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Soil-landscapes of Western Australia's Rangelands and Arid Interior

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CONTENTS

1. INTRODUCTION

Western Australia has seen a great deal of land resource mapping over the past 40 years, but at varying scales of intensity and the only consistent coverage across the entire State remained the *Atlas of Australian Soils* published in the late 1960s. This report documents the process of placing the most recent and detailed mapping of Western Australia's Rangelands and Arid Interior that is available into a hierarchy of soil-landscape mapping units. It also provides descriptions of the soil-landscape regions, provinces and zones identified.

These updated maps and descriptions will form part of Western Australia's contribution to the Australian Soil Resource Information System (ASRIS), describing the upper four levels of the mapping hierarchy. ASRIS was initiated through the National Land and Water Resources Audit (NLWRA) in 1999. It is designed to provide on-line access to the best available soil and land resource information across Australia in a consistent format (ASRIS 2006).

A hierarchy of mapping units with seven levels will allow for comprehensive reporting on land suitability and soil resources from the National down to the Sub-regional scale. Initially, ASRIS aims to provide descriptions of the soils and landscapes of the upper three levels of the hierarchy across the entire continent. The lower levels containing more detailed scaled information will be added as they become available. A consistent set of land qualities is described for map units (tracts). Descriptions from the lowest level of the hierarchy feed into summaries at higher levels. Information relates to soil thickness, water storage, permeability, salinity, fertility, and erodibility. ASRIS includes a soil profile database with fully characterised and representative sites.

While the mapping for the Agricultural Area of Western Australia was already in a suitable format for inclusion into the ASRIS hierarchy, the surveys covering the Rangelands and Arid Interior only showed a single level of mapping. As such they could not be directly included into either the hierarchy used by ASRIS or in the Department of Agriculture's Map Unit Database (Schoknecht *et al.* 2004).

Adapting the Rangeland and Arid Interior surveys into the top four levels of the mapping hierarchy in Western Australia has led to the creation and description of 2 previously unidentified soil-landscape regions (hierarchy level 1), 18 new soil-landscape provinces (hierarchy level 2) and 95 new soil-landscape zones (hierarchy level 3). In addition, the descriptions of four previously identified regions, six existing provinces and 12 existing zones have been updated. Around 1787 new soil-landscape systems (hierarchy level 4) have also been created and added to the Department's Map Unit Database.

The soil-landscape descriptions contained in this report, along with the associated digital mapping and data stored Map Unit Database, represent a major advance in the provision of natural resource information in Western Australia. They enable a consistent presentation and analysis of soil and landform data across the State. This work complements Interim Biogeographic Regionalisation for Australia (IBRA) prepared by Environment Australia (2000). They enable data from localised areas to be assessed in a regional, statewide or national context.

Through ASRIS, the work described in this report will form part of Australia's contribution to the Global Soil and Terrain Database (WORLD-SOTER) being coordinated by the Food and Agriculture Organization of the United Nations (FAO 2006). This will facilitate placing local data in a global framework.

Rather than an end point, this publication should be seen as beginning the process of integrating mapping of the Rangelands and Arid Interior into ASRIS and the Department of Agriculture and Food's Map Unit Database. While considerable work remains to be done updating the mapping, edge-matching surveys and attributing map units, a framework for improving and prioritising soil-landscape data across Western Australia now exists.

2. EXISTING MAPPING AND DATA

2.1 The Agricultural Area and mapping unit hierarchy

In the 1980s, the Department of Agriculture commenced a 15 year program to map the soil-landscapes of the Agricultural Area in Western Australia. This mapping covers approximately 315,500 km^2 of the south-west (11.2% of Western Australia) from Geraldton to Esperance (see Figure 2.1) and delineates repeating patterns of landscapes and associated soils. Soil-landscape mapping differs from soil mapping in that the landscape component is an explicit part of the mapping.

This mapping of the Agricultural Area was conducted independently from mapping of the Rangelands, and is described in detail by Schoknecht *et al.* (2004). The Agricultural Area mapping has been completed at scales ranging between 1:50,000 and 1:250,000. All map unit boundaries have been captured digitally using a computer-aided mapping system.

Part of the mapping program included the development of a nested hierarchy of soil-landscape mapping units (Schoknecht *et al.* 2004). This hierarchy has six levels and complements the hierarchy for soil mapping being adopted at a national scale by the Australian Soil Resource Information System (ASRIS 2006).

The Department of Agriculture and Food's mapping hierarchy deals with differing levels of complexity in both landscape and soil patterns. It aims to maintain a consistent approach across a range of mapping scales, and at varying levels of detail in the associated data. The mapping and data can be presented at scales ranging from 1:25,000,000 to 1:50,000. The hierarchy permits correlation between different surveys and enables computer processing of data on a state wide (or national) level. It provided the means by which pre-existing surveys were incorporated into a seamless soil-landscape map across the Agricultural Area.

Each level of the Department's soil-landscape mapping hierarchy is a subdivision of the preceding level. The highest two levels are ***regions*** and ***provinces***, provinces being subdivisions of the regions. Both are based on a framework introduced by CSIRO (1983) for the whole of Australia (see Figure 2.2). Provinces are in turn sub-divided in ***zones***. The zones and the remaining three levels (***systems, subsystems*** and ***phases***) are mainly based on mapping conducted by the Department. In a few cases, older CSIRO soil surveys have been used.

Each map unit is assigned a unique symbol[1], unique for that particular map unit across the entire State. The level of map unit in the hierarchy is implicit in the symbol: the first character of the label is the Region; the 2nd the Province; the 3rd the Zone; the 4th and 5th the System; the 6th and 7th the Subsystem; and the remainder (up to **12** characters) the Phase. This is demonstrated in Table 2.1.

[1] This is sometimes referred to as the link label.

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Table 2.1: Symbols used for map unit labels

Level	*Unit name*	*Unit symbol*	*Examples*	
1	Region	single-digit number	**2**	**2**
2	Province	single-digit number	2**5**	2**1**
3	Zone	single-digit number	25**6**	21**5**
4	System	2 characters, alpha, title case	256**Jc**	215**Sr**
5	Subsystem	2 characters, numeric or alpha upper case	256Jc_**3**	215Sr**BL**
6	Phase	Up to 13 characters, alphanumeric	256Jc_3**d**	215SrBL**wy**

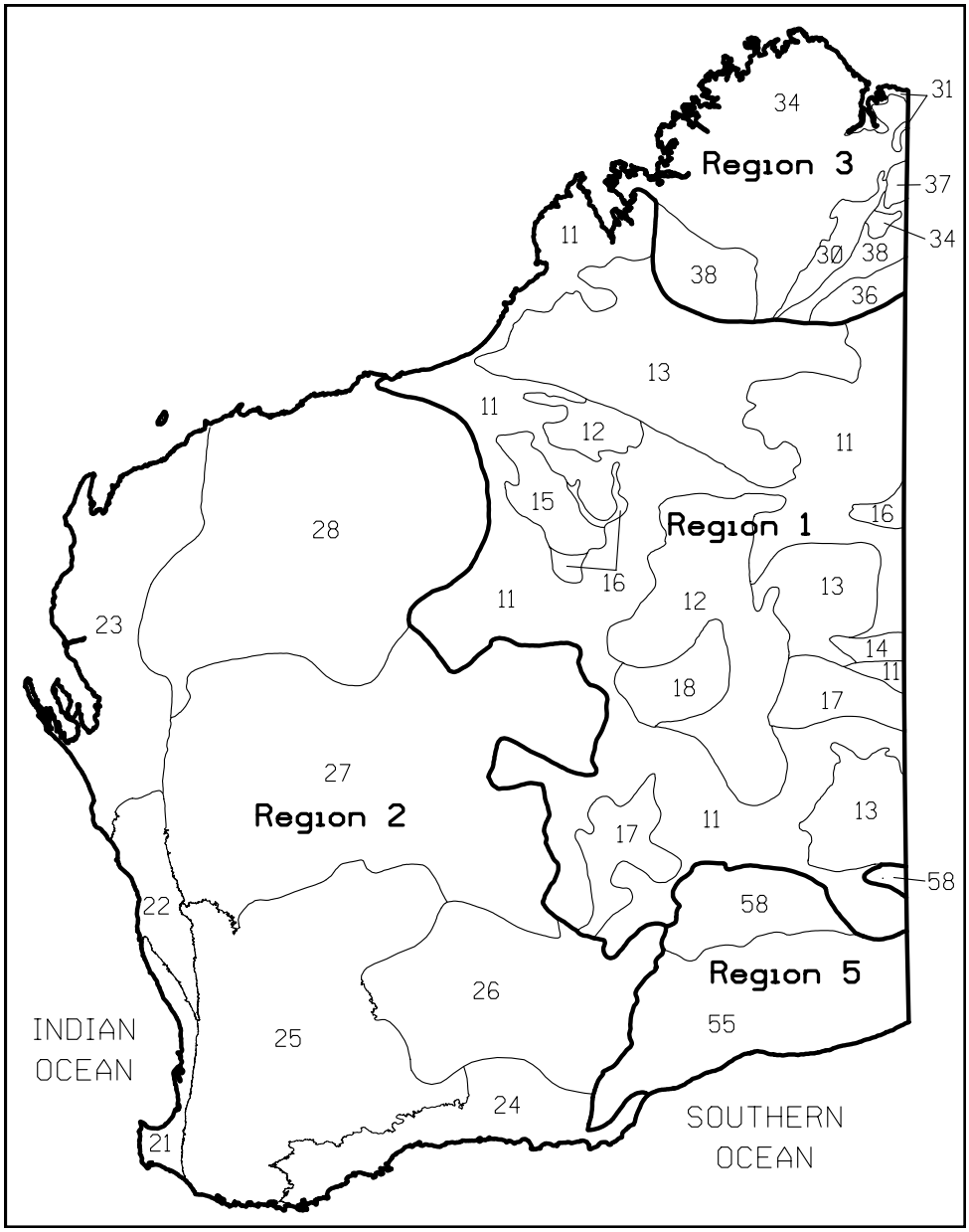

Figure 2.2 Provisional soil-landscape regions and provinces for Western Australia adapted from CSIRO (1983) prior to the incorporation of rangeland surveys and Atlas of Australian Soils mapping (from Schoknecht et al. 2004)

An example of the mapping hierarchy is shown in Figure 2.3, while Table 2.2 displays a range of examples of these unique symbols.

Table 2.2: Examples of map unit symbols used for map unit labels

Map unit symbol	Map unit hierarchy decode
Provinces:	
22	Western Region (2), Greenough Province (2)
25	Western Region (2), Avon Province (5)
Zones:	
212	Western Region (2), Swan Province (1), Bassendean Zone (2)
242	Western Region (2), Stirling Province (4), Albany Sandplain Zone (2)
Systems:	
216Co	Western Region (2), Swan Province (1), Leeuwin Zone (6), Cowaramup Upland System (Co)
222Co	Western Region (2), Greenough Province (2) Dandaragan Plateau Zone (2), Coalara System (Co)
258Tr	Western Region (2), Avon Province (5), Northern Zone of Ancient Drainage (8), Trayning System (Tr)
Subsystems:	
258TaUL	Western Region (2), Avon Province (5), Northern Zone of Ancient Drainage (8), Tandegin System (Ta), Ulva Subsystem (UL)
259Ek_3	Western Region (2), Avon Province (5), South-western Zone of Ancient Drainage (9), East Katanning System (Ek), Subsystem 3 (_3)
254MpKP	Western Region (2), Avon Province (5), Warren-Denmark Zone (4), Manjimup Plateau System (Mp), Kapalarup Subsystem (KP)
Phases:	
216GrKPr	Western Region (2), Swan Province (1), Leeuwin Zone (6), Gracetown Ridge System (Gr), Kilcarnup Subsystem (KP), rocky dune phase (r)
257Ca_1s	Western Region (2), Avon Province (5), Southern Zone of Rejuvenated Drainage (7), Carrolup System (Ca), Subsystem 1 (_1), sandy phase (s)
214WsYLvw	Western Region (2), Swan Province (1), Donnybrook Sunkland Zone (4), Whicher Scarp System (Ws), Yelverton Subsystem (YL), wet valley phase (vw)

Along with the mapping, the Department developed a Map Unit Database as a repository of map unit and soil type data (Schoknecht *et al.* 2004). This contains descriptions of all the map units. Part of this description presents the map unit's components by per cent. This is a proportional listing of the unmapped land units which make up the map unit.

Each land unit consists of a Soil Group of Western Australia and its qualifier (Schoknecht 2002) as well as the landform position in which it occurs. For example a *Red loamy earth (alkaline) occurring on a well drained flat* is a different land unit to a *Red loamy earth (acid) occurring on a well drained flat* or a *Red loamy earth (alkaline) occurring on a slope of 5-10% gradient*. See Section 2.3.2 of Schoknecht *et al.* (2004) for more details.

