</td>
<td>1g and 4g</td>
<td>1e, 4f</td>
<td>Ararak, Desdemona, Yanganco, Yowie</td>
</tr>
<tr>
<td>FGS</td>
<td>saline stony slopes on granite</td>
<td>5a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGS/FOL</td>
<td>saline footslopes and stony plains on greenstones</td>
<td>5b</td>
<td></td>
<td>Hootauui, Leonora, Yilangani</td>
</tr>
<tr>
<td>PLA</td>
<td>saline alluvial plains</td>
<td>5c</td>
<td></td>
<td>Carnegie, Cyclopa, Gumbreak</td>
</tr>
<tr>
<td>DRN</td>
<td>drainage lines below granite uplands</td>
<td>5d</td>
<td>6b</td>
<td>Crot, Gumbreak, Hamilton</td>
</tr>
<tr>
<td>PLS</td>
<td>highly saline alluvial plains</td>
<td>6b, 6c, 5c</td>
<td></td>
<td>Darlot, Yilangani</td>
</tr>
<tr>
<td>PLI</td>
<td>gilgais</td>
<td>6a</td>
<td></td>
<td>Bunyip, Doney</td>
</tr>
<tr>
<td>DRF</td>
<td>drainage foci</td>
<td>6b</td>
<td></td>
<td>Cunyu, Melaleuca, Steer</td>
</tr>
<tr>
<td>CLA</td>
<td>claypans</td>
<td>6b</td>
<td></td>
<td>Darlot, Pan</td>
</tr>
<tr>
<td>CHM</td>
<td>drainage channels</td>
<td>alluvial deposits</td>
<td></td>
<td>Hamilton, Monitor, Wilson</td>
</tr>
<tr>
<td>LAB</td>
<td>floors of salt lakes</td>
<td>saline sediments</td>
<td></td>
<td>Carnegie</td>
</tr>
<tr>
<td>KOP</td>
<td>kopis dunes flanking salt lakes</td>
<td>gypsiferous sediments</td>
<td></td>
<td>Carnegie, Darlot</td>
</tr>
</tbody>
</table>
Some of the land units are characterised by deposits rather than by developed soils. Alluvial deposits occur in active flow channels. Saline sediments occur in the lake beds of salt lake systems. Gypsumiferous sediments, as described previously, occur on salt lake beds and as copi dunes adjacent to salt lakes.

Deep earthy red sand and shallow red earth on hardpan, with or without a stony mantle, are the most widespread soils in the survey area. Deep earthy red sand occurs on extensive sandplains in the north, east and south-west of the survey area. Shallow red earth on hardpan occurs on level to gently inclined plains carrying sheet flow from uplands to salt lakes throughout the survey area.

Red sands occur principally on sandplain, wanderrie banks and dunes. Lithosols occur on hills and breakaway plateaux throughout the survey area. Calcareous red earths occur in areas affected by groundwater calcretes, predominantly in the south-western part of the survey area but also associated with the salt lake chains throughout the survey area. Red earths occur on plains and drainage zones throughout the survey area. Duplex soils occur in localised areas, in particular on saline alluvial plains associated with the salt lake systems and on footslopes below granite breakaways or greenstone hills. Clay soils occur in localised areas on highly saline alluvial plains, gilgais, claypans and on drainage features such as drainage foci.

Soil erosion

Disturbance of the soil surface, such as loss of vegetative cover, reduced cryptogamic crusting or removal of the stony mantle, may lead to accelerated erosion in areas which are susceptible to erosion.

Many of the land surfaces of the survey area are protected from erosion in a number of ways; by the generally low relief; generally level to gently inclined slopes of the plains which promote low velocity diffuse sheet flow; extensive cryptogamic crusting, particularly on the sheet flow plains and on the alluvial plains associated with the salt lakes; common gravelly and stony mantles; and predominantly hardsetting or firm surface condition.

The following soils are generally protected by a stony mantle: shallow red sands (1b, 1c), red sand with ferruginous gravel (1d), lithosols (2), shallow red earths on rock (4b, 4c) and red earth and red clay with a stony mantle (4e, 6c).

The deep sands of the sandplain and dunes (1f, 1g) are stabilised by vegetation. However, after fire they are susceptible to wind erosion until adequate vegetative cover is restored. Red sands on calcrite or hardpan (1a, 1e) may be subject to wind erosion.

Shallow calcareous red earths (3a), calcareous red earth on greenstone (3b) and red earths on calcrite (4a), are susceptible to water erosion. Red earths on hardpan without a protective stony mantle (4d) and deep red earths (4g) are subject to water erosion through sheet flow and to wind erosion.

The duplex soils are the most susceptible to erosion. Shallow duplex soils on rock (5a, 5b, 5d) are particularly susceptible to water erosion where they occur on footslopes and drainage lines. Sandy-surfaced saline duplexes (5c) are susceptible to water and wind erosion. Secondary salinisation was observed on duplex soils, particularly on alluvial plains associated with the salt lake systems. When the topsoil is removed by wind and/or water erosion, the exposed clay subsoils disperse when they are wet and then seal, preventing further infiltration of water. Sodium, in the form of salt, is drawn up by capillary action causing the top of the subsoil horizon to become more saline and less suitable for plant growth, thus not allowing the area to regenerate. An area of high salinity, high sodicity and very low permeability at the soil surface is left (Hubble et al. 1983).

Cracking clays (6a) have stable surfaces. Red clays without a protective stony mantle (6b) are subject to water and wind erosion.

Accelerated erosion was recorded at 10.3% of the traverse assessments in the survey area (see the 'Resource condition' chapter). Of the recordings 8.9% were slight, minor or moderate (i.e. up to 50% of the surface affected) and 1.4% were severe or extreme (> 50% of the surface affected). Most of the accelerated erosion recorded was caused by water, rather than wind; rilling, scalding and micro-terracing (or sheeting) were the most common types of erosion observed.

At the inventory sites severe or extreme erosion (i.e. >75% of the site affected) was only observed on two soil types: sandy-surfaced saline duplex (5c) and shallow duplex with a stony mantle, on granite (5a). Sandy-surfaced saline duplex soils occur on alluvial plains associated with salt lakes, while shallow duplex soils with a stony mantle, on granite, occur on footslopes and saline stony plains. The land units on which these soils occur are susceptible to water erosion as they receive run-on from upland areas, and they support halophytic shrublands which are subject to preferential grazing. The sites with severe or extreme erosion have reduced vegetative cover with projected foliar cover between 2.5 and 10%.

Moderate erosion (i.e. 25-30% of the site affected) was recorded on these soils, and on shallow red earth on hardpan (4d), shallow duplex on greenstone (5b), shallow duplex on granite (5d) and red clay (6b).

Minor erosion (i.e. 10-25% of the site affected) was recorded on red sand on hardpan (1e), shallow calcareous red earth on calcrite (3a), red earth on calcrite (4a) and deep red earth (4g).

Slight (i.e. <10% of the site affected) or no accelerated erosion was observed at inventory sites on all other soil types.

Soils and land use

The most extensive land use in the survey area is pastoralism where native vegetation is grazed by domestic stock. Most arid zone soils are low in chemical fertility because of the pre-weathering of the
soil parent material. The soils within the survey area are generally shallow, underlain by hardpan or rock, and thus have low water-holding capacity. Vegetation types with high pastoral value are generally restricted to areas with a favourable combination of soil and drainage patterns, such as the duplex soils on alluvial plains receiving run-on which support low halophytic shrublands. At the other extreme, the deep red sands of the sandplain and dunes rely on rainfall for moisture and have very low water holding capacity because of the lack of finer particles which hold moisture. They support spinifex hummock grasslands with very low pastoral value.