1. Regions
Broad subdivisions of the Australian continent (Division of Soils, CSIRO 1983).
e.g. ***The Western Region (2)***

2. Provinces
Provides a broad overview of the whole state suitable for maps at scales of about 1:5,000,000 (Division of Soils, CSIRO 1983).
e.g. ***Avon Province (25)***

3. Zones
Areas defined on geomorphologic or geological criteria, suitable for regional perspectives.
e.g. ***Warren-Denmark Southland Zone (254)***

4. Systems
Areas with recurring patterns of landforms, soils and vegetation, suitable for regional mapping at scales of 1:250,000.
e.g. ***Frankland Hills System (254Fh)***

5. Subsystems
Areas of characteristic landforms features containing definite suites of soils, suitable for mapping at regional scales of 1:100,000.
e.g. ***Frankland Hills 1 Subsystem (259Fh_1)***

6. Subsystem phases
Division of subsystems based on land use interpretation requirements.
e.g. ***Frankland Hills 1 granitic phase (254Fh_1g)***

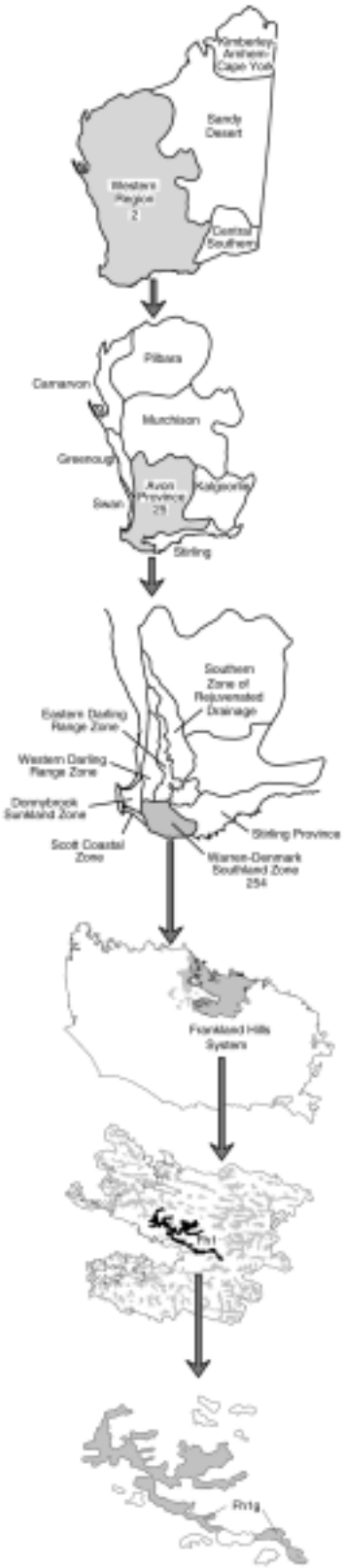

Figure 2.3: Levels of the soil-landscape mapping hierarchy (adapted from Stuart-Street 2005).

2.2 The Rangelands

Existing land system and rangeland surveys cover approximately 1,282,500 km^2 of Western Australia's Rangelands (45.6% of the State). These surveys have mostly been produced at a scale of 1:250,000. The extent of these surveys is shown in Figure 2.4 while a list of the surveys is presented in Table 2.3.

2.2.1 History of rangeland survey in Western Australia

The mapping of soils, landscapes and vegetation in the Rangelands of Western Australia commenced in 1953 with a survey of the lands and pastoral resources of the North Kimberley area by the CSIRO (Speck *et al.* 1960). This survey adopted the land system approach developed by Christian and Stewart (1953). In these surveys, a land system is defined as "an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation". Subsequent CSIRO land system surveys covered the Wiluna-Meekatharra (Mabbutt *et al.* 1963), West Kimberley (Speck *et al.* 1964) and Ord-Victoria (Stewart *et al.* 1970) areas.

In the 1960s the Department of Lands and Surveys[2] commenced a program of rangeland surveys in the Kimberley and Pilbara. These surveys classified the land into broad pasture types, mainly for the purpose of estimating paddock and station carrying capacities. They are briefly discussed by Pringle (1991).

By the end of the decade, responsibility for mapping Rangeland areas became a joint responsibility of the Department of Agriculture[3] and the Department of Lands and Surveys. They surveyed the Gascoyne Catchment (Wilcox and McKinnon 1972) using a procedure similar to CSIRO, but replacing the concept of land systems with rangeland types in which recurring patterns of pastures and landforms occur. An assessment of range condition was an important part of this survey.

Subsequent surveys adopted a similar approach but returned to the use of the name land systems. Major surveys completed to date cover the eastern Nullarbor Plain (Mitchell *et al.* 1979), Ashburton catchment (Payne *et al.* 1983), Carnarvon Basin (Payne *et al.* 1987), Roebourne Plains (Payne and Tille 1992), Murchison (Curry *et al.* 1994), North-eastern Goldfields (Pringle *et al.* 1994), Sandstone-Yalgoo-Paynes Find (Payne *et al.* 1998), Pilbara (Van Vreeswyk *et al.* 2004b), and Broome Coastal (Cotching 2005). The combined area covered by the CSIRO and published rangeland surveys is around 1,217,000 km^2 (43.3% of the State).

Additional rangeland surveys completed, but as yet unpublished, include the Kambalda Western Mining (Payne *et al.*), Goongarrie (Payne), and South Kimberley (Payne *et al.*). Draft line-work for the Lower Murchison Survey has been completed and is also available (Hennig in prep.). The combined area covered by these surveys is around 65,500 km^2 (2.4% of the State).

A rangeland survey of the Western Nullarbor is currently underway, while surveys of the Southern Goldfields, Lake Johnston and Wiluna Extension areas are yet to commence. The combined area of these future surveys is around 291,400 km^2 (10.4% of the State).

2.2.2 Land systems

The map units used in the rangeland surveys are land systems, defined as "an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation". For most rangeland surveys, landscape and vegetation were the main criteria used to identify

[2] Later to become the Department of Land Administration.

[3] Currently the Department of Agriculture and Food.

the land system. Since the 1970s, the surveys have concentrated on pasture types, range condition and pastoral potential.

Each land system is made up of one or (more commonly) a number of unmapped land units. The published land system descriptions include a table showing these component land units and their proportional allocation (i.e. the typical percentage area of the land system that they occupy). Each land unit is described in terms of landform, soil and vegetation. In all of the surveys, soils have been described for each of the land units, but the descriptions are often brief and may be based on limited data. A typical example of a land system description, from the Pilbara survey, is presented in Appendix 1.

2.2.3 Correlation of surveys

Originally the rangeland surveys were conducted largely in isolation from each other and little attempt was made to correlate areas between surveys. As a result, there were numerous examples of mismatched boundaries. In some cases the same area of land has been mapped on two separate surveys with different boundaries and land systems. The western portion of the Wiluna-Meekatharra survey is covered by the Belele sheet of the Murchison survey. There was also some overlap between the Ashburton and Carnarvon Basin surveys.

Problems also emerged correlating land system names. For example, areas adjacent and identical to the Buldiva land system[4] from the North Kimberley Survey (Speck *et al.* 1960) were mapped as the Pinkerton land system in the Ord-Victoria Survey (Stewart *et al.* 1970). In adjacent areas of the West Kimberley survey (Speck *et al.* 1964) they were mapped a Precipice land system. Consequently, three different names can apply to what is basically the same land system.

Further, there are a few cases where the same name has been applied to totally different land systems. For example, the Jubilee land system in the Nullarbor survey is a “dissected clay and kankar plateau with infrequent large dongas and common small claypans” while the Jubilee land system of the Ashburton and Carnarvon Basin surveys is described as “limestone hills and undulating stony plains”.

By the 1980s, as more surveys adjoining existing surveys were commenced, efforts to correlate mapping increased. Some land systems were identified as occurring across a number of surveys. However, due to natural variations, the systems often alter gradually across their range. This resulted in the situation where the same map unit ended with somewhat different descriptions in different surveys while retaining the same basic concept. In late 2005 and early 2006, Alan Payne and Alicia Gardner prepared (as far as possible) a single, unified description for each of the land systems.

Possibly the earliest attempt to revisit existing surveys to improve the quality of the mapping was the work of Kubicki and Beer (1975). They investigated the suitability of land in the North Kimberley for the legume Townsville stylo and undertook considerable reinterpretation of the aerial photos, redrawing land system boundaries. This work was continued by Payne (1985) who prepared a land system based map showing the pastoral potential of the entire Kimberley. Where possible, he edge-matched boundaries from the three different CSIRO surveys and correlated the land systems.

The advent of digital mapping in the late 1980s added impetus to correlation attempts. Not only was it easier to view discrepancies, but the potential of producing one-off maps for specific requirements increased the desirability of seamless survey boundaries. Over the next decade and a half, existing surveys were edge-matched on an ad hoc basis by Alan Payne, Peter Curry and Sandra Van Vreeswyk.

[4] Dissected sandstone plateaux and ranges

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Table 2.3: Rangeland surveys

Survey	Report reference (publication date)	Status[1]	Area (km^2)	Published scale	Project code[2]
Anna Plains	Cotching (2005)	P	3,814	1:700,000	BRM[3]
Ashburton River	Payne *et al.* (1983 and 1988)	P	96,016	1:250,000	ASH
Broome Coastal	Cotching (2005)	P	9,516	1:700,000	BRM
Carnarvon Basin	Payne *et al.* (1987)	P	86,592	1:250,000	CBS
Gascoyne River	Wilcox and McKinnon (1972)	P	76,254	1:250,000	GAS
Goongarrie	Payne (unpub.) 2001	NP	18,317	1:250,000	GOO
Kambalda (Western Mining survey)	Payne *et al.* (unpub.) 1998	NP	5,762	1:150,000	KAM
Lake Johnston	-	NS[4]	62,184	-	-
Lower Murchison	Hennig (in prep)	IP	15,952	1:250,000	LMU
Murchison River	Curry *et al.* (1994)	P	98,960	1:250,000	MUR
North Kimberley	Speck *et al.* (1960)	P	93,800	1:250,000	KIM[5]
North-eastern Goldfields	Pringle *et al.* (1994)	P	114,908	1:250,000	NEG
Nullarbor	Mitchell *et al.* (1979 and 1988)	P	55,510	1:250,000	NLB
Ord-Victoria	Stewart *et al.* (1970)	P	80,500	1:250,000	KIM[6]
Pilbara	Van Vreeswyk *et al.* (2004b)	P	197,517	1:250,000	PRP
Roebourne Plains	Payne and Tille (1992)	P	9,952	1:250,000	PRP[7]
Sandstone-Yalgoo-Paynes Find	Payne *et al.* (1998)	P	107,950	1:500,000[8]	SYP
South Kimberley	Payne *et al.* (in prep.) 1998	NP	26,000	1:250,000	KIM[9]
Southern Goldfields	-	NS	52,717	1:250,000	-
West Kimberley	Speck *et al.* (1964)	P	130,000	1:250,000	KIM[10]
Western Nullarbor	Waddell *et al.* (in prep.)	IP	84,790	1:250,000	WNB
Western Nullarbor Extension	-	NS	50,212	-	-
Wiluna Extension	-	NS	41,472	-	-
Wiluna-Meekatharra	Mabbutt *et al.* (1963)	P	54,340	1:250,000	WMA

1. IP = In preparation, NP = Complete but not published, NS = Not started, P = Published.
2. Three letter code used to identify the survey in the Map Unit Database (Section 2.2.4).
3. ANP has been combined with Broome Coastal for publication
4. The Lake Johnston area contains large areas of Unallocated Crown Land and this is likely to be a reconnaissance survey only.
5. Originally NKY at a scale of 1:1,000,000 but all of the Kimberley surveys have been combined into a single project.
6. Originally OVC at a scale of 1:1,000,000 but all of the Kimberley surveys have been combined into a single project.
7. Originally ROE but later combined with Pilbara Survey
8. Mapping conducted for 1:250,000 publication scale.
9. Never assigned individual code as all of the Kimberley surveys have been combined into a single project.
10. Originally WKY at a scale of 1:1,000,000 but all of the Kimberley surveys have been combined into a single project.

Problems with registration when drafting maps of the original surveys have also led to some inaccuracies. Improved aerial photography, better base maps and the availability of digital mapping enabled correction of some of these. Currently land system boundaries in the Kimberley are being redrawn by Phil Goulding, Alan Payne and Noel Schoknecht with the aid

of digital geological, contour and terrain model maps, as well as LANDSAT imagery and Google Earth.

Digital mapping and the databases also led to adoption of a convention of unique three letter codes for each land system. Previously a two letter code (and earlier a one letter code) was used to identify units. However with an increasing number of land systems (526 had been identified by early 2006) duplication of these codes was becoming common.

For example, the symbol *Co* has been used for the Coonangoody land system in the West Kimberley Survey, Cockburn land system in the Ord-Victoria, Colville land system in the Nullarbor, Collier land system in the Ashburton and Cole land system in the Murchison Survey. With a three letter code these symbols became *CON*, *COK*, *COV*, *COR* and *COL* respectively. While each three letter code is unique to the land system, it may apply to a number of different surveys. For example Boolaloo land system (*BOO*) is found in the Ashburton, Roebourne Plains and Pilbara surveys.

Where the same name has been applied to different land systems in different surveys, a number is added to the land system name and different three letter code is applied. For example the Fossil land system found in the Gascoyne and Ashburton surveys is different to the Fossil land system originally mapped in the West Kimberley[5]. To avoid confusion, these have been renamed Fossil 1 land system (*FSI*) and Fossil 2 land system (*FSL*) respectively.

2.2.4 Digital data storage

As with the mapping of the Agricultural Area, copies of existing (both original and modified line-work) rangeland surveys are maintained in digital form by the Department of Agriculture and Food in South Perth. Map unit polygon boundaries are captured via MicroStation design files and stored in MGE with links to ORACLE. Mapping is usually manipulated using Intergraph Geomedia warehouses. See Sections 2.2.2 and 2.2.7 of Schoknecht *et al.* (2004) for more details.

The naming convention for the most recent edge-matched digital copy of the survey is *rrang* followed by the three letter project code as shown in Table 2.3. Where the name ends with *_g* this denotes that the file is projected in the GDA94 datum as is the case with the most current versions of each survey[6]. For example, the Ashburton River survey is stored in files named *rrangash_g* while the Carnarvon Basin survey is stored in files named *rrangcbs_g*.

Within these digital files, each land system polygon is identified by a six letter database link label. The naming convention is that the first three letters are always *RGE* to indicate that the map unit is a rangeland land system unit. The second three letters relate to the unique three letter land system symbol described in Section 2.2.3. The six letter labels provide a link to the Map Unit Database.

All of the rangeland land systems have been entered into the Map Unit Database. Soil Groups of Western Australia (Schoknecht 2002) have been allocated to each land system on a proportional basis. The allocations were assigned by Peter Hennig and Noel Schoknecht in 2004 using the land unit percentages and soil type descriptions from published surveys. As yet no attempt has been made to identify the Soil Group qualifiers or to link the Soil Groups to a landscape position in the Map Unit Database.

2.2.5 Incorporating medium to high intensity surveys

A number of medium to high intensity surveys have been completed in areas already covered by rangeland surveys, mostly in the Kimberley and around Carnarvon. Many of these are soil surveys of existing or potential irrigation areas. Some of these surveys have

[5] While the former consists of hilly terrain, the latter consists of extensive plains with cracking clays.

[6] Copies of the surveys as originally published were mostly captured in the AGD84 datum and remain in that format. For example, the file containing the original version of the Ashburton survey is named *ashburt.edi*.

adopted, and subdivided, the land systems mapped in the rangeland surveys. A list of these medium to high intensity surveys is presented in Table 2.4.

Line-work and map units from some of these medium to high intensity surveys have since been incorporated into the digital copies of the Kimberley and Carnarvon Basin surveys. In many cases this involved combining soil map units into land systems. A variety of surveys (see Table 2.4) have been incorporated into the digital file of the Kimberley survey by Noel Schoknecht and Alan Payne. Peter Tille incorporated the mapping of Wells and Bessell-Browne (1990), Wells *et al.* (1992) and Tille and Smolinski (2003) into the digital file of the Carnarvon Basin survey. Some examples of mis-joins between the original mapping and the newly incorporated mapping require future investigation.

Table 2.4: Medium to high intensity surveys in the Rangelands

Survey location (map number)	Report reference (publication date)	Status[1]	Area (km^2)	Scale	Survey type	Project code[2]
Carlton Plain	Stoneman (1988)	P	123	1:77,000	Soil	CPL
Carnarvon Irrigation District	Wells and Bessell-Browne (1990)	P	41	1:15,000	Soil	CNV
Carnarvon LCDC	Wells *et al.* (1992)	P	321	1:50,000	Soil-landscape	CAR
Ivanhoe north west	Dixon and Holman (unpub.) 1980	NP	265	1:50,000	Soil	INW
Ivanhoe-Carlton Hill Stations	Schoknecht *et al*. (unpub.) 2004	NP	7,843	1:50,000	Land unit	OBP[3]
Ivanhoe Plain	Aldrick *et al* (1990)	P	228	1:25,000	Soil	IVA
Ivanhoe West Bank	Schoknecht and Grose (1996a)	P	17	1:25,000	Soil	IVP
Knox Creek Plain	Schoknecht and Grose (1996b)	P	57	1:25,000	Soil	KNX
Lower Gascoyne	Tille and Smolinski (2003)	P	104	1:50,000	Soil-landscape	LGS
Mantinea Flats/Goose Hill	Burvill (1991)	P	125	1:125,000 (approx.)	Soil	MGH
Mantinea Loop	Schoknecht and Grose (1996c)	P	12	1:25,000	Soil	MAN
Maxwell-Biyoogoong Plain	Schoknecht (unpub.) 1994	NP	156	1:50,000	Soil-landscape	MAX
North-west Packsaddle	Schoknecht (1996a)	P	3	1:25,000	Soil	NWP
Ord Regeneration Reserve[4]	De Salis (1993)	P	9,845	1:100,000	Land system	ORG
Packsaddle infill	Schoknecht (1996b)	P	1	1:12,000	Soil	PIN
Packsaddle Plain	Stoneman (1972)	P	45	1:25,000	Soil	PAC
Violet Valley-Bow River Station	Schoknecht *et al*. (unpub.) – 2005	NP	4,557	1:50,000	Land unit	OBP[3]
Weaber Plain	Dixon (1996)	P	192	1:25,000	Soil	WEA

1. NP = Complete but not published, P = Published.
2. Three letter code used to identify the survey in the Map Unit Database (Section 2.2.4).
3. These land unit surveys have not been assigned their own project, but are included in the Ord-Bonaparte upscaling project (OBP) along with the other detailed surveys from the Kununurra area.
4. Currently being incorporated into the Kimberley survey.

2.3 The Atlas of Australian Soils

No land system mapping is yet available for the Western Nullarbor, Southern Goldfields, Wiluna Extension and Lake Johnston survey areas (291,400 km^2). In addition no mapping is currently planned for the Arid Interior (966,500 km^2). As a result, the most detailed level of land resource mapping available over 43.2% of Western Australia is the *Atlas of Australian Soils*. Most of this area lies within the Arid Interior (inland from the pastoral stations).

The *Atlas of Australian Soils* was prepared in the 1960s and published as a number of different sheets at a scale of 1:2,000,000. Four of these sheets cover Western Australia:

- Sheet 10 (Northcote *et al*. 1968) covering most of the Arid Interior as well as the Southern Goldfields survey area;
- Sheet 5 (Northcote *et al*. 1967) covering the Lake Johnston and Western Nullarbor survey areas;
- Sheet 6 (Bettenay *et al*. 1967) covering a small portion of the Arid Interior lying to the north of the Wiluna-Meekatharra survey; and
- Sheet 9 (McArthur and Wright 1967) covering a narrow strip of the Arid Interior adjoining the Kimberley surveys.

While the *Atlas of Australian Soils* is presented as a soils map, it is in reality a soil-landscape map. The mapping units are associations of soil delineated by landscapes (Northcote *et al*. 1967). The map unit descriptions start with a summary of the landscape (in which geology is often mentioned). Soils are described in terms of the Factual Key (Northcote 1979), with chief and associated soils listed (and often related to landscape positions or geology).

Line-work from the *Atlas of Australian Soils* was digitally captured by the Department of Agriculture in the late 1980s from the (mostly 1:250,000 scale) map sheets containing the original CSIRO line-work. All map sheets have been combined into a single MicroStation design file (*ssoilaas.dgn*).

The naming convention for the *Atlas of Australian Soils* map units in the Map Unit Database and on the digital map is the letter *AAS* followed by the map unit symbol as it appears on the published maps. For example map unit *My98* becomes *AASMy98*, *SV9* becomes *AASSV9* and *A2* becomes *AASA2*.

In the 1990s, Noel Schoknecht allocated Soil Groups of Western Australia (Schoknecht 1997[7]) to the *Atlas of Australian Soils* mapping units on a proportion basis (i.e. by percentage). This allocation was based on the information presented in the Legend 2 contained in the Explanatory Data accompanying each of the map sheets. The information was then entered into the Department of Agriculture's Map Unit Database.

It needs to be recognised that this allocation of Soil Groups was a 'rough and ready' exercise, both in terms of correlating the Soil Group of Western Australia to the Factual Key classifications and in estimating the proportion of soil present in each map unit. No attempt has yet been made to record information about soil group qualifiers or landscape positions in which the soil groups occur.

[7] These were later updated to version 3 Soil Groups of Western Australia (Schoknecht 2002).

3. METHODOLOGY

3.1 Hierarchy level of map units

The first step in placing the existing rangeland surveys, and the *Atlas of Australian Soils* mapping, into the Department of Agriculture and Food's mapping unit hierarchy (as used in the Agricultural Area) was to determine the level of the hierarchy to which the map units belonged. Unfortunately, the scale of mapping units across the rangeland surveys is not always consistent and many land systems probably lie somewhere between the system and subsystem level.

In the earlier surveys, the land systems created tended to be broader and encompass a greater variety of soils and landscapes. Buldiva in the North Kimberley survey for example could be viewed as closer to the zone level of mapping.

In some more recent surveys, where mapping was much more intricate and detailed, many of the systems mapped are closer to the subsystems in scale. An example is the many occurrences of the Waguin land system (stony and sandy plains with occasional low breakaways) in the North-eastern Goldfields. These tend to cover relatively small areas (50-1000 ha) totally surrounded by larger units[8]. Some of these larger units, such as the Bullimore land system (extensive sandplains), sit quite comfortably at the system level.

Due to time constraints and complexity of the task (a total of 526 different land systems and almost 35,000 individual polygons had been identified in various rangeland surveys to the beginning of 2006), it was not practical to treat different land systems differently.

It was decided to assign virtually all of the land systems of the Rangelands to the system level of the hierarchy (equivalent of level 4 in the ASRIS hierarchy). There were a few exceptions, mainly lake beds and claypans that have now been recognised as subsystems of the surrounding system.

The map units in the *Atlas of Australian Soils* also present a challenge. While mostly broader in scale than the rangeland land systems, they remain below the zone level. As an interim measure the *Atlas of Australian Soils* units have been classified as *not ranked* units, lying outside the map unit hierarchy proper, but recognised as occurring below the zone level. This is not a very satisfactory solution and requires future review.

3.2 Identifying soil-landscape regions, provinces and zones

The soil regions and provinces of CSIRO (1983) formed the basis for identifying the boundaries of soil-landscape regions and provinces of the Agricultural Area, as well as provisional boundaries for the remainder of the State (see Figure 2.2). However, it was decided at the national level that the ASRIS mapping will be primarily guided by the boundaries identified by Jennings and Mabbutt (1977).

Jennings and Mabbutt (1977) prepared a map of the physiographic outlines and regions of Australia (Figure 3.1) at a scale of 1:12,000,000. Their aim was to "provide a regional basis for an understanding of land characteristics that are dependent upon landforms". The continent was firstly divided into three Divisions: the Eastern Uplands; the Interior Lowlands; and the Western Plateau Division. Western Australia[9] falls entirely within the latter.

[8] In the adjoining Wiluna-Meekatharra survey, individual occurrences of the Waguin land system tend to fall into the 500-5,000 ha size range.

[9] The Western Plateau also incorporates most of the Northern Territory and South Australia.

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Table 3.1: Physiographic Sections identified by Jennings and Mabbutt (1977)

North Australian Plateaux Province	
123	Bonaparte-Diemen Lowlands
129	Ord-Victoria Plateaux
Kimberley Province	
131	Kimberley Plateau
132	Drysdale Lowlands
133	Couchman Uplands
134	Leopold-Durack Ranges
135	Yampi Peninsula
136	Richenda Foothills
137	Fitzroy Plains
138	Napier Limestone Ranges
139	Springvale Foothills
140	Halls Creek Ridges
141	Fitzroy Ranges
Lander Barkly Plains Province	
147	Wiso Sandplain
155	Birrundudu Plain
156	Tanami Sandplain and Ranges
157	Sturt Creek Floodout
Central Australian Ranges Province	
165	Amadeus Lowland
166	Rawlinson-Petermann Ranges
167	Kulgera Hills
168	Musgrave Ranges
169	Warburton Ranges
Sandland Province	
170	Dampier Tablelands
171	Eighty Mile Plain
172	Anketell Hills
173	Great Sandy Desert Dunefield
174	Stansmore Dunefield and Ranges
175	Gibson Desert Plains
176	Redvers Dunefield
177	Macdonald Sandplain
178	Stanley Hills and Dunes
179	Carnegie Hills
180	Leemans Sandplain
181a	Great Victoria Desert - main dunefield
181	Great Victoria Desert - Northwest Dunes and Hills

Pilbara Province	
182	DeGrey Lowlands
183	Nullagine Hills
184	Rudall Tablelands
185	Hamersley Plateaux
186	Chichester Range
187	Fortescue Valley
188	Augustus Ranges
Western Coastlands Province	
189	Onslow Plain
190	Carnarvon Dunefield
191	North West Cape Ridges
192	Kennedy Range
193	Carnarvon Plain
194	Shark Bay Peninsulas
195	Yaringa Sandplain
196	Greenough Hills
197	Dandaragan Tablelands
198	Swan Plain
199	Donnybrook Lowland
200	Leeuwin Peninsula
Yilgarn Plateau Province	
201	Murchison Plateau
202	Glengarry Hills
203	Salinaland Plateau
204	Woodrarrung Hills
205	Northam Plateau
206	Narrogin-Ongerup Plateau
207	Coonana-Ragged Plateau
208	Darling Range
209	Collie-Kalgan Slopes
210	Albany Headlands and Inlets
211	Stirling and Barren Hills
212	Esperance Hills
Nullarbor Plain Province	
213	Carlisle Plain
214	Bunda Plateau
215	Roe Plain
216	Israelite Plain

Each division has been subdivided into provinces, and these are in turn subdivided into sections. Figure 3.1 shows the provinces and sections within Western Australia, while Table 3.1 provides a brief summary of the sections. See Appendix 2 for a brief description of the sections identified by Jennings and Mabbutt (1977). Their boundaries sometimes correlate with those of CSIRO (1983) shown in Figure 2.2, but there are some significant differences.