This survey has identified 452 km² with severely degraded vegetation and eroded soils. This damage has been caused by many factors, including inappropriately high stock rates (often associated with large numbers of native and feral animals) and inappropriate location of station infrastructure such as watering points, tracks and fences.

Table 3 shows the erosion hazard for pastoral land use of land units in the survey area, as determined by the inherent susceptibility of the soil to erode (as discussed previously) and by the pastoral value of the vegetation it supports.

Mining occurs throughout the survey area although its impacts are very localised. Disturbance as a result of mining or minor exploration was recorded at 0.74% of the traverse assessments in the survey area.

Mining is largely confined to the greenstone domain; to the hills and ridges (such as Bevon and Brooking land systems), and the erosional surfaces below them (such as Gundockerta, Violet and Nubev land systems). To a lesser extent, mining affects the alluvial plains based on hardpan (such as Kundee, Monk and Tiger land systems). The soils on the hills, ridges and erosional plains are often protected by a stony mantle; rills and gutters may develop downslope if the mantle is disturbed. Gridlines and tracks need to be appropriately located and constructed to minimise disturbance on sensitive areas. For example, on plains carrying sheet flow, any disturbance to the soil or vegetation should be minimised to avoid channelling flow along disturbed or compacted areas. Minimising disturbance should include such practices as the use of root rakes or raised blades to roll the vegetation with minimal soil disturbance and the avoidance of vehicle movements during wet conditions where tracks left would lead to an erosion hazard.

The Chamber of Mines of Western Australia (undated) have produced exploration guidelines for the mining industry which emphasise the need for environmental care. The Department of Minerals and Energy impose conditions on all mining tenements which require minimal environmental impact. Any disturbance to the surface of the land caused by exploration and mining activities must be rehabilitated to a non-erodible self-sustaining condition.

Tourism is not an intensive land use in the survey area. Impacts of this land use on the soils would be from uncontrolled vehicular movement. Fragile areas, such as breakaway footslopes, may need to be protected from unrestricted access.

### Regeneration of degraded land

For successful regeneration there must be adequate available soil moisture for plant germination and establishment and suitable niches on the soil surface in which a seed can lodge, germinate and establish.

Many techniques may be used to trap and use rainfall and run-off to provide soil water. These include land shaping (such as embankments and water ponding), cultivation techniques (using implements such as ploughs and pitters which also provide a suitable bed for seeds), and soil amelioration. Soil amelioration may be required for soils which contain high levels of salts, particularly sodium salts. The low levels of available soil moisture often associated with these saline or sodic soils can be improved with soil ameliorants. Regeneration trials in the arid shrublands showed gypsum to be a successful soil ameliorant in encouraging perennial shrub establishment on sodic soils (Ward 1990).

Successful stabilisation will depend, very largely, on the regeneration of vegetative cover coupled, in some cases, with earth works.

All these techniques have limitations, and selection of the most suitable ones will depend on soil type and position in the landscape. Some techniques are described in detail in Williams and Shepherd (1991).

### Table 3. Land units with associated soil and vegetation type, pastoral value and erosion hazard for pastoral land use

<table>
<thead>
<tr>
<th>Land unit</th>
<th>Soil type</th>
<th>Vegetation type</th>
<th>Pastoral value</th>
<th>Erosion hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcrete platforms in trunk valleys</td>
<td>Red sand and calcreaceous red earth on calcrete (t, e, 3a)</td>
<td>Calcrete platform woodlands/shrublands and calephytytic pearl blue bush shrublands (CAPW, CPBS)</td>
<td>High</td>
<td>Low-moderate</td>
</tr>
<tr>
<td>Plains at the foot of granite rises</td>
<td>Shallow red sand on granite (1b)</td>
<td>Sandy granitic acacia shrublands (SGRS)</td>
<td>Low</td>
<td>Very low</td>
</tr>
</tbody>
</table>
Table 3.—continued

<table>
<thead>
<tr>
<th>Land unit</th>
<th>Soil type</th>
<th>Vegetation type</th>
<th>Pastoral value</th>
<th>Erosion hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains and low rises with ferruginous lag</td>
<td>Red sand and deep red earth with ferruginous lag (1d 4g)</td>
<td>Laternitic hardpan mulga tail shrublands or laternitic mulga wanderrie grassy shrublands (LMMS, LMWS)</td>
<td>Moderate</td>
<td>Very low</td>
</tr>
<tr>
<td>Wanderrie banks</td>
<td>Red sand or hardpan or sandy-red earth (1e, 1g, 1f)</td>
<td>Wanderrie bank mulga wanderrie grassy shrublands (WABS)</td>
<td>Moderate</td>
<td>Very low-low</td>
</tr>
<tr>
<td>Sand dunes</td>
<td>Deep siliceous red sand (1f)</td>
<td>Sand dune shrubland (SDHS, SASP)</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Sandplain</td>
<td>Deep earthy red sand (1g)</td>
<td>Sandplain spinifex hummock grassy shrublands (SASP, SACS)</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Granite domes and tors</td>
<td>Rock outcrop with pockets of detrital sand</td>
<td>Granite hill mixed shrublands (GRHHS)</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Plateaux, hill crests and slopes, ridges and low rises with exposed rock</td>
<td>Lithosols and rock outcrop (2)</td>
<td>Breakaway mixed shrublands, greenstone hill acacia shrublands and greenstone hill (non-halophytic) eucalypt woodlands (BRXS, GHAS, GNEW)</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Plains with underlying calcrete</td>
<td>Shallow calcareous red earth and red sand on calcrete (3a, 1a)</td>
<td>Calyphytic casuarina acacia woodlands/shrublands (CCAS)</td>
<td>Moderate</td>
<td>Low-moderate</td>
</tr>
<tr>
<td>Low rises, footslopes and plains on calcareous greenstone</td>
<td>Calcareous red earth and shallow duplex on greenstone (3b, 5b)</td>
<td>Eucalypt chenopod woodlands (PECW)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Plains and drainage tracts in calcareous systems</td>
<td>Deep calcareous red earth and red sand on calcrete (3c, 1a)</td>
<td>Calcareous plain eucalypt malleae/acacia shrublands (CEAS)</td>
<td>Low</td>
<td>Very low-low</td>
</tr>
<tr>
<td>Stony plains and drainage tracts on granite</td>
<td>Red earth and shallow red sand, with a stony mantle, on granite (4b, 1c)</td>
<td>Stony plain acacia-eremophila shrublands (SAE)</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Hillslopes and stony plains on greenstones</td>
<td>Shallow red earth on greenstone (4c)</td>
<td>Stony ironstone mulga shrublands (SIMS)</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Sheet flood plains underlain by massive hardpan</td>
<td>Shallow red earth on hardpan (4d)</td>
<td>Hardpan wash plain scattered mulga tail shrublands (HPMS)</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Stony upper plains with underlying hardpan</td>
<td>Shallow red earth, with a stony mantle, on hardpan (4e)</td>
<td>Upland small bluebush species shrublands (USBS)</td>
<td>Moderate</td>
<td>Very low</td>
</tr>
<tr>
<td>Vegetation groves on sheet flood plains</td>
<td>Deep red earth (4g)</td>
<td>Mulga groves on hardpan wash plains (GRMU)</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Plains with loamy soils</td>
<td>Deep earthy red sand or red earth (1g, 4g)</td>
<td>Mulga wanderrie grassy shrublands (MUWA)</td>
<td>Moderate</td>
<td>Very low-low</td>
</tr>
<tr>
<td>Saline lower footslopes and stony plains on granite</td>
<td>Shallow duplex with a stony mantle, on granite (5a)</td>
<td>Saline bluebush mixed shrublands (SBMS)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Saline footslopes and stony plains on greenstone</td>
<td>Shallow duplex on greenstone and red clay with a stony mantle (5b, 6c)</td>
<td>Calyphytic pear bluebush shrublands/woodlands and stony bluebush mixed shrublands (CPBS, SBMS)</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Where degradation has been severe it may not be possible to regenerate the land, for example, where the topsoil has been removed, exposing subsoil which has become sealed. The original plant species which were adapted to previous conditions may now be excluded by new conditions they cannot tolerate. It is necessary to stabilise these areas if they are undergoing active accelerated erosion. The only option may be to control total grazing pressure and to avoid further disturbances such as the construction of tracks or gridlines.