In order to facilitate correlation with other States, the provinces and divisions of Jennings and Mabbutt (1977) have been used as the primary basis for identifying soil-landscape regions and provinces in the Rangelands and Arid Interior. The CSIRO soil regions and provinces were also consulted and in some cases deemed more appropriate. In general, the mapping of Jennings and Mabbutt seems to represent the Kimberley and Arid Interior better than that of CSIRO.

Where existing rangeland surveys reports contained maps of physiographic regions, these were used as an initial basis for identifying the soil-landscape zones. These maps were deemed highly relevant as they were drawn by people who spent considerable time surveying the area. They also had the added benefit of often relating directly to the land system boundaries.

Maps by Myers and Hocking (1988) and Tyler and Hocking (2001) showing the major tectonic units of Western Australia (Figure 3.2) also had a significant influence on determining soil-landscape region, province and zone boundaries. An attempt was made to limit the geological variation of the soil-landscape units. As well as influencing the nature of the landforms and soils, the underlying geology has a major impact on the hydrogeological properties of an area.

Beard's map (1990) showing the botanical districts of Western Australia (Figure 3.3) was also consulted, as was his mapping of the component vegetation systems (Beard 1974-1981) and the related Interim Biogeographic Regionalisation for Australia (IBRA) regions (Environment Australia 2000).

The rangeland land system maps themselves were used to identify broad patterns. Land system maps were digitally coloured according to rangeland land type (Pringle 1994, Van Vreeswyk and Godden 1998, Van Vreeswyk *et al*. 2004a) to identify areas of similar country and to highlight where major changes occurred.

Each rangeland land system had previously been allocated to one of 47 types (see Appendix 3). These land types are a combination of landscape and vegetation. Examples include: *Hills and ranges with spinifex grasslands*; *Stony plains with acacia shrublands*; *Sandplains with acacia, mallees and heath*; and *Alluvial plains with halophytic shrublands*.

Acacias and annual wildflowers on stony ground in the Murchison Province (S Davies)

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Figure 3.3: Botanical districts of Western Australia (adapted from Beard 1990)

3.3 Drawing boundaries and assigning map unit link labels

3.3.1 Rangeland surveys

The MicroStation design files described in Section 2.2.4 were used to create the soil-landscape boundaries in the Rangelands. To these digital versions of the land system maps were referenced the maps of the: physiographic provinces and sections of Jennings and Mabbutt (1977); soil regions and provinces of the CSIRO (1983); tectonic units of Tyler and Hocking (2001); and the vegetation systems of (Beard 1974-1981). A pattern file of the rangeland land types; a LANDSAT TM image of Western Australia; and a sun-shaded digital terrain model were also referenced.

Within the design files, the link label on each individual polygon was changed to reflect the map unit hierarchy. The six letter labels were replaced with a five character symbol as used in the Agricultural Area (Section 2.1). The first three characters are numerals denoting the region, province and zone to which the system belonged, and the next two letters identifying the system. Where possible, an attempt was made to ensure that the two letter system code matched the labels appearing on the original maps.

An example is provided by the Bandy system which originally had the link label of *RGEBAN* and display label of *Ban*. The link label was changed to *266Ba* where it occurred in the Norseman Zone and *271Ba* where it occurred in the Irwin River Zone. In the Northern Zone of Ancient Drainage the link label *258Ba* was already allocated[10], so the symbol for the Bandy system in this zone became *258By*. The display label remained *Ban*.

The link labels were changed to reflect the region, province and zone that the polygon fitted into best. In the MicroStation design file, a fence was placed around the proposed zone boundary, and the labels on individual systems within the fence were then altered through global changes. After a few changes, a pattern file of the map was produced coloured according to soil-landscape zones. This pattern file showed those polygons that had been placed within the zone (and those which remained unallocated), and was used to review the zone boundary.

Although the linework of Jennings and Mabbutt was the starting point for identifying the zone boundaries, it was too broad to use as a basis for placing individual land system polygons into zones at a scale of 1:250,000. Greater emphasis was placed on trying to ensure that the polygons were kept in ‘natural’ groupings of land systems. The physiographic regions from the survey reports and the patterned rangeland land type maps proved to be very useful aids in this process.

Where two or more land systems tended to occur in association, an attempt was made to ensure that as many polygons of those systems as possible were placed within the same zone. For example, the Augustus, Jamindie, Charley and Collier systems are often found in association and have been included in the North Bangemall Hills Zone (299) while the Capricorn, Edward, Kooline and Ashburton systems have been included in the adjoining Ashburton Valley Zone (298).

As the original rangeland surveys had given limited consideration of broader scale mapping units than the land systems, groupings such as those described above were rarely pure. The Augustus, Jamindie and Collier systems are also common in the Bulloo Plains and Hills Zone (290) where they are found in association with the Divide and Nooingnin systems. A land system such as Augustus may occur in eight different zones, while Robe system is found in nine zones across three provinces.

There were also many examples of outliers, isolated from the main occurrences of these land systems. These were usually placed in the same zone as their surrounding units, even if

[10] To the Baladjie System from the Bencubbin survey (Grealish and Wagnon 1995).

only a couple of polygons of that land system occurred in the zone[11]. This was done largely in order to keep the zone map tidy, so as not to lose the big picture in the minor details.

In some cases, there was another reason for separating the outliers. A good illustration is the Rocklea system (rugged basalt hills and dissected plateaux). In the Chichester Ranges Zone (282) where it is a dominant land system, Rocklea is comprised largely of the plateaux surfaces. In the De Grey-Roebourne Lowlands Zone (281), however, Rocklea tends to occur as isolated hills and hill tracts rising out of the plain. Here the system is dominated by scree slopes. Though closely related, these two occurrences of Rocklea would have differing proportion of soils and landforms, so it makes sense to map them as separate units.

Individual polygons of some land systems cover large areas and spread across a number of zone boundaries. A good example of this is the River land system (flood plains and terraces flanking major rivers and creeks). A single land system polygon mapped in the Pilbara survey starts off as the narrow floor of a gorge in the rugged sedimentary and volcanic terrain of Chichester Ranges (282), spreads out as it crosses the stony flats of the granitic Abydos Plains and Hills Zone (283) and finally becomes a broad expanse of floodplains and channels amongst the alluvium and sand sheets of the De Grey-Roebourne Lowlands Zone (281). In such cases, the polygon was split into a number of small polygons depending upon the soil-landscape zone through which it passed.

Polygons were also split to smooth zone boundaries, especially if the land system was common in both of the adjoining zones. In some cases the boundaries of tectonic units of Tyler and Hocking (2001) were used to divide land systems between zones. One large polygon of the Uaroo land system was split along a line following the eastern edge of the Carnarvon Basin. To the west where it overlay the Carnarvon Basin sedimentary rocks it was placed into the Yanrey Plains Zone (203). To the east, where it overlay the granitic rocks of the Gascoyne Complex, it was placed into the Stuart Plains and Hills Zone (296).

3.3.2 Atlas of Australian Soils

A digital version of the *Atlas of Australian Soils* was created for areas where no more recent or detailed mapping was available by trimming the map of the State to exclude existing surveys in the Rangelands and the Agricultural Area.

The process for placing the polygons from this trimmed version of the *Atlas* into the mapping unit hierarchy was similar to that applied to the rangeland surveys. There was a heavy emphasis on the mapping of Jennings and Mabbutt as well as the tectonic units of Tyler and Hocking (2001), with the vegetation systems of Beard (1974-1981) also prominent.

Along the border with the Northern Territory and South Australia, the zone boundaries were matched as far as possible with those of Colin Pain's revision of Jennings and Mabbutt's line-work appearing as level 3 on the ASRIS website (ASRIS 2006). An attempt was also made to match the border region zone boundaries to the IBRA sub-regions (Environment Australia 2000) as these will play a major influence on the placing of the Northern Territory mapping into the ASRIS hierarchy (Dave Howe, pers. comm.).

Unlike the land systems identified in the rangeland surveys, no rangeland land types had previously been assigned to the *Atlas of Australian Soils* map units. An attempt was made to allocate these rangeland land types to the Atlas units. These allocations were achieved by consulting both the landform descriptions contained in the explanatory data for the Atlas maps (Bettenay *et al*. 1967, McArthur and Wright 1967, Northcote *et al*. 1967 and Northcote *et al*. 1968); and the vegetation associations of Beard (1974-1981) that corresponded with the Atlas map units (see 'Vegetation descriptions' in Section 3.6 for more details).

[11] Despite being one of the systems characterising the difference between the North Bangemall and Ashburton Valley Zones, there are still four occurrence of Augustus system in the latter.

In cases where a rangeland land system from an adjoining survey clearly correlated with an *Atlas of Australian Soils* map unit, the land type assigned to the former was also allocated to the latter.

In some cases no suitable rangeland land type was available to describe the Atlas unit, usually because one had not been created for the particular combination of landform and vegetation. In such cases an additional rangeland land type was created and allocated. This extended the list to 64 rangeland land types and the proposed additional land types are presented in Appendix 4.

While these newly applied rangeland land types did not play a significant role in identifying soil-landscape zone boundaries within the Arid Interior, they proved useful in the preparation the zone descriptions.

Line-work from the digital map of tectonic units and the vegetation systems of Beard (1974-1981) were used to split some of the *Atlas of Australian Soils* units in places. In some cases, where it appeared more accurate, vegetation system line-work was used to replace Atlas line-work. Where splits were made or line-work replaced, the new line-work is shown in the MicroStation design file in a different colour. The colours used are as follows:

- Colour 0 (black) – Additional line-work from air photo interpretation for the Broome Coastal Survey (Cotching 2005);
- Colour 1 (blue) – *Atlas of Australian Soils* line-work;
- Colour 2 (green) - Vegetation systems boundaries;
- Colour 3 (red) - Tectonic unit boundaries;
- Colour 4 (yellow) - Jennings and Mabbutt region boundaries;
- Colour 6 (orange) – Interpretations from Landsat-TM image; and
- Colour 14 (cream) – Best estimate of where continuation of boundary is likely to go.

The *Atlas of Australian Soils* units did not fit comfortably into the soil-landscape mapping unit hierarchy, though they clearly sit below the zone level. The Atlas labels, ranging from two to five characters and containing numerals and letters, also do not lend themselves to the hierarchy convention of a two letter code for soil-landscape systems.

As an interim measure, therefore, the *Atlas* units have been assigned no system in their link labels, the zone numeral being followed by a double under-bar and then the map unit symbol as it appeared on the original map. For example the *Atlas* unit *My98* in the Great Sandy Desert Zone (112) becomes *112__My98*. It is not the intention to suggest that *My* is a subsystem and *98* is the phase, rather that *My98* lies somewhere below the zone level.

3.4 Edge-matching survey

An attempt was made to edge-match the *Atlas of Australian Soils* line-work to existing rangeland surveys. In some places the Atlas unit was an obvious extension of a rangeland soil-landscape system[12] and the link label was changed extending the rangeland system into the Arid Interior. Elsewhere, Atlas boundaries were altered so that they joined system boundaries from adjoining rangeland surveys. The aim was to ensure some conceptual correlation between the Atlas unit and the rangeland systems (though this was not always possible). For example, both the Atlas units Oc49 and Fa9[13] often correspond with either the Augustus or Collier land systems[14].

[12] This was identified by overlying the *Atlas of Australian Soils* line-work for the whole of Western Australia on top of the line-work from the rangeland surveys.

[13] Pediments and stony hills on fine-grained sedimentary rocks and basic dykes.

[14] Undulating stony uplands, hills and ranges on Bangemall Group sediments.

In many cases, the soil-landscape system boundaries had to finish at the edge of the rangeland surveys as they showed greater detail and complexity than the Atlas units. Occasionally an Atlas boundary would have to be ended abruptly at the edge of the Arid Interior survey where there was no suitable rangeland system boundary to connect it to.

Similar attempts were made to edge-match the *Atlas of Australian Soils* to adjoining surveys in the Agricultural Area. These were Bencubbin (Grealish and Wagnon 1995); Southern Cross-Hyden (Verboom and Frahmand, in prep.); Jerramungup (Overheu, in prep.); and Salmon Gums-Esperance-Ravensthorpe (Nicholas and Gee, in prep.) land resource surveys.

As the rangeland survey program was conducted independently from the surveys of the Agricultural Area, the mapping units were poorly correlated across this divide. The Sandstone-Yalgoo-Paynes Find rangeland survey abuts the Geraldton (Rogers 1996), Three Springs (Grose, in prep.), Moora-Wongan Hills (Griffin and Frahmand, in prep.) and Bencubbin (Grealish and Wagnon 1995) land resource surveys, while the Lower Murchison rangeland survey abuts the Geraldton survey.

To complicate matters further, there was a degree of overlap between these surveys. Areas of freehold land within the boundaries of the Lower Murchison survey[15] had been mapped as part of the Geraldton survey. An area of the Sandstone-Yalgoo-Paynes Find mapping extends into the Geraldton mapping around Nullewa Lake east of Morawa and the Bencubbin mapping to the east of Lake Moore. There were also unmapped gaps between the surveys: Crown land in the north-east of the Geraldton survey (including Wandana Nature Reserve); and unmapped areas of cleared land near the edges of the Sandstone-Yalgoo-Paynes Find survey.

Some progress has been achieved towards producing a seamless boundary between mapping the Rangelands and agricultural areas. This was assisted through the use of a digital copy of unpublished mapping undertaken by Gary Rogers, extending the Geraldton soil-landscape boundaries into the edges of the rangeland surveys. This mapping involved aerial photo interpretation only, and often there was no label to identify the map unit. However it was still very useful and allowed some Geraldton soil-landscape subsystem units to be extended onto the adjoining surveys[16]. As the Geraldton mapping is currently under review, it has also been possible to extend some of the rangeland systems into this survey as part of the edge-matching process and draw boundaries on land previously unmapped within this survey.

3.5 System descriptions

The soil-landscape system descriptions were based on data previously entered into the Map Unit Database. Each of the new soil-landscape systems created from the rangeland surveys was matched to a pre-existing land system in the database.

For example, the new soil-landscape systems *280Bg*, *287Bg*, *294Bg*, *296Bg* and *299Bg* are all linked to the Boolgeeda land system (*RGEBGD*). The unified description prepared by Alan Payne and Alicia Gardner (see Section 2.2.3) for Boolgeeda land system has been loaded into the MU_SUM_DESC field in the MUNIT table ('Summary Description' on the Map Unit Properties Form) for each of the linked new soil-landscape systems. The allocations of Soil Groups of Western Australia for *RGEBGD* were copied into the MUNIT_WASOILGRP_LUNIT table (under the 'Components (by %)' tab of the Map Unit Properties Form) for each of the new systems.

[15] As well as covering a small area on the edge of the Murchison survey.

[16] Some of these changes may be incorporated into the published version of the Lower Murchison rangeland survey.

To indicate the source of the data, the words *Cloned from RGEBGD* was entered into the MU_SIMILAR field in the MUNIT table ('Similar map units' on the Map Unit Properties Form) and the MUWASGLU_NOTES field in the MUNIT_WASOILGRP_LUNIT table for these units.

From the digital versions of the mapping, the area of each soil-landscape system occurring within each of the rangeland surveys was calculated. This data was used to identify the source survey for the soil-landscape system (the survey in which the greatest area of the system occurs). This source survey was then recorded in the MU_USAGE field ('Other usage' on the Map Unit Properties Form). For example, the Carnarvon Basin survey (CBS) is the source survey for *294Bg*, while for *299Bg* the source is the Ashburton survey (ASH) and for both *280Bg* and *287Bg* the source is the Pilbara survey (PRP).

As the descriptions of the land systems can vary from survey to survey, the source survey will contain the most appropriate descriptions and details for populating Database fields in the future. As an interim measure, the map unit legend description from the source survey was placed into the MU_NOTES field in the MUNIT table ('Map Unit Notes' under the 'Other Descriptions' tab of the Map Unit Properties Form).

For map units identified in the Arid Interior, Soil Groups of Western Australia allocations were copied from the *Atlas of Australian Soils* units already entered into the Map Unit Database (Section 2.3). For example the data for *ASSAB48* was used to populate *124__AB48*, *581__AB48* and *618__AB48*.

As no map unit descriptions had previously been entered into the Map Unit Database for the *Atlas of Australian Soils*, a MS-Word document containing the map unit descriptions from the published explanatory data was used to populate the MU_LFORM_NOTES and MU_SOILS_NOTES fields in the database. The summary descriptions (MU_SUM_DESC) were populated with the rangeland land type descriptions (Section 3.3.2) as an interim measure.

3.6 Compiling region, province and zone descriptions

Soil-landscape region, province and zone descriptions were written with the aid of soil-landscape system data contained in the Map Unit Database. A one paragraph description of each region, province and zone has been generated by concatenating the brief descriptions entered into the database for the following fields: landform; geology; soils; vegetation; and location.

Landform descriptions were based primarily on the 47 rangeland land types (see Appendix 3) allocated to the systems as described in Section 3.5 above. These were already allocated to soil-landscape systems derived from the rangeland surveys, but had not previously been assigned to the *Atlas of Australian Soils* units. In order to provide a more consistent description of landforms and vegetation, these land types where allocated to the *Atlas of Australian Soils* units in the Arid Interior (Section 3.3.2).

Using MS-Access queries to combine the area of the soil-landscape system with the landform component of its allocated land type[17], it was possible to calculate a proportional allocation of landforms within each region, province and zone.

The brief landform description was written using these proportional allocations and followed the conventions that:

- where two landforms were co-dominant (roughly equal area) the term *and* was used to join them
- where landform(s) comprised approximately half the area of the of the dominant landform(s) they were preceded by the term *with*; and

[17] For example, land type 1 (*hills and ranges with acacia shrublands*) and land type 2 (*hills and ranges with spinifex grasslands*) were grouped together as *hills and ranges*.

- where the landforms comprised around 10%[18] or less of the total area they were preceded by the term *and some* (or *with some* in cases where the subdominant landforms were absent).

For example, a zone that comprised 50% sandplain, 20% alluvial plain, 20% stony plain and 10% hills and ranges would be described as: 'sandplains *with* alluvial plains and stony plains (*and some* hills and ranges)'. However, if the proportions had been 35%, 35%, 20% and 10% respectively, the description would read: 'sandplains *and* alluvial plains *with* stony plains (*and some* hills and ranges)'.

In some cases the landform descriptions were modified to match the terminology contained in the descriptions of Jennings and Mabbutt (1977), the CSIRO (1983) or the physiographic regions appearing in the published rangeland surveys.

Geology descriptions were based on the tectonic units shown on the mapping of Tyler and Hocking (2001) and descriptions of the Geological Survey of Western Australia (Myers and Hocking 1988). A visual comparison was made of soil-landscape zone boundaries with a digital map of tectonic units. The main tectonic unit(s) on which each zone was located was recorded along with the prominent rock types. Where the age of the rocks had an influence on determining zone boundaries, this was also included.

Soil descriptions were written using the terminology of Schoknecht (2002). In MS-Access, queries were built combining the proportional allocation of Soil Groups of Western Australia to the soil-landscape systems with the area of the systems to calculate the area of each Soil Group within each zone, province and region. Where the zone, province and region extended into the Agricultural Area, the Soil Group allocations to the agricultural soil-landscape sub-systems and phases were included in the calculations. In preparing the soil descriptions, the conventions described above for the landform descriptions were adhered to.

Vegetation descriptions were generated from two main sources. First a digital copy of the map of the soil-landscape zones was compared with a digital copy of vegetation associations of Beard (1974-1981) using an Intergraph Geomedia spatial intersection query. This produced the area of each vegetation association within each soil-landscape zone, indicating the dominant associations.

These data were then compared with the vegetation components of the rangeland land types determined as described for the landscape component above. From here the proportional areas of vegetation in each zone, system and region were calculated. Again, the conventions described for the landform descriptions were adhered to.

For the Arid Interior (where no existing vegetation description was available for the *Atlas of Australian Soils* units) an Intergraph Geomedia spatial intersection query was used to determine the area of each of the vegetation associations within each of the newly created soil-landscape units (e.g. *123__AY1* or *615_BA20*). The associations were then summarised into categories equivalent to the vegetation component of the rangeland land types[19]. The dominant vegetation component of the unit was combined with the landform component (derived from the Atlas explanatory data) to determine its rangeland land type.

Location descriptions were written after viewing the soil-landscape zone boundaries overlain on a combined image of 1:1,000,000 scale topographic maps sheets in an Intergraph Geomedia workspace.

An attempt was made to select prominent and well known geographic features (e.g. major towns, rivers, lakes or mountain ranges) when describing the distribution of the zones,

[18] Landforms making up less than 5% of the area were rarely included.

[19] For example, the association described by Beard *et al.* as "hummock grasslands, open medium tree & mallee steppe; marble gum (*E. gonglocarpa*) and mallees (e.g. *Eucalyptus youngiana*) over hard spinifex (*Triodia basedowii*) between sandhills" was simplified to *spinifex grassland with eucalypts*.

provinces and regions. However this was often not possible, especially in the Arid Interior where it was necessary to resort to naming more obscure features. In many cases pastoral stations are mentioned in the descriptions, usually on the basis of the location of the station homestead.

The geographic features named in the descriptions appear in the road atlas “Road and tracks Western Australia” (QPA 2006). Regional names used (such as the Pilbara, Goldfields, Wheatbelt, Nullarbor Plain or Gibson Desert) are shown on Figure 2.1.

4. REGION, PROVINCE AND ZONE DESCRIPTIONS

This section presents descriptions of the soil-landscape regions (Figure 4.1), provinces and zones identified within Western Australia's Rangelands and Arid Interior. The descriptions are arranged in numerical order in accordance with the mapping unit hierarchy.

A brief description is provided for each region, province and zone. These are derived from the Map Unit Database, being a combination of the landscape, geology, soils, vegetation and location fields described in Section 3.6. For the regions and provinces, the description is presented in italics directly underneath the region or province title. For the zones, the brief descriptions are presented in tabular form at the end of the relevant province description. These tables also include the total area (in square kilometres) covered by the zone within Western Australia. Where part of the zone extends into the Agricultural Area and is therefore covered by pre-existing soil-landscape surveys, the area previously mapped[20] is also recorded (in parenthesis).

Detailed descriptions are provided for each region and province arranged under the following sub-headings:

Location and boundaries detailing the extent of the region or province. This includes its area in square kilometres as well as the proportion of Western Australia which it occupies. Towns or major geographical features occurring within its boundary are mentioned. Also discussed is the geographical relationship to adjoining regions or provinces and correlation with other mapping (e.g. Jennings and Mabbutt 1977 or CSIRO 1983). As well as a description of the course of the boundary, there is often some discussion of the rationale for determining its location;

Geology detailing the major tectonic units (Hocking and Tyler 2001) on which the region or province has formed as well as the nature and age of the underlying rocks;

Landforms detailing the major landscapes present in relation to the underlying geology;

Soils detailing the major Soil Groups of Western Australia (Schoknecht 2002) present in relation to the landforms and geology;

Climate detailing the bioclimate (as described by Beard 1990[21]) and range in rainfall across the region or province (Figures 4.2 and 4.3);

Vegetation detailing the distribution of the major vegetation associations (and prominent species) in relation to the soils, landforms and geology; and

Component Provinces/Component Zones listing either the provinces occurring within the region, or the zones within the province. This list also provides some of the rationale used to identify the component province or zone by relating them to existing geological, physiographical, soil or biogeographical mapping.

Where the regions, provinces and zones described extend into the Agricultural Area, both the brief and detailed descriptions cover the entire unit, not just the proportion lying within the Rangelands and Arid Interior. For soil-landscapes that extend across the State border, only the portion in Western Australia has been described. Mapping of the Northern Territory and South Australia is yet to be completed and many of the datasets used to prepare the descriptions are specific to Western Australia.

[20] Although in most cases the area covered by the existing soil-landscape survey lies entirely within the Agricultural Area, the Salmon Gums-Esperance-Ravensthorpe survey (Nicholas and Gee, in prep.) also includes a sizeable area of unallocated Crown land beyond the agricultural districts.