### References


Chamber of Mines of Western Australia (undated). Exploration guidelines for field personnel. Perth, Western Australia.


Vegetation

H.J.R. Pringle

The major vegetation formations within the survey area as mapped by Beard (1974, 1975, 1976 and 1981a) are described in the 'Regional vegetation' chapter of the Review section of this report. The survey described here developed further on Beard's work and that of Dell et al. (1988) and Dell et al. (1992) by investigating aspects of the biophysical environment in more detail.

A summary of major taxa recorded during the survey is presented in the first part of the chapter. There are numerous plant forms within these taxa, ranging from short-lived ephemeral grasses and forbs to long-lived trees that exceed 10 m in height. The major plant forms and the physical environments with which they are commonly associated are discussed in the second part of this chapter.

Regional patterns of distribution are discussed at a plant community and species level, putting the survey into a broader biogeographic perspective in the third section of this chapter.

Vegetation patterning occurs at a number of scales, largely driven by variations in scales at which physical environmental variables or processes occur or operate. These various scales of patterning are briefly discussed. A detailed ecological classification at a landform/plant community scale has been developed and is presented in the subsequent 'Ecological assessment' chapter of this report. Finally, the important topic of nature conservation is discussed - in this instance it is restricted to consideration of vegetation and floristic conservation. The links between the conservation status of various components of the biota, and between the living and non-living components of ecosystems, are generally beyond the current scope of rangeland surveys.

Taxonomic summary

The plant taxonomy used is that recommended by the Western Australian Herbarium and is based on the Census of Vascular Plants of Western Australia (Green 1985) and its most recent cumulative supplement (No. 7-November 1988).

Eight hundred and twenty-five species of vascular plants representing 290 genera in 82 families were collected during the survey, including 619 perennial species and 206 annuals. A small number of botanical families contain a large proportion of perennial plant species (see Table 1). Within these families, the genera Acacia, Eremophila and Cassia (Senna) are predominant in shrub communities, Atriplex and Maireana in low Chenopod shrublands, Acacia and Eucalyptus in low woodlands and Triodia in hummock grasslands.

Table 1. Major families and dominant genera of perennial plant species in the survey area

<table>
<thead>
<tr>
<th>Family</th>
<th>Number of species</th>
<th>Dominant genera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthaceae</td>
<td>8</td>
<td>Pilosella</td>
</tr>
<tr>
<td>Caesalpinioideae</td>
<td>11</td>
<td>Casea (Senna)</td>
</tr>
<tr>
<td>Chenopodiaceae</td>
<td>71</td>
<td>Atriplex, Halosarcia, Maireana, Rhagodia</td>
</tr>
<tr>
<td>Malvaceae</td>
<td>17</td>
<td>Lawrence, Sida</td>
</tr>
<tr>
<td>Mimosaceae</td>
<td>55</td>
<td>Acacia</td>
</tr>
<tr>
<td>Myoporaceae</td>
<td>56</td>
<td>Eremophila</td>
</tr>
<tr>
<td>Myrtaceae</td>
<td>88</td>
<td>Eucalyptus, Melaleuca, Thryptomene</td>
</tr>
<tr>
<td>Poaceae</td>
<td>38</td>
<td>Eragrostis, Eriachne, Plectrochne, Triodia</td>
</tr>
<tr>
<td>Proteaceae</td>
<td>30</td>
<td>Grevillea, Hakea</td>
</tr>
<tr>
<td>Solanaceae</td>
<td>13</td>
<td>Solanum</td>
</tr>
</tbody>
</table>

The Myrtaceae contained the greatest number of species, many of which are found exclusively on the extensive sandplains of the survey area, often in conjunction with Triodia basedowii (hard spinifex). The second largest family is the Chenopodiaceae whose species characterise alluvial plains flanking salt lake systems. The Poaceae (grasses) are found in a wide variety of environments, most prominently on deep, coarse textured soils, whilst the Myoporaceae consists mainly of the genus Eremophila, which occurs on all soil types in the survey area but is most conspicuous and diverse on neutral to acidic loams. The acacias dominate the Mimosaceae, are most diverse in sandplain, and frequently provide the dominant taxa on neutral to acidic red earths.

Detailed lists of plant species are collated in Appendix 1 of this report, the contents of which are summarised in Table 2. While declared rare and priority flora are listed in the flora conservation section of this chapter, not all of these species were observed or collected during this survey project.

Table 2. Contents of Appendix 1 - plant species lists

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(i)</td>
<td>All collected perennial species, distribution, life form and habitat</td>
</tr>
<tr>
<td>1(ii)</td>
<td>Common perennial species with common names</td>
</tr>
<tr>
<td>1(iii)</td>
<td>Collected and recorded annual species</td>
</tr>
<tr>
<td>1(iv)</td>
<td>Collected lichens and mosses</td>
</tr>
</tbody>
</table>

Major plant forms and their environmental associations

The major plant forms encountered are ephemeral grasses and forbs, perennial grasses, low (< 1 m tall) and mid shrubs (1 to 2 m tall), tall shrubs (> 2 m tall), mallees and trees. They generally occur together in combinations reflecting various environmental influences, past and present. Their combinations are described in the 'Ecological assessment' chapter of this report.
Annual or short-lived bunch grasses

As Beard (1990) observed, annual or ephemeral grasses are favoured by summer rains. They are sometimes present throughout the year. However, they are most abundant following rains in the warmer months of the year. Ephemeral grasses occur in a variety of environments, few of which do not support them at some time of the year in good seasons.

*Aristida contorta* (wind grass) is a very widely occurring species found on non-saline soils. It is most conspicuous on stony plains where it is often the dominant plant in good seasons. *Eragrostis dielsii* (maile love grass) is common in environments in which perennial halophytes predominate, whilst *Dactyloloenium radulans* (button grass) is often encountered on heavier soils in the north of the survey area. Annual or short-lived bunch grasses sometimes present throughout the year. *Eriachne flaccida* (claypan grass) is a common component of these communities, whilst *Digitaria broomii* and *Eragrostis* sp. were also encountered. These grasses are more common to the north of the survey area where non-saline clay soils are more common. Their occurrence to the west of the survey area would suggest that soil factors rather than climate limit their distribution in the survey area.

**Ephemeral forbs**

The ephemeral forbs are spectacular in good winter seasons, developing into colourful mosaics of yellow, pink and white between scattered perennial plants. The dominant wildflower genera include *Cephalotespernum*, *Erodium*, *Velleia*, *Ptilotus*, *Brunonia*, *Helipterum*, *Gnepisus*, *Ptilotus*, *Brachycome* and *Waitzia*. Ephemeral forbs are also common in both summer and winter across a wide environmental range. *Sclerochaeta* (bindus) is the dominant genus in this group. Species of the *Amaranthaceae*, *Chloanthaceae* and *Goodeniaceae* are common fire ephemerals in hummock grasslands.

**Perennial grasses**

Perennial grasses are common throughout the survey area. They occur in quite specific groups which correspond closely with edaphic factors. Two major groups or alliances may easily be recognised in the field: the wanderrie bunch grasses and the spinifex hummock grasses. In the north of the area there are also isolated pockets of claypan bunch grasses. These groups are dealt with in some detail in the following 'Ecological assessment' chapter of this report.

a) **Bunch grasses**

Wanderrie grasses occur predominantly on soil intermediate between the deep coarse sands supporting spinifex hummock grasslands and the shallow clay loams supporting extensive *Acacia aneura* (mulga) tall shrublands. As such, wanderrie grasses are found on sandy tracts (e.g. wanderrie banks) in *A. aneura* plains, and run-on areas in spinifex hummock grassland sandplains. However, they occur most extensively in broad plains with deep sandy loam or loamy sand soils, particularly in the northern half of the survey area. Scattered *A. aneura* trees or tall shrubs are usually present.

*Eragrostis criopoda* (woolly butt) is easily the most widespread and abundant of the wanderrie grasses, followed by *Eriachne helmsii* (buck wanderrie), *Monachather paradoxa* (broad-leaved wanderrie) and *Thyridolepis* species (*T. multiculmis* and *T. michelliana* - soft wanderrie) only occur as true perennials in the northern extreme of the survey area, and then only patchily. Elsewhere, these species appear to perenniate only if there is a succession of good seasons.

A less common group of perennial bunch grass species is found on clay soils in run-on areas such as claypans and drainage tracts, mainly in the north of the survey area. *Eriachne flacida* (claypan grass) is a common component of these communities, whilst *Digitaria broomii* and *Eragrostis* sp. were also encountered. These grasses are more common to the north of the survey area where non-saline clay soils are more common. Their occurrence to the west of the survey area would suggest that soil factors rather than climate limit their distribution in the survey area.

b) **Hummock grasses**

Spinifex is an uniquely Australian plant form found on infertile soils in arid conditions (Beard 1981b, Williams 1982). Narrow inrolled leaves and resinous exudates help minimise water loss in this harsh environment. Their resinous nature makes them highly flammable, possibly a co-adaptation to fire, which may suppress competition from shrubs.

The spinifex hummock grasslands occur almost exclusively on deep sands in the survey area, unlike the situation further northwards where they are found on an increasing variety of land surfaces (Beard 1981b). *Triodia basedowii* (hard spinifex) is the most widespread and abundant spinifex species, often occurring as vast expanses in the east of the survey area. In the more dissected surfaces associated with the Yilgarn block and its greenstone belts, spinifex sandplains are restricted mainly to the backslopes of breakaways (which can be up to 10 km long). They occur occasionally on nearly level sandplains fringing salt lakes, as on Albion Downs station. *T. basedowii* is also found on sandy banks in salt lake country. *Triodia scariosa* is common in the extensive sandplains in the south of the survey area, whilst *Plectrachne melvillei*, *P. rigidissima*, *Triodia secunda* and *T. irritans* (porcupine grass) were rarely encountered. *Triodia irritans* also occurs on isolated calcrite platforms along palaeodrainage axes which have been largely covered by red sand in the north-east of the survey area.

**Low and mid shrubs**

This is an extremely diverse group of plants ranging from prostrate low shrubs to those almost 2 m tall. They occur on almost every type of land surface and in every plant community in the survey area. For ease of description, and in recognition of physiological characteristics, two main components may be distinguished, the non-succulent, generally
sclerophyllous species and the succulent and semi-succulent species. The former group may be split into heath and non-heath species.

a) Non-succulent species

The heath species are confined largely to sand plains and are most abundant and diverse in the south-western part of the survey area. Frequently dominant species include Baccaea cryptandra, Micromyrtus flaviflora, Thryptomene maconneci, Phedalia canaliculata, Produlotis athoferi, and Wehia thryptomeneoides although such is the diversity and richness of this component of the flora that many other species are locally dominant.

The non-heath species include a large number of shrub species found in almost every plant community. *Ptilotus obovatus* (cotton bush) is the most common of these species whilst *Solanum lasiophyllum* (flannel bush) is also widespread. The non-heath species are dominated by the genus *Eremophila* and to a lesser extent by *Cassia* (Senna). These species occur on a variety of land surfaces, most of which have non-saline red earthy soils that have neutral or acidic soil reaction trend.

Some *Eremophila* species are distributed across most of the land surfaces upon which this group is found. Others, however, are more specific and are useful indicators of physical environmental characteristics. On sandier soils, *Eremophila gilesei* and *E. foliosissima* are common, whilst on shallow, stony soils, *Eremophila abietina, E. exilifolia* (little turpentine poverty bush) and *E. fraseri* (turpentine bush) are common. Species found predominantly on hardpan plains include *Eremophila clarkei, E. georgei, E. glandulifera, E. homoplastica* and *E. metallicorum*. Other common species found on hardpan plains include *Canthium lineare, Cassia artemisoides* (silver cassia), *Cassia nemophila* (desert cassia), *Dianella revoluta* (blue flax lily), *Eremophila forrestii* (Wilcox bush), *E. latrobei* (warty-leaf eremophila), *E. margarethae* (sandbank poverty bush), *Ptilotus obovatus* (cotton bush), *Sida calyxynemenia* (tall sida), *Solanum lasiophyllum* (flannel bush) and *Spartothamnella teucriflora* (mulga broomush).

This group of non-succulent plants includes species frequently found in areas with heavier textured or duplex soils in the company of succulent shrubs. These include *Cassia nemophila* (desert cassia), *Cratylytilis subspinescens* (sage), *Dodonea lobulata* (hop bush), *Acacia hemitieles* (tan wattle), *Eremophila maculata* (emu bush), *E. malacoides, E. panonii* (broom bush), *E. scoparia* (broom bush), *Frankenia species* and *Ptilotus divaricatus* (climbing mulla mulla).

The non-succulent species exhibit a variety of adaptations to an arid environment with predominantly infertile soils. In most of these species leaves are small and narrow, presenting a small surface area from which to lose moisture. Furthermore, many are sclerophyllous and hence have lower nutrient requirements (Beadle 1966) and may be better adapted physiologically to prolonged dry periods (Morrow and Mooney 1974). Some species such as *Ptilotus obovatus* (cotton bush), *Solanum lasiophyllum* (flannel bush) and *Eremophila forrestii* (Wilcox bush) have densely hirsute foliage which reduces the impact of solar radiation and provides an insulated microenvironment at the leaf surface. *Eremophila fraseri* and *E. abietina* (fir-like eremophila) exude resinous substances which presumably also help reduce evaporative water loss.

b) Succulent or semi-succulent species

The succulent or semi-succulent shrubs are most common on the heavier, more alkaline soils associated with alluvial plains and salt lake systems, and on juvenile soils developed on weathered rock. The group is dominated by species of the Chenopodiaceae, particularly the genera *Atriplex* (saltbushes), *Halosarcia* (samphires) and *Maireana* (bluebushes). Plants such as *Gunniopsis quadrifida* (sweet samphire) exude salts, whilst the bluebushes generally store them in fleshy leaves. *Frankenia* species are particularly prolific salt-exuding plants (Mitchell and Wilcox 1988) although they are not succulent. Samphires are generally restricted to highly saline soils, whilst species of saltbush and bluebush are found on a variety of weakly saline or non saline soils, usually in the more fertile parts of landscapes where nutrients tend to be concentrated.