[21] Based on the classification of Bagnouls and Gaussen 1957

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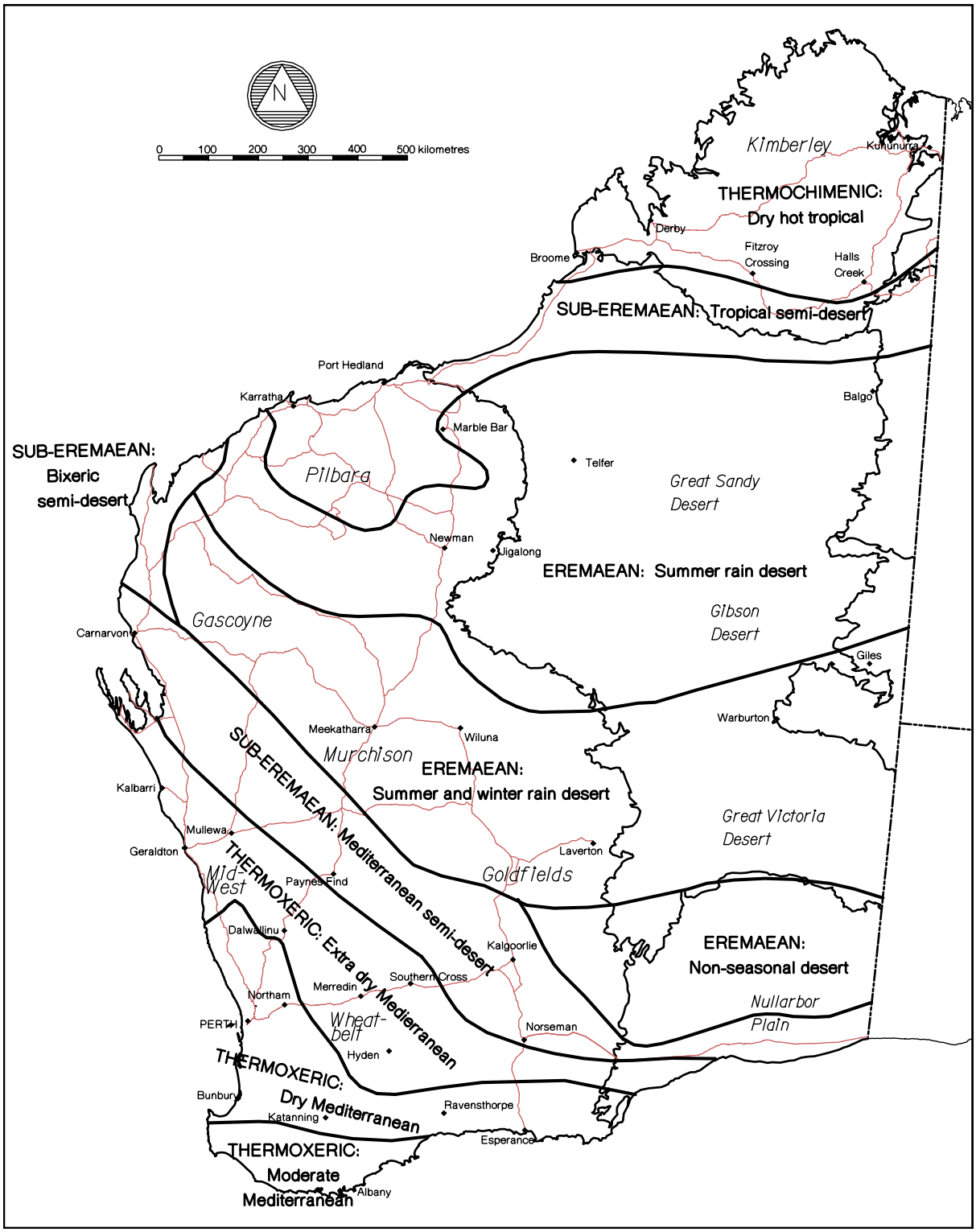

Figure 4.2: Bioclimes of Western Australia (from Beard 1990)

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Figure 4.3: Mean annual rainfall for Western Australia (from Pringle et al. 1994)

Acacia shrubland with hilly terrain in the background in the Ashburton Province

In the south-east of the State, the flat limestone plain of the Nullarbor terminates dramatically at the cliffs of the Great Australian Bight (PJ Waddell)

1 Sandy Desert Region

Sandplains and dunes (with some undulating plains and uplands) on the sedimentary rocks of the Canning, Gunbarrel and Officer Basins. Red deep sands and Red sandy earths with some Shallow gravels and Red loamy earths. Spinifex grasslands with scattered eucalypts (and some mulga and mallee shrublands). Located in the Arid Interior between Eighty Mile Beach, Wolfe Creek, Warburton, the Nullarbor, Lake Carnegie and Jigalong.

Location and boundaries: Although most of the Sandy Desert Region is situated in Western Australia, it also dominates the western half of South Australia. Within WA, it occupies around 768,250 km^2 covering almost a third of State (30.4%). This is much of the Arid Interior, south of the Kimberley Region, east of the Western Region, north of the Nullarbor Region, and west of the Lander-Barkly Plains and Central Australian Ranges Regions.

Within this region lie the Great Sandy, Little Sandy, Gibson and Great Victoria Deserts. Few settlements of significance occur over this vast area. The mining centre of Telfer is in the north-west. Other small settlements include Balgo, Punmu and Mindibungu Communities and Tjukayirla and Ilkurlka Roadhouses.

Although the Sandy Desert Region is based on the Sandland Province of Jennings and Mabbutt (1977), its boundaries have been adapted to reflect the tectonic units of Hocking and Tyler (2001). In the main, land overlying the Canning[22], Officer and Gunbarrel Basins (as well as the western occurrence of the Patterson Orogen) has been placed in this region. This has resulted in the Rudall Tablelands and Sturt Floodout Sections of Jennings and Mabbutt being included while the Redvers Dunefield, Macdonald Sandplain, Carnegie Hills and Leemans Sandplain Sections have been excluded. The Dampier Tablelands Section has been excluded due to its affinity with the Kimberley.

The boundary extends east from Roebuck Bay (just south of Broome), following the southern edge of the Kimberley to Wolfe Creek, before swinging south past Balgo and Kiwirrkurra to Warburton. From here it heads east into South Australia, along the southern edge of the Musgrave Ranges, then south-east (almost to Coober Pedy) and south to the edge of Lake Gairdner. From here it heads west (passing just to the north of Ceduna and Penong) before arcing around the northern edge of the Nullarbor. Is passes Maralinga before returning to Western Australia above Forrest Lakes and heading on to Lake Minigwal on the south-western corner of the Great Victoria Desert. From here it heads northwards (passing west of Rason Lake, Lakes Yeo and Throssell) to Lake Carnegie, from where it swings north-west, heading almost to Kumarina on the Great Northern Highway. It then heads north, skirting the eastern edge of the Pilbara, past Jigalong and more or less follows the Vermin Proof Fence to the coast near the mouth of the De Grey River. It then follows Eighty Mile Beach back to Roebuck Bay.

Along with the Lander-Barkly Plains and Central Australian Ranges Regions, the Sandy Desert Region lies within the Sandy Desert Region described by Northcote and Wright (1983).

Geology: The region overlies sedimentary rocks of the Canning, Gunbarrel and Officer Basins, the surface layers of which date from the Devonian through to the Cretaceous Periods. In the east, the Proterozoic sedimentary rocks of the Yeneena Basin and the Proterozoic gneiss and sedimentary rocks of the Rudall Complex make up part of the Paterson Orogen.

[22] With the exclusion of the Fitzroy Trough, Lennard Shelf and Jurgurra Terrace.

The Tertiary Period saw extensive development of ironstone and silcrete duricrusts. Erosion and deposition, with wind playing a major role, occurred during wetter and drier phases of the Quaternary resulting in an aeolian mantle across much of the region.

Landforms: As the name implies, this large and very sparsely occupied region is dominated by sandy deserts (sandplains and longitudinal dune fields) which occur on gently undulating plains or low tablelands. There are also areas of stony gibber desert on gently undulating lateritic uplands. Minor components include rugged ranges; isolated residual sandstone hills, mesas and buttes; calcrete plains; wash plains; and salt lakes.

Soils[23]***:*** Sandy soils are dominant, with Red sandy earths common on sandplains and Red deep sands on the dunes. Shallow gravels with Deep sandy gravels are founds on lateritic plains and tablelands. The hills and ranges have Stony soils, Red loamy earths, Red shallow loams, Red shallow sands and Red sandy earths. Red-brown hardpan shallow loams are found on wash plains, stony plains and the footslopes of some hills. Calcareous loamy earths occur on calcrete plains while Salt lake soils are also present.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly 150-250 mm, dropping to 100 mm in the south-east. There is greater chance of summer rain in the north while rain is most likely in either summer or winter in the south. In the north, the bioclimate becomes Sub-Eremaean (a tropical semi-desert with 9-11 dry months) and rainfall increases to 600 mm near Roebuck Bay.

Vegetation: Although mostly arid desert, is little is not at least sparsely vegetated. Hummock grasslands of feathertop spinifex (*Triodia schinzii*) with scattered desert bloodwood (*Corymbia dichromophloia*) and mixed shrubs dominate the northern sandplains and dunefields. In the south these are replaced by hard spinifex (*T. basedowii*) grasslands with open low tree and mallee steppe of marble gum (*Eucalyptus gongylocarpa*) and mallees (e.g. *E. youngiana*). In the central and southern portions, mulga (*Acacia aneura*) shrublands are sometimes present, especially on the gravelly plains of the Gibson Desert and the hardpan wash plains. Spinifex grasslands also dominate the hills, ranges and calcrete plains. Pindan shrublands are present in the north-west.

Component provinces: The Sandy Desert Region has been divided into four soil-landscape provinces within WA (Figure 4.4):

- Canning Province (11) is based on the Canning Basin tectonic unit of Tyler and Hocking (2001);
- Gunbarrel Province (12) is based on the Gunbarrel Basin tectonic unit of Tyler and Hocking (2001);
- Officer Province (13) is based on the Officer Basin tectonic unit of Tyler and Hocking (2001); and
- Paterson-Yeneena Province (15[24]) is based on the Paterson Orogen and Yeneena Basin tectonic units of Tyler and Hocking (2001).

[23] Soil descriptions are derived from allocations of Soil Groups of Western Australia (Schoknecht 2002). These in turn are based on interpretations of the brief descriptions and Factual Key (Northcote 1979) classifications published in the *Atlas of Australian Soils*. As much of this region has not been surveyed, soil descriptions and component province and zones should be viewed as educated estimates at best.

[24] Currently there is no province allocated to the hierarchy code 14. Originally this code was allocated to the MacDonnell Province by Schoknecht *et al.* (2004) but this no longer belongs in the Sandy Desert Region.

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11 Canning Province

Sandplains and dunes (with some undulating plains and uplands) on the sedimentary rocks of the Canning Basin. Red deep sands and Red sandy earths with Shallow gravels (and some Red loamy earths and Deep sandy gravels). Spinifex grasslands with desert bloodwood (and some mulga and pindan wattle shrublands). Located in the northern Arid Interior between Eighty Mile Beach, Wolfe Creek and Warburton.

Location and boundaries: Canning Province occupies about 399,400 km^2 (15.8% of WA) in the northern Arid Interior. It includes most of the Great Sandy Desert and the north of the Gibson Desert. This province is situated to the south of the Fitzroy Province; west of the Sturt and Western Desert Ranges Provinces; north of the Gunbarrel Province; and east of the Officer, Paterson-Yeneena and Fortescue Provinces.

The boundary is based on the Canning Basin tectonic unit (Tyler and Hocking 2001). The main exclusion is the northern portion where the Fitzroy Trough, Lennard Shelf and Jurgurra Terrace underlie the Fitzroy Province[25].

The boundary extends east from Roebuck Bay (just to the south of Broome) across the bottom of the Dampier Peninsula to the Fitzroy River near Manguel Creek Station, before swinging south-east following the edge of the Great Sandy Desert to the Hall Range (south-east of Fitzroy Crossing). From here it heads east along the edge of the Great Sandy Desert to Wolfe Creek Meteorite Crater, and then turns south to Warburton. From here it heads north-west (past Well No. 26 on the Canning Stock Route and Lake Dora) to the Vermin Proof Fence, which it then follows to the coast near the mouth of the De Grey River. Finally it follows the shore of Eighty Mile Beach back to Roebuck Bay.

Geology: Canning Province is situated over the Phanerozoic sedimentary rocks of the Canning Basin. These include Cretaceous marine and continental shale, siltstone and sandstone; Jurassic marine and continental sandstone and siltstone; Permian marine and continental sandstone, siltstone and shale coal measures; and Carboniferous-Permian glacigene, marine and continental siliclastic sedimentary rocks. Devonian sediments are found in the north-east corner near Wolfe Creek. A couple of relatively small inliers of the Amadeus Basin are also included (the Neoproterozoic shales and sandstones of the Baron and Clutterbuck Inliers).

Landforms: The Great Sandy Desert is largely dunefields. These are predominantly stable linear dunes with swales opening locally into sandplains. Dune lineation is generally east to west, but towards the coast the trend tends north-west to south-east. Among these dunefields there are some small claypans and depressions as well as isolated residual sandstone hills. There are also many exposures of ironstone gravels and some breakaways capped by laterite duricrust.

The Gibson Desert is dominated by gently undulating upland with much ironstone gravel on the surface. There are some breakaways (mesas, buttes and bluffs) capped by lateritic duricrust and some local marginal transgression by longitudinal dunes. Similar terrain is found in the Anketell Hills to the north of Telfer. Low to steep hilly country with mesas and buttes (sometimes capped with laterite) on sandstone is found in the Stansmore Range in the north-east and Edgar Range in the north-west. Calcrete plains, coastal plains, salt lakes and flood-outs are minor components.