Several succulent low and mid shrubs are found on the red earth soils dominated by sclerophyllous plants. These species include *Enchytraea tomentosa* (ruby saltbush), *Maireana convexa* (mulga bluebush), *M. georgei* (George's bluebush) *M. melanocoma* (pussy bluebush), *M. theiosides* (lax bluebush), *M. triptera* (three-winged bluebush), *M. villosa* and *Rhagodia eremaea* (tall saltbush).

Tall shrubs

Tall shrubs are the dominant stratum on most of the hardpan plains and adjacent uplands where soils are generally shallow red earths on siliceous hardpan or bedrock. The most widely distributed and common tall shrubs are from the genera *Acacia* and *Eremophila*. The acacias generally have small sclerophyllous phylloids, whilst *Eremophila* species often have viscid, hairy or scaly leaves which reduce water loss and help plants tolerate water stress.

*Acacia* tall shrublands on hardpan plains are generally dominated by a single species; *A. aneura* (mulga). Other common acacias which are occasionally dominant on these plains are *A. craspedocarpa* (hop mulga), *A. linophylla* (wanyu), *A. ramulosa* (bowgada) and *A. tetragonophylla* (curara). On sandier tracts in which wanderrie grasses are also present, *A. linophylla ramulosa* or *A. coolgardiensis* (sugar brother) may be dominant. Several acacias are also common in spinifex hummock grasslands, most noticeably *A. coolgardiensis, A. murraya* (fire wattle), *A. juniperina* and *A. pachyacra*.

*Acacia aneura* often encroaches into chenopodiaceous succulent shrublands on the upper fringes of alluvial plains adjacent to salt lake systems.
It also occurs on hillsides and stony plains with *A. quadrifolia* (granite wattle) and, occasionally, *A. brachystachya*. On hills, *A. aneura* is often replaced by other acacias such as *A. aff. resinomarginata* and *A. quadriflora*.

On stony plains, *Eremophila macmillaniana* (grey turpentine bush), *E. fraseri* (turpentine bush) and *E. platycalyx* (granite poverty bush) are common or dominant tall shrubs. These *Eremophila* species are particularly abundant on extensive quartz plains on granite bedrock distributed throughout the survey area.

**Mallees**

There are three common groups of mallees (multi-stemmed eucalypts). The first group is found in spinifex sandplains and is most widely represented by *Eucalyptus youngiana* (large-fruit mallee) and *E. kingsmillii*. These species have very woody nuts which are perhaps as much an adaptation to fire (protection of seed) as they are to herbivory by parrots. The other eucalypts in the survey area tend to have considerably smaller nuts with much less woody investment.

The second group of mallees is found on sandy soils over calcareous pans in the south of the survey area. The most common species are *E. trichopoda* and *E. concinna* (desert gum). *E. laxophleba* (York gum) is more common on similar land surfaces to the immediate west of the survey area; whilst it was not recorded during this survey, its distribution includes the south-west of the survey area (Dell et al. 1988).

The third group, which includes *E. salubris* var. *salubris* (gimlet), is found low in the landscape on heavier textured soils in association with *Atriplex vesicaria* (bladder saltbush).

**Trees**

The most common trees in the survey area are acacias, eucalypts and *Casuarina cristata* (black oak).

Acacia woodlands occur on broad plains with deep sandy loams or loamy sands over hardpan, most extensively in the south of the survey area. Similar land surfaces further north are dominated more frequently by wanderrie grasses and the tall shrub form of *A. aneura*. In the far north of the survey area, *Acacia prinocarpa* (gidgee) is a common tree on hardpan plains with shallow soils, whilst in the south of the survey area *A. papyrocarpa* (western myall) trees are occasionally found over chenopod understoreys.

Eucalypt trees are found on four distinct land surfaces. In the north and east of the survey area, *Eucalyptus gongylocarpa* (marble gum) is common in extensive spinifex hummock grasslands on sandplains and on the sides of sand ridges. Its bark provides protection against fire and it is able to re-sproout after fire. The major creeklines of the survey area, such as Sullivan's Creek north-west of Leonora, support a fringing woodland dominated by *Eucalyptus camaldulensis* (river red gum).

*Eucalyptus salmonophloia* (salmon gum) is generally found in association with *E. salubris* and *Atriplex vesicaria* on heavy textured alluvial soils in the south-west of the survey area. *Eucalyptus lesouefii* (Goldfields blackbutt) grows on shallow calcareous soils on weathered greenstone, often upslope from gimlet and salmon gum plains. *Casuarina cristata* is commonly found in the south of the survey area, on shallow calcareous soils adjacent to salt lakes with acacias and occasional mallees, and with *Maireana sedifolia* (pearl bluebush) on weathered greenstones.

**Other plant forms**

The vegetation of the survey area includes other, less common plant forms, such as sedges, in fringing communities of creeks and rock pools, parasitic mistletoes (*Amyema* and *Lysiana* spp.) commonly found on tall shrubs and trees, semi-parasitic tall shrubs such as *Santalum spicatum* (sandalwood), and ferns (*Cheilanthes* spp.). A perhaps neglected area of the biota are the cryptogams: algae, lichens, liverworts and mosses that are widespread but seldom recorded, collected or studied. A list of lichens and mosses collected during the survey is presented in Appendix 1(iv) of this report.

**Regional distribution of plant communities and species**

The overwhelming patterning of plant community and species distributions can be related back to morphotectonics and geomorphology. For the majority of communities and species the distribution is related to recurring patterns of landform sequences associated with sub-parallel salt lake palaeodrainage systems and greenstone belts running through a granite dominated block (craton). These landscape patterns are described in the 'Geomorphology' chapter of this report.

Differences in the proportions of the component communities and species across the survey area correspond closely with the proportions of major land surface types. For instance, hummock grasslands are dominant along the eastern and northern edges of the survey area where sandplains are the dominant landform and there is little dissection of the landscape by recent erosional processes. In the centre of the survey area, around Leonora, there are only isolated pockets of spinifex sandplain and *Acacia aneura* (mulga) shrublands and woodlands are dominant on extensive Quaternary alluvium.

In the south of the survey area the vegetation and its patterning are different - particularly in the south-west. Here, mallees and eucalypt trees commonly provide the dominant stratum, whereas to the north they are only found fringing creek lines or scattered through hummock grasslands. This difference is probably more a reflection of a combination of climate and soils than morphotectonics and geomorphology. Firstly, rainfall is more reliable in the south-west, particularly in winter. Secondly, the extensive siliceous hardpan so prevalent throughout the mulga zone to the north and north-west is largely replaced by a calcareous pan. Furthermore, in the south there are
extensive areas of alluvial plains draining greenstone uplands that have calcareous clay soils rather than duplex soils over hardpan (as occurs further north).

Lakes Rebecca, Marmion and Ballard approximate the boundary between the dominance of siliceous hardpan to the north and alkaline and calcareous soils to the south.

The major types of communities restricted to the south of the survey area are eucalypt woodlands and mixed Casuarina cristata (black oak) - mallee-acacia woodlands or shrublands. The eucalypts are found with chenopod understoreys on heavier alkaline soils and with acacia shrublands on lighter textured soils. Where soils are generally shallow over calcrete Casuarina cristata woodlands are common, sometimes with understoreys dominated by Maireana sedifolia immediately adjacent to salt lake beds. Shrublands dominated by Allocasuarina species occur on hills and ridges in the south-west corner of the survey area. Whilst heathlands occur throughout the survey they are most extensive in the south-western sandplains; hummock grasslands predominate on sandplains further north.

Several species have distributions that extend only partly across the survey area. Species more widely distributed to the south and south-west include the following eucalypts: E. salmonophloia (salmon gum), E. salubris (gimlet), E. Dunesta (Dundas blackbutt), E. lesueufii (Goldfields blackbutt), E. concinna (desert gum) and E. laxophleba (York gum). Acacia hemitelenes (tan wattle), Dryandra arborea (Yilgarn dryandra), Dodonea lobulata (hop bush), Eremophila dempsteri, E. scoparia (broom bush), E. Weldii, Maireana suadefolia (lax bluebush), Olearia muelleri (Goldfields daisy) and Triodia scariosa (spinifex) are also more common south and south-west of the survey. Calycopeplus ephedroides (broom spurge), common around Hospital Rocks in the south of the survey area, is more common to the west of the survey area (R.J. Cranfield, personal communication).

Maireana sedifolia (pearl bluebush), Acacia papyrocarpa (western myall) and Crategus cuneaefolia (false bluebush) extend south into the gum belt, but are more extensive on the Nullarbor Plain and surrounds to the south-east (McKenzie and Robinson 1987, Mitchell et al. 1988 and Beard 1990).

There is also a suite of species more extensively distributed to the north of the survey area. Some of the more common of these include Acacia dictyophleba, A. prainacarpa (gidgee), Eremophila cuneifolia (royal poverty bush), E. parsonii (broom bush), Eucalyptus chippendalei (a bloodwood), Isilema sagittiflorum (red Flinders grass), Maireana melanocoma (pussy bluebush), Pilostemon rotundifolius (royal mulla mulla), and Solanum asbyae. Some of these species are more common in the vast sandplains to the north (e.g. A. dictyophleba and E. chippendalei), whilst others are more widely distributed in the mulga zone to the north-west (e.g. M. melanocoma and E. cuneifolia).

The species with very narrow distributions found partly or wholly within the survey area occur on a variety of land surfaces. The surfaces with which they are most commonly associated are partially stripped surfaces over weathered rock, gritty surfaced plains and drainage foci fringe granite domes, greenstone hills and sandplain. These surfaces generally occur high in the landscape, although this is not the case for sandplains in the east of the area where they comprise the dominant surface.

Apatophyllum magilvrayi was collected on deeply weathered granite in the north of the survey area. It is a new species and the first recording of the genus in Western Australia. Eriastemon linearis was collected below a granite dome in the north-east of the survey area. Its other known distributions are in South Australia. Eucalyptus pimpiana, known from a single population in the south-east of the survey area, was recollected. It is a low mallee that grows to approximately a metre high. Another restricted species, Grevillea inconspicua, was encountered several times on duricrusted greenstones and on basalt hills and low rises.

As with most large regions, there are biogeographical trends across this survey area. They are frequently obscured by recurrent landsurface patterns which have a major influence on plant distributions. The major trend across the survey is from the south-west corner to the north-east corner involving a change from eucalypt woodlands through A. aneura (mulga) and chenopod mosaics into extensive spinifex hummock grasslands. The patterning in the landscape in terms of vegetation, and the way it is sifted by physical environmental variables, is discussed below and in more detail in the 'Ecological assessment' chapter of this report.

Patterning in the landscape

Beard (1974, 1975 and 1976) mapped vegetation formations within the survey area. These formations are analogous to dominant plant communities, and, as such, are discussed in the previous section. For most of the survey area Beard recognises stunted acacia tall shrublands on upland areas, types of chenopod succulent steppe fringing salt lake systems and mulga low woodlands between. In the far north and east he recognises the predominance of hummock grasslands, and, in the south, eucalypt woodlands are mapped. As previously discussed, the eucalypt line is probably related to soil types and climate, whilst patterns further north are generally recurring toposequences related to the morphotectonic structure of the survey area. Soils are certainly very important influences on the distribution of vegetation formations; however, their patterning at this scale is very much a reflection of morphotectonic structure and Cenozoic geomorphic processes.

Within the vegetation formations or primary vegetation types (Beard 1990) are mosaics of plant communities. The distribution of plant communities within the broad formations or major types mapped by Beard reflect edaphic and hydrological characteristics associated with landform patterns in recurring toposequences. In most cases, the
boundaries between landforms and their soils and vegetation are sharp. If one considers spatial variation in three dimensions, the most profound changes are along the axis of the slope of the land. Along this axis are the primary landform and catenary sequences, whereas across the slope changes are often more subtle. This is particularly so in lower parts of the landscape where changes in the intensity of run-on are subtle and only cause local variations in species' densities. Higher in the landscape, differential weathering and erosion of underlying rock produces greater landform, soil and vegetation diversity.

Examples of the variable vegetation diversity with slope are illustrated by considering the Monk and Sherwood land systems (see the 'Land systems' chapter of this report). Sherwood includes breakaways with stunted low shrubs on the plateaux and a variety of communities on scree slopes below scarpas, depending on the salinity of the rubble supporting the plants. Short footslopes support chenopod low shrublands, often in a floristic mosaic reflecting tributary drainage patterns. The footslopes give way to extensive stony plains, which have sub-parallel drainage lines through them, supporting Acacia aneura communities on loams, or chenopod communities on duplex soils. The stony plains support scattered A. aneura and eremophila shrublands.

In contrast, and downslope of the Sherwood land system, the Monk land system generally supports A. aneura tall shrublands throughout, the tall shrub layer is denser and the understorey often less developed in areas receiving more concentrated run-on. Basically, however, the same species are involved throughout. Wanderrie grasses may occur on occasional sandy banks in the lowest parts of this land system.

The trend of decreasing variation in the vegetation downslope is broken at the salt lake systems that occur in the lowest parts of the landscape. These are usually strong zonations related to salinity involving changes from samphires and Frankonia species in highly saline areas adjacent to bare lake beds, through mixed chenopod communities often with Atriplex vesicaria (bladder saltbush) communities and Maireana pyramidata (sago bush) communities, which often have scattered Acacia aneura (mulga) further upslope. Within these zonation patterns are also sandy banks and dunes and occasional kopie dunes. These features support quite different vegetation again, adding to the diversity in this part of the landscape. Carnegie land system (Mabbutt et al. 1963, and this report) is the most extensive example of this type of country.

Plant communities also exhibit considerable internal heterogeneity. Unlike the patterns described above, some of the patterning is a direct result of plant-environment interactions, however, this is not always the case.

On Acacia aneura (mulga) shrublands on hardpan plains mulga is gathered into groves along the contour. Whilst it is unclear exactly how these groves develop, they are associated with subtle changes in slope. The groves are on subtle breaks of slope and have deeper soil above the hardpan than do the intervening intergrove areas (Mabbutt and Fanning 1987). The intergrove areas act as run-off areas which shed water and nutrients to the groves, in which much of the vegetation is concentrated.

Groves also occur on gentle slopes supporting eucalypt woodlands. The understorey is often different within the eucalypt grove as compared to the intergrove areas. For instance, in mallee/acacia shrublands, the eucalypt groves often support species such as Maireana georgei (George's bluebush) and Olearia muelleri (Goldfields daisy), whilst the intergrove consists of acacias and low shrubs such as Ptilotus abnatus (cotton bush).