Soils: Red deep sands and Red sandy earths are the main soils of the dunefields and sandplains. Also present in depressions between dunes are Red loamy earths and Shallow gravels. The uplands of the Gibson Desert and Anketell Hills have Shallow Gravels, Deep

[25] Other minor portions of the Canning Basin excluded from this province are a small tongue of the Wallal Embayment extending onto the Fortescue Province and the southern Waukarlycarly Embayment extending into the Paterson-Yeneena Province.

sandy gravels and Red deep sands. On hilly terrain there are Red loamy earths and Red sandy earths, with Red shallow loams, Red shallow sands, Stony soils and Shallow gravels.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert, commonly with 12 dry months a year. Mean annual rainfall is mostly in the 150-300 mm range with a greater chance of summer rain in the north tending to an even chance of rain in summer or winter in the south. In the north, the bioclimate becomes Sub-Eremaean (tropical semi-desert with 9-11 dry months) and rainfall increases to 600 mm near Roebuck Bay.

Vegetation: The dominant vegetation of the dunefields is hummock grasslands of feathertop spinifex (*Triodia schinzii*) with scattered desert bloodwood (*Corymbia dichromophloia*) and mixed shrubs. Soft spinifex (*T. pungens*) grasslands associate with desert bloodwood, desert walnut (*Owenia reticulata*) and pindan wattle (*Acacia platycarpa*). On sandplains inland from Eighty Mile Beach are pindan shrublands with *A. eripoda* and scattered low bloodwoods (*Corymbia* spp.) over soft spinifex and curly spinifex (*T. bitextura*) grasslands. Mulga (*A. aneura*) shrublands over hard spinifex (*T. basedowii*) are found on the Gibson Desert along with desert bloodwood over feathertop spinifex.

Component zones: Canning Province has been divided into eight soil-landscape zones (Figure 4.4a):

- Great Sandy Desert Zone is based on the northern portion[26] of the Great Sandy Desert Dunefield Section of Jennings and Mabbutt (1977) and correlates with a combination of the the Sand Ridge Division and Dune Fields Region of Wright (1964);
- Eighty Mile Coast and Flats Zone is based on the coastal strip of the Eighty Mile Coast Plain Section of Jennings and Mabbutt (1977);
- Sturt Creek Zone is based on the Sturt Creek Floodout Section of Jennings and Mabbutt (1977);
- Stansmore Dunefield and Ranges Zone is based on the western portion[27] Stansmore Dunefield and Ranges of Jennings and Mabbutt (1977);
- Edgar Ranges Zone is based on the patterns evident on the land system, pasture land and soils maps of Speck et al (1964) and lies within the Great Sandy Desert Dunefield Section of Jennings and Mabbutt (1977);
- Nita Sandplain Zone is based on a combination of the inland portion of Eighty Mile Coast Plain Section and the western portion of the Anketell Hills Section[28] of Jennings and Mabbutt (1977);
- Anketell Hills Zone is based on the Anketell Hills Section of Jennings and Mabbutt (1977); and
- Northern Gibson Desert Zone[29] is based on the northern portion of the Gibson Desert Plains Section of Jennings and Mabbutt (1977).

[26] The portion that overlies the Canning Basin. The southern portion overlies the Gunbarrel Basin, and it may be advisable to merge these two zones in the future if no significant difference is identified.

[27] The portion that overlies the Canning Basin.

[28] This western portion of the Anketell Hills Section does not seem to match Jennings and Mabbutt description very well, being predominantly sandplain and saline flats.

[29] The portion that overlies the Canning Basin. The southern portion overlies the Gunbarrel Basin, and it may be advisable to merge these two zones in the future if no significant difference is identified.

112 - Great Sandy Desert Zone (236,250 km^2)	Sandplains and dunes on sedimentary rocks of the Canning Basin. Red deep sands and Red sandy earths with some Red loamy earths and Shallow gravels. Spinifex grasslands with eucalypts and some acacia shrublands. Located in the northern Arid Interior between Dampier Downs Station, Lake Gregory, Giles and De Grey River.
113 - Eighty Mile Coast and Flats Zone (4,700 km^2)	Coastal plains, dunes and alluvial plains (with some tidal flats and beaches) on Marine shoreline and aeolian deposits over Cretaceous Canning Basin sedimentary rocks. Calcareous loamy earths, Tidal soils and Loamy duplexes with Red deep sands, Calcareous deep sands and Calcareous shallow loams. Tussock grasslands and halophytic shrublands with bare tidal flats, melaleuca thickets and mangroves. Located in the north-west coast between Broome and Port Hedland.
114 - Sturt Creek Zone (2,725 km^2)	Alluvial plains, flood-outs and sandplains on alluvial and lacustrine valley-fill deposits over sedimentary rocks of the Canning Basin. Red deep sands with Loamy duplexes and Sandy duplexes and some Saline wet soils and Red sandy earths. Spinifex grasslands and sedgelands with coolibah. Located in the north-eastern Arid Interior around Lake Gregory (south of Wolfe Creek).
115 – Stansmore Dunefield and Ranges Zone (37,750 km^2)	Sandplains and dunes (with some hills and ranges) on sedimentary rocks of the Canning Basin. Red sandy earths and Red deep sands with Red loamy earths and some Calcareous loamy earths. Spinifex grasslands with desert bloodwood and shrubs (including acacias). Located in the north-eastern Arid Interior between Wolfe Creek, Lake Gregory and the Stansmore Range.
116 – Edgar Ranges Zone (2,350 km^2)	Hills, ranges, lowlands and alluvial plains (with some sandplains and dunes) on Jurassic Canning Basin sandstone and mudstone. Red deep sands and Yellow sandy earths with Shallow gravels and Stony soils. Spinifex grasslands with eucalypts, pindan shrublands and tussock grasslands. Located in the north-western Arid Interior around Dampier Downs and Mowla Bluff Stations.
117 - Nita Sandplain Zone (26,200 km^2)	Sandplains and dunes on Cretaceous Canning Basin sedimentary rocks. Red deep sands with some Red sandy earths. Pindan shrublands and shrubby spinifex grasslands. Located in the north-west coast hinterland between Broome and the De Grey River.
118 – Anketell Hills Zone (18,975 km^2)	Undulating upland and plains (with some sandplains and dunes) on Cretaceous Canning Basin sedimentary rocks. Shallow gravels with Red deep sands, Red sandy earths and Deep sandy gravels. Spinifex grasslands with eucalypts and acacias. Located in the Great Sandy Desert to the south-east of Mandora and north-west of Percival Lakes.
119 – Northern Gibson Desert Zone (70,425 km^2)	Undulating plains and uplands (with sandplains and dunes) on Cretaceous Canning Basin sedimentary rocks. Shallow gravels with Red deep sands, Red sandy earths and Deep sandy gravels. Spinifex grasslands with mulga shrublands (with some desert bloodwood and acacias). Located in the central Arid Interior between Well No. 33 (Canning Stock Route) and Warburton.

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12 Gunbarrel Province

Sandplains and dunes (with undulating plains and uplands) on the sedimentary rocks of the Gunbarrel Basin. Red sandy earths and Red deep sands with some Red loamy earths, Shallow gravels and Red-brown hardpan shallow loams. Spinifex grasslands with mallee, marble gum and mulga (and some desert bloodwood). Located in the southern Arid Interior between Well No. 24 (Canning Stock Route), Warburton, the Nullarbor and Lake Minigwal.

Location and boundaries: Within WA, Gunbarrel Province occupies about 266,900 km^2 (10.6% of the State). It is in the southern Arid Interior to the south of the Canning and Western Desert Ranges Provinces, north of the Nullarbor and Tarcoola-Quondong Provinces, and east of the Murchison, Ashburton, Officer and Paterson-Yeneena Provinces. This province includes the Great Victoria Desert and the southern portions of the Great Sandy and Gibson Deserts.

The boundary is based on the Gunbarrel Basin tectonic unit (Tyler and Hocking 2001). It extends from Well No. 24 (on the Canning Stock Route to the north-east of Lake Disappointment) south-east to Warburton. From here it heads east into South Australia, along the southern edge of the Musgrave Ranges and almost to Coober Pedy, then south and west back into Western Australia above Forrest Lakes (on the northern edge of the Nullarbor). It then continues west to Lake Minigwal (on the south-western corner of the Great Victoria Desert) before swinging north to Lake Carnegie and back to Well No. 24.

Geology: The province is situated over the Phanerozoic sedimentary rocks of the Gunbarrel Basin. These include Cretaceous sandstone; Carboniferous-Permian glacigene, marine and continental siliclastic sedimentary rocks; and Devonian arenite. A small area of Ordovician basalt is also present near Lake Gillen.

The Gunbarrel Basin overlies the Officer Basin, which comes to the surface in the north-east (along the boundary with the Musgrave and Warburton Range Provinces). Here are Neoproterozoic conglomerate, sandstone and arenite.

In the south-west are the Mesoproterozoic granite, dolerite, gabbro and ultra-basic intrusions, and Archaean gneiss of an outlier of the Biranup Complex (Albany-Fraser Orogen).

Landforms: The Great Victoria and Great Sandy Deserts are dominated by sandplains with longitudinal and ring dunes separated by interdune corridors and plains. These sandplains sit at an elevation of 350-500 m AHD[30], dropping to less than 300 m in the south. They contain occasional outcrops of sandstones, laterites and silcretes, some calcareous mounds, and occasional salt pans. Also present are scarpland-breakaways and residuals of various forms (cuestas, mesas, buttes, stony hillocks and hills). These are usually surrounded by stone and gravel pavements. Shallow valleys (with lakes, claypans, salt pans, calcrete platforms, sand dunes, kopi dunes and calcareous dunes) are usually a relatively minor component of the landscape. There are some prominent salt lakes.

The Gibson Desert, at elevation of 400-500 m AHD, is dominated by dissected lateritic uplands of flat to hilly topography with shallow detrital valleys and pediment slopes. On these uplands are extensive gravel pavements, some small sandy plains, low escarpments of breccia and laterite, and lateritic mesas and buttes.

Soils: The sandplains and dunes have Red sandy earths and Red deep sands with some Red loamy earths. Shallow gravels are found on the lateritic uplands of the Gibson Desert along with Red-brown hardpan shallow loams, Red deep sands and Deep sandy gravels. The scarpland-breakaways and residuals have Red-brown hardpan shallow loams, Stony soils, Red loamy earths and Red shallow loams.

[30] AHD – Australian Height Datum, equivalent to height above sea level based on mean sea level for 1966-68.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, commonly with 12 dry months a year. Mostly the rainfall is in the 150-200 mm range with an even chance of either summer or winter rain, though there is a tendency towards summer rain in the north. In the south-east rainfall drops to 100 mm with no seasonal tendency. In the south-west it rises to 250 mm with a tendency to winter falls.

Vegetation: Hummock grasslands of hard spinifex (*Triodia basedowii*) are common on sandplains in the south. These are found in association with open low tree and mallee steppe of marble gum (*Eucalyptus gongylocarpa*) and mallees (e.g. *E. youngiana*). To the north, mulga (*Acacia aneura*) scrub replaces marble gum and mallee. Grassland of feathertop spinifex (*T. schinzii*) with scattered desert bloodwood (*Corymbia dichromophloia*) and mixed shrubs also appears on the dunefields. Hard spinifex and mulga dominate the gravelly plains of the Gibson Desert.

Component zones: Gunbarrel Province has been divided into five soil-landscape zones within Western Australia (Figure 4.4b):

- Northwestern Great Victoria Desert Zone is based on Northwest Dunes and Hills of the Great Victoria Desert Dunefield Section described by Jennings and Mabbutt (1977);
- Southern Great Sandy Desert Zone is based on the south-east portion[31] of the Great Sandy Desert Dunefield Section of Jennings and Mabbutt (1977);
- Southern Great Victoria Desert Zone is based on Main Great Victoria Desert Dunefield Section of Jennings and Mabbutt (1977) and corresponds to the Okaralnga, Victoria Desert and Lake Wright environmental associations of Laut *et al.* (1977b);
- Southern Gibson Desert Zone is based on southern portion[32] of the Gibson Desert Plains Section of Jennings and Mabbutt (1977); and
- Sydney-Simpson Zone overlies an outlier of the Albany-Fraser Orogen of Tyler and Hocking (2001).

NOTE: *Sydney-Simpson Zone (128) could be altered to become an outlier of the Nanambinia Zone (264).*

[31] The portion that overlies the Gunbarrel Basin. The northern portion overlies the Canning Basin and the south-west directly overlies the Officer Basin. It may be advisable to merge two or more of these zones if no significant difference is identified.

[32] The portion that overlies the Gunbarrel Basin. The northern portion overlies the Canning Basin. It may be advisable to merge these two zones in future if no significant difference is identified.