In many cases chenopod low shrublands exhibit considerable internal heterogeneity. This is particularly obvious on the alluvial plains fringing salt lakes where the vegetation structure and cover may be uniform, but the composition is typically a mosaic of sub-communities with characteristic dominant or co-dominant species. Hacker (1979) found these differences correlate closely with subtle differences in soil characteristics and internal drainage patterns. The variable salinity of soil surfaces applies selective pressure on species germination, whilst salinities deeper in the profile affect subsequent establishment.

It appears that patterning within plant communities is variably a function of drainage characteristics, plant-environment interactions, and subtle edaphic changes. On gently sloping plains there appears to be a concentrating of resources into contour-aligned fertile patches or groves in much the same way as described by Mabbutt and Fanning (1987) immediately to the north of this survey area. In adjacent run-off areas the level of internal heterogeneity was observed to be considerably less.

Soil phase patterns are emerging as indicators of ecosystem health in many site types. These patterns are clearest on chenopod alluvial plains with duplex soils. It would appear that loose sand is trapped by low shrubs and, as more of this sediment accumulates and becomes stabilised by cryptogams, distinct bush mounds develop. On these mounds, soil nutrient concentrations are comparatively high and infiltration rates are greater than in adjacent areas (Tongway and Greene 1989). Bush mounds are fertile patches at an even finer scale than groves, and represent critical sites for future germination, particularly following shrub deaths. In some respects, the distribution of bush mounds and consequent redistribution of scarce resources exert control on the future distribution of perennial plants at such sites. The breakdown of these mounds represents the loss of favoured establishment niches and a retarding of the regeneration process. The longer the regeneration process requires, the more likely erosion of surface soil (containing disproportionately high nutrient concentrations) will occur. The loss of coarse textured surface sediments represents an irreversible loss of that site's potential to support the previous type of plant community.

Fire is an influence on vegetation superimposed on many of the patterns discussed above, particularly in...
the relatively undissected landscapes with extensive sandplain in the north, east and south-west of the survey area. Variation occurs as mosaics of different aged burns with various seral states and pathways. Sometimes spinifex assumes dominance after a brief period (say five years) of short-lived herbaceous shrubs and ephemeral grasses, in other cases, shrublands of Acacia, Grevillea, Hakea and heath species emerge.

Fire has also affected large areas south of Menzies following the bushfires of the mid 1970s. The bushfires extended across plant communities not usually subject to fire (and hence not adapted to it), for example, *Maireana setosiata* (pearl bluebrush), and *Casuarina cristata* (black oak) communities. *Stipa* species (spear grasses), following consecutive abnormally high rainfall years, appear to have fuelled many of the fires in the region (J. Morrissey, pers. comm.), much as they do in chenopod communities on the Nullarbor Plain.

Fire superimposes its influence on other scales of patterning, for example, burning of spinifex grasslands releases nutrients locked up in hummocks. Nutrients are spread out more evenly by wind, and may support less clumped vegetation as a result. Fire can also lead to the emergence of *Acacia* and *Cassia* dominated shrublands in wide areas which previously supported a more varied mosaic of plant communities not usually subject to burning.

In conclusion, it would appear that plant-environment interactions are very important factors influencing plant distribution at fine scales whereas, at broader scales, climate, geomorphology and edaphic factors are critical. Surface hydrology on the extensive alluvial plains of the survey area is very influential at the site type (landform/plant community) scale. Fire superimposes its own patterns at a variety of scales, most commonly (but not entirely) on sandplains.

**Flora conservation**

Flora conservation involves the management of biodiversity at a variety of levels, including the plant community and individual species level (Biological Diversity Advisory Committee, undated, c. 1992). These two levels are dealt with separately, the latter in terms of rare and/or endangered species.

Threats to flora conservation in this survey area include the introduction of exotic plant species, grazing by domestic stock, introduced feral animals and kangaroos, mining and tourism and possibly the decline in the traditional practices of indigenous people, not necessarily in that order of severity of threat. Climate change is a global issue beyond the scope of a rangeland survey report, suffice to say that the situation requires monitoring and a preparedness to review land use planning and land management accordingly. Graetz et al. (1988) suggest that major phytogeographic shifts are unlikely to occur in Australia’s rangelands, but that areas of chenopod shrubland could become wooded grasslands. Edaphic controls may limit such changes in Western Australia.

(i) **Conservation of plant communities**

Pastoralism is the most extensive land use in the survey area. It involves the development of permanent water points which act as a focus for animal distribution - particularly stock, feral animals and kangaroos. More importantly it involves levels of herbivory considerably greater than before establishment of the industry. The provision of water during prolonged dry periods allows for the maintenance of grazing pressure when previously it would have declined.

Grazing by herbivores is not totally controlled by the distribution of available drinking water. Grazing preference is exerted for certain types of vegetation, which has been classified into site types in the ‘Ecological assessment’ chapter of this report. The following site types appeared to receive a disproportionately high level of grazing pressure as a result of animal preference:

- calcrite platform woodlands/shrublands (CAPW);
- mulga drainage line shrublands/woodlands with chenopod understoreys (DMCS);
- mulga groves on hardpan plains (GRMU);
- drainage tract mulga shrublands (DMRU);
- mulga tall shrublands with claypan grass understoreys (CPMG).

These site types all represent ‘fertile patches’ in the landscape.

A second suite of site types are preferentially grazed because they include comparatively dense stands of palatable perennial shrubs. These site types have chenopod low and mid shrub strata and comprise site type group 4: mixed halophytic low shrublands on depositional plains and group 5: chenopod low or mid shrublands on hillsides and stony plains (’stony chenopod’).

Most pastoral stations are well developed and broken into management units by fencing. This tends to provide some limit to grazing preference, but can also exacerbate the situation when small areas of preferred site types are encloscd with large areas of comparatively poor pastoral country. Chenopod shrublands on fragile breakaway footslopes are particularly threatened by inappropriate fencing and water point location.

Pastoralists have used exotic species in the area in regeneration projects. *Cenchrus ciliaris* (buffel grass) has been tried, but has largely failed to establish and spread as it has in pastoral lands to the north-west, particularly in the Pilbara and Ashburton River catchment. Whilst the introduction of exotic species may be highly desirable from a resource conservation perspective, there is always the danger that such species may spread from intended areas of use to the
detriment or exclusion of native species. To date, there have not been any serious expansions of exotic pasture species to the exclusion of natives in the survey area.

Feral goats deserve particular mention as a threat to nature conservation in the survey area. In contrast to sheep, it appears that they favour rugged terrain and adjacent mulga plains as much as chenopod alluvial plains (personal observations).

The tolerance of goats to prolonged dry spells and their high reproductive capacity makes them well adapted to the rangelands in this survey area (see Fletcher 1991). Without ongoing control they have the capacity to inflict damage on a scale beyond that which has occurred from historic overgrazing by sheep. Feral donkeys, camels, rabbits and horses are present in the survey area, however, they currently do not pose the same level of threat as that posed by goats.

Mining occurs as small, scattered areas of very intense activity in which alteration of the environment may be profound. The greatest threat mining poses to biological diversity in the survey area is perhaps the introduction of invasive exotic species in seed mixes for mine site rehabilitation. To date, introduced (not necessarily by miners) exotic species such as *Carrichtera annua* (Ward’s weed) and *Rumex vesicarius* (native hops) have not spread beyond heavily disturbed areas and at present do not represent a major threat to biological diversity. It would appear that they lack the capacity to compete with adapted native species in natural undisturbed ecosystems. Mining occurs on land surfaces (such as greenstone hills) in which rare and/or endangered species are disproportionately distributed. Environmental inventories, prior to mining, attempt to identify these situations. This report does not represent an adequately detailed data source for such inventories.

Tourism potentially poses threats of bushfires, disturbances from regular human activities (such as vehicle impacts) and the accidental introduction of invasive exotic species. Should tourism become a more extensive and intensive land use, these threats will need to be considered by Government agencies and local land managers. No evidence of tourism adversely affecting flora conservation was observed during the survey.

In an ideal world, the threats to flora conservation discussed above would be minimised by exclusion from use of carefully selected (and hopefully replicated) areas set aside for nature conservation management. These areas would be selected on the basis of detailed biophysical survey information detailing all aspects of the biotic and abiotic components of the region. Unfortunately, resource use planning has preceded nature conservation planning and most of the biological diversity in this survey area occurs on pastoral leases. The social, political and economic barriers to acquisition of pastoral lands for nature conservation are considerable and regional nature conservation strategies will need to recognise this. Threatened communities will require special management for survival, and multiple land use may provide a workable solution in this regard (see Cohen 1992). Certainly, resource users in the area will need to become involved in nature conservation if regional nature conservation objectives are to be achieved.

(ii) Conservation of rare and/or endangered species

The following species in this survey area are declared rare flora:

- *Conospermum toddii* (Collection no. 2682)
- *Grevillea inconspicua* (Collection no. 6757)
- *Prostanthera magnifica* (Collection no. 7760)
- *Hemigenia exilis* (presumed extinct, but possibly RJC 7125)

Numerous species have been included in the Department of Conservation and Land Management Priority Flora List (Table 3), two thirds of them were collected during the survey.

A new species and genus of the Celastraceae to Western Australia, *Apatophyllum macgillivrayi* (Collection no. 2751) was found during this survey. The first collection of *Eriostemon linearis* in Western Australia was also made during the survey. There are also a number of collections whose identification has yet to be finalised but which may be new species (Cranfield, personal communication). They are listed with their collecting numbers below.

<table>
<thead>
<tr>
<th>Species</th>
<th>Collecting Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia sp.</td>
<td>2817</td>
</tr>
<tr>
<td>Acacia sp.</td>
<td>2770</td>
</tr>
<tr>
<td>Baeckea sp.</td>
<td>2738</td>
</tr>
<tr>
<td>Hemigenia sp.</td>
<td>RJC 7125</td>
</tr>
<tr>
<td>Hibiscus sp.</td>
<td>2585</td>
</tr>
<tr>
<td>Hibbertia sp.</td>
<td>RJC 6771</td>
</tr>
<tr>
<td>Logania sp.</td>
<td>2720</td>
</tr>
<tr>
<td>Phyllanthus sp.</td>
<td>2492</td>
</tr>
<tr>
<td>Sida sp.</td>
<td>2775</td>
</tr>
</tbody>
</table>

The land surfaces most commonly associated with rare and/or endangered species are breakaway plateaux, granite, greenstone and basalt hills and sandplains. These surfaces generally support vegetation that is not preferred by domestic stock, and many of these species are not readily grazed by stock. Observations made during the survey suggest that the uplands in which some of these species occur are preferred habitats for goats. It is not known whether goats graze these species, however, they have an ability to continue degradation of native vegetation by grazing less palatable species beyond the capacity of sheep (Fletcher 1991). As such, goats may pose a serious threat to the preservation of these threatened taxa. This possibility highlights the need for feral animal control in the survey area and provides an opportunity for nature conservation agencies and local land managers to combine their efforts towards effective resource and nature conservation management.
Table 3. Species included in the Department of Conservation and Land Management’s Priority Flora List (Hopper et al. 1990)

<table>
<thead>
<tr>
<th>Collection number</th>
<th>Species</th>
<th>Common name</th>
<th>Growth form</th>
<th>Priority code*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2390</td>
<td>Acacia eremophila var. variabilis</td>
<td>-</td>
<td>shrub</td>
<td>3</td>
</tr>
<tr>
<td>2751</td>
<td>Apotheophyllum macgillivrayi</td>
<td>-</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>HP 91016</td>
<td>Calytrix creswellii</td>
<td>star flower</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>2205</td>
<td>Calytrix praecox</td>
<td>star flower</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>2848</td>
<td>Dampiera ramosa</td>
<td>-</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>Eremophila 'amorphosa'</td>
<td>-</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>Eremophila 'evera'</td>
<td>-</td>
<td>low shrub</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>Eremophila 'mirabilis'</td>
<td>-</td>
<td>low shrub</td>
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</tr>
<tr>
<td>2851</td>
<td>Eremophila pustulata</td>
<td>-</td>
<td>low shrub</td>
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</tr>
<tr>
<td>7020</td>
<td>Eucalyptus jutsonii</td>
<td>Jutson's mallee</td>
<td>mallee</td>
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<td>2987</td>
<td>Eucalyptus rigidula</td>
<td>desert wando</td>
<td>mallee</td>
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<tr>
<td>2407</td>
<td>Eucalyptus pinniniana</td>
<td>-</td>
<td>mallee</td>
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<tr>
<td>-</td>
<td>Frankenia georgii</td>
<td>-</td>
<td>low shrub</td>
<td>3</td>
</tr>
<tr>
<td>-</td>
<td>Gnephosis arachnoides</td>
<td>-</td>
<td>annual herb</td>
<td>1</td>
</tr>
<tr>
<td>7922</td>
<td>Gnephosis intonsa</td>
<td>Shaggy gnephosis</td>
<td>annual herb</td>
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<tr>
<td>2330</td>
<td>Granitites integanta</td>
<td>-</td>
<td>low shrub</td>
<td>3</td>
</tr>
<tr>
<td>7483</td>
<td>Gymnolepis georgiana</td>
<td>-</td>
<td>shrub</td>
<td>4</td>
</tr>
<tr>
<td>-</td>
<td>Hylasophema strobilus</td>
<td>-</td>
<td>annual herb</td>
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</tr>
<tr>
<td>7148</td>
<td>Lepidobolus deserti</td>
<td>-</td>
<td>rush</td>
<td>4</td>
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<tr>
<td>-</td>
<td>Morella stipata</td>
<td>-</td>
<td>low shrub</td>
<td>3</td>
</tr>
<tr>
<td>7590</td>
<td>Newcastelia insignis</td>
<td>-</td>
<td>low shrub</td>
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</tr>
<tr>
<td>-</td>
<td>Personia leucopogon</td>
<td>-</td>
<td>low shrub</td>
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</tr>
<tr>
<td>2575</td>
<td>Philotheca tubifera</td>
<td>-</td>
<td>shrub</td>
<td>1</td>
</tr>
<tr>
<td>7532</td>
<td>Verticordia interioris</td>
<td>-</td>
<td>low shrub</td>
<td>3</td>
</tr>
</tbody>
</table>

* Priority code 1 - taxa with few poorly known populations on threatened lands.
  2 - taxa with few poorly known populations on conservation lands.
  3 - taxa with several poorly known populations, some on conservation lands.
  4 - rare taxa, not currently threatened, but require monitoring.

Note: These species have been checked against an updated but as yet unpublished version of the Declared Rare and Priority Flora List, dated 28/10/92.

References