122 - Northwestern Great Victoria Desert Zone (94,450 km^2)	Sandplains and dunes (with some undulating plains and uplands) on sedimentary rocks of the Gunbarrel Basin. Red sandy earths and Red deep sands with some Red loamy earths and Red-brown hardpan shallow loams. Mulga shrublands and spinifex grasslands with mallee. Located in the southern Arid Interior sitting between Lake Carnegie, Rason Lake and Warburton.
123 - Southern Great Sandy Desert Zone (27,075 km^2)	Sandplains and dunes (with some uplands and mesas) on sedimentary rocks of the Gunbarrel Basin. Red sandy earths with Red deep sands and some Shallow gravels, Red loamy earths and Red-brown hardpan shallow loams. Spinifex grasslands with desert bloodwood and shrubs and some mulga scrub. Located in the central Arid Interior between Well No. 24 (Canning Stock Route) and Lake Burnside.
124 -Southern Great Victoria Desert Zone (87,550 km^2)	Sandplains and dunes (with some gravelly plains and calcrete plains) on sedimentary rocks of the Gunbarrel (and Officer) Basin. Red deep sands and Red sandy earths with some Red loamy earths. Spinifex grasslands with mallee scrub and some mulga and eucalypt woodlands. Located in the southern Arid Interior between Lake Minigwal and the South Australian border.
125 - Southern Gibson Desert Zone (52,150 km^2)	Lateritic uplands (with some sandplains, dunes, mesas and alluvial plains) on sedimentary rocks of the Gunbarrel Basin. Shallow gravels with Red deep sands and Red-brown hardpan shallow loams and some Deep sandy gravels, Red sandy earths and Red Loamy earths. Spinifex grasslands with mulga scrub. Located in the central Arid Interior between Warburton, Baker Lake and the Hutton Range.
128 - Sydney Simpson Zone (5,650 km^2)	Undulating plains, calcrete plains and sandplain with dunes on Proterozoic gneiss and volcanic rocks of the Albany-Fraser Orogen (Biranup Complex). Red sandy earths and Red loamy earths with Red deep sands and Calcareous loamy earths. Spinifex grasslands with mallee and some mulga shrublands. Located in the southern Arid Interior between Rason Lake and Kitchener (Trans-Australian Railway).

Burning spinifex grasslands on red sandplain (PJ Waddell)

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13 Officer Province

Sandplains and dunes (with some hardpan wash plains, hills and ranges) on sedimentary rocks of the north-western Officer Basin. Red sandy earths with Red deep sands and some Red loamy earths, Red shallow loams and Red-brown hardpan shallow loams. Spinifex grasslands with scattered bloodwood and some mulga shrublands. Located in the western central Arid Interior between Lake Disappointment, Jigalong and Lake Burnside.

Location and boundaries: This province occupies about 66,950 km^2 (2.7% of WA). It is in the central western part of the Arid Interior occupied by the Little Sandy Desert. It is to the south of the Paterson-Yeneena Province, west of the Gunbarrel Province, north and east of the Ashburton Province, and east of the Fortescue Province.

The boundary is based on the exposed north-western extension of the Officer Basin tectonic unit of Tyler and Hocking (2001). Excluded is the Gibson Sub-basin which has been placed in the Paterson-Yeneena Province[33].

The boundary extends from Constance Headland (to the south of Lake Disappointment) north-west to the Oakover River (east of Balfour Downs Station). It then swings south-west, past Jigalong, to Beyondie Lakes (to the east of Kumarina Roadhouse on the Great Northern Highway) and then south-east, past the Lee Steere Range (and crossing the Canning Stock Route at Well No. 6), to Lake Burnside. From here it heads north back to Constance Headland.

Officer Province correlates with the south-western portion of the Great Sandy Dunefield Section of Jennings and Mabbutt (1977).

Geology: It is situated over the Neoproterozoic sandstone, conglomerate and shale of the north-western extension of the Officer Basin (previously known as the Savory Basin). In the north is the Wells Sub-basin which contains similar rocks but is part of the Paterson Orogen.

Also present are minor sandstone glacigene rocks; and dolerite, gabbro and ultrabasic intrusions. In the east are the Mesoproterozoic sedimentary rocks of outliers of the Edmund and Collier Basins.

Landforms: Sandplains with a variable, but usually high, proportion of longitudinal sand dunes cover most of this province which mostly has elevation of 450-600 m AHD. Reticulate dunes are also present and claypans are often associated with the sandplains.

There are also some extensive, flat and gently sloping wash plains on which red-brown hardpan frequently outcrops. These sometimes have a surface cover of gravels. Scattered sandstone hills (comprising dissected rocky mesas, pediments and small valleys with dunes) are fairly common, as are laterite residuals. Gravelly sandplains are found in some places as are saline plains with salt lakes and dunes of sand and gypsum.

Soils: Sandplains are dominated by Red sandy earths, with Red deep sands on the dunes. Red loamy earths are also found on the sandplains. Red-brown hardpan shallow loams, Red loamy earths and Red shallow loams are found on the wash plains. On the hills there are Stony soils, Red shallow loams, Red Shallow sands and Red loamy earths. Salt lake soils, Saline wet soils and Calcareous loamy earths are associated with the saline plains.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, often with 12 dry months a year. Mean annual rainfall is mostly in the 200-250 mm range with greater chance of summer falls, but drops to 150 mm in the east.

[33] The Gibson Sub-basin was originally mapped as part of the Yeneena and Karara Basins which was part of the rationale for including it in the Paterson-Yeneena Province. It may be advisable to review the boundaries between these provinces in the future.

Vegetation: The dominant vegetation is hummock grasslands. Hard spinifex (*Triodia basedowii*) is found on interdune sandplains with acacia and grevillea shrubs and desert oak (*Allocasuarina decaisneana*). Feathertop spinifex (*T. schinzii*) occurs on dunes with scattered bloodwoods (*Corymbia* spp.) and mixed shrubs. Low mulga (*Acacia aneura*) woodlands are found on wash plains while the saline plains support samphire (*Halosarcia* spp.) succulent steppe.

Component zones: Only one soil-landscape zone has been recognised (Figure 4.4c)[34]:

131 - Little Sandy Desert Zone (66,950 km^2)	Sandplains and dunes (with some hardpan wash plains, hills and ranges) on sedimentary rocks of the north-western Officer Basin. Red sandy earths with Red deep sands and some Red loamy earths, Red shallow loams and Red-brown hardpan shallow loams. Spinifex grasslands with scattered bloodwood and some mulga shrublands. Located in the western central Arid Interior between Lake Disappointment, Jigalong and Lake Burnside.

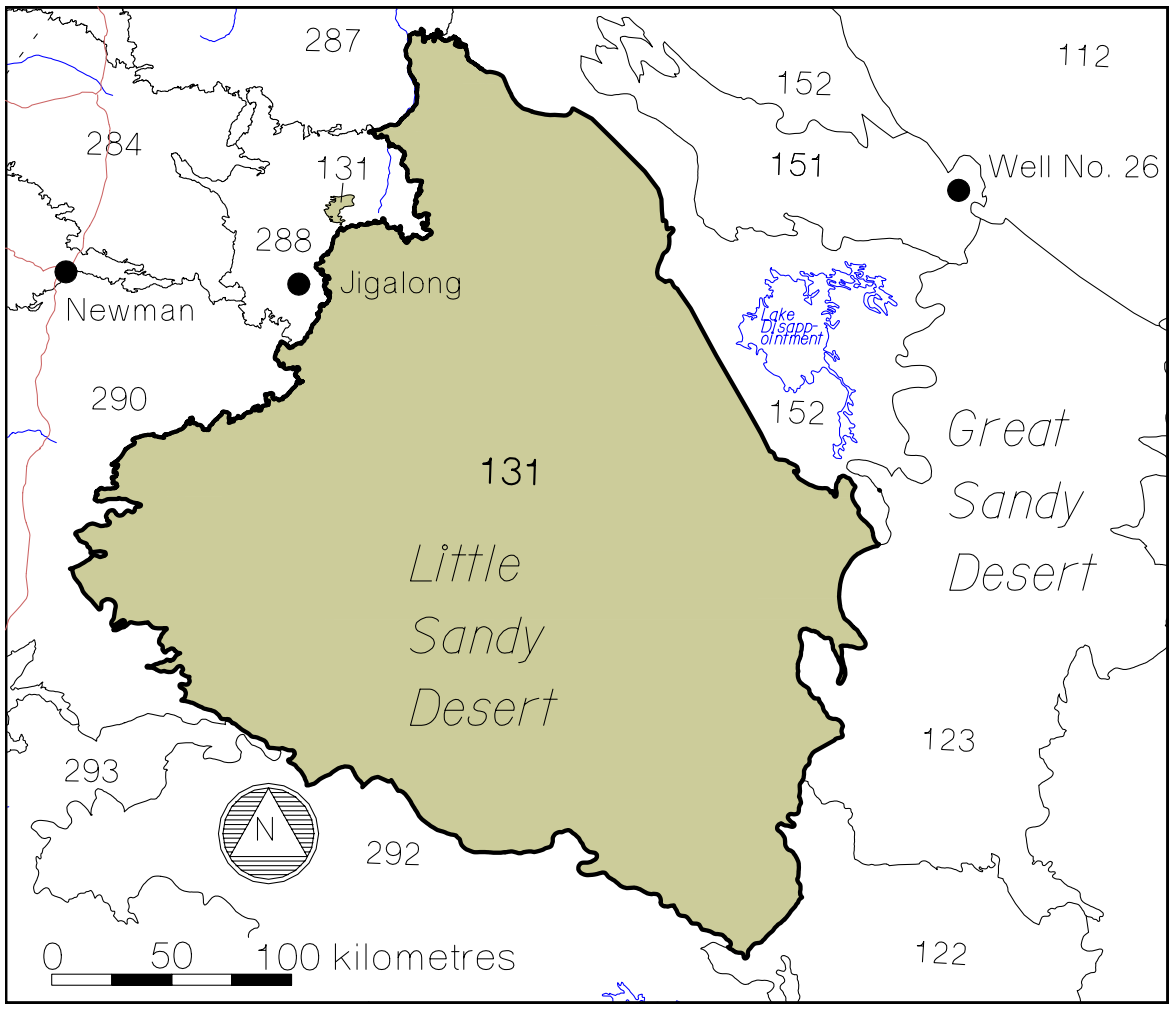

Figure 4.4c: Soil-landscape zone of the Officer Province

[34] The Wells Sub-basin (part of the Paterson Orogen) could provide a basis for sub-dividing this province, however no differences in geology, soils or landforms are immediately apparent. There may be merit in including the Gibson Sub-basin in this province rather than in the Paterson-Yeneena Province.

15 Paterson-Yeneena Province

Sandplain, dunes, hills and ranges (with some salt lakes and calcrete plains) on the sedimentary rocks and gneiss of the western Paterson Orogen and Yeneena Basin. Red sandy earths with Red deep sands and Stony soils (and some Red loamy earths, Red shallow loams, Bare Rock, Salt lake soils and Red shallow sands). Spinifex grasslands with scattered eucalypts and acacias and some salt lakes. Located in the western Arid Interior between the Oakover River, Telfer, Lake Disappointment and Lake Auld.

Location and boundaries: It occupies about 35,000 km^2 (1.4% of WA). It is in the western Arid Interior around Rudall River, south of the Canning Province, west of the Gunbarrel Province, north of the Officer Province, and east of the Fortescue Province.

The boundary is based on the Yeneena Basin and Paterson Orogen tectonic units (Tyler and Hocking 2001). It excludes the Wells Sub-basin (part of the Officer Basin within the Paterson Orogen) and that portion of the Northeast Pilbara Sub-basin falling within the Paterson Orogen. Included is the southern tip of the Waukarlycarly Embayment of Canning Basin.

The boundary extends from Constance Headland (south of Lake Disappointment) north-west to the Oakover River (east of Mt Divide Station). It then swings north, approximately following the route of the Vermin Proof Fence, to the Ulalling Hills (east of Warrawagine Station). From here it doubles back and heads south to Telfer, then north once more to Lake Waukarlycarly, before heading south-east (past Lake Dora) to Well No. 26 on the Canning Stock Route. Finally it swings south back to Constance Headland.

It correlates with the Rudall Tablelands Section of Jennings and Mabbutt (1977). While the boundaries seem to correlate with the northern occurrence of the Broadhurst Province of Northcote and Wright (1983), there is little correlation to the description they provide[35].

Geology: The province overlies the north-western Patterson Orogen and Yeneena Basin.

Patterson Orogen is a complex area. In the south is the non-concealed portion of the Gibson Sub-basin (Officer Basin) that contains Neoproterozoic sandstone, siltstone, mudstone, and stromatolitic and non-stromatolitic dolomite. In the north-west is the Rudall Complex that includes Palaeoproterozoic granitoid rock, amphibolite, quartzite, orthogneiss, schist, chert, metamorphosed ultramafic rock, carbonate rocks and banded iron-formation. On the western margin is the Gregory Granitic Complex (Pilbara Craton) comprising Archaean metamorphosed granitoid rock, syenogranite, and granophyre.

The Yeneena Basin in the north contains Mesoproterozoic and Neoproterozoic sandstone, shale and carbonate. Also included is a small portion of the Waukarlycarly Embayment (Canning Basin) which contains Phanerozoic sedimentary rocks.

Landforms: This province is centered on the Throssell, Paterson and Broadhurst Ranges that rise to an elevation of 500 m AHD. These rugged ranges have extensive areas of bare rock and are based on the metamorphic, granitic and sedimentary rocks of the Rudall Complex and Yeneena Basin. Associated with them are low ranges and hills that are transgressed by dunes in places and flanked by small plains.

Surrounding the ranges are extensive areas of sandplain at an elevation of 250-400 m AHD. These have a variable, but usually high, proportion of longitudinal sand dunes. There are also scattered sandstone hills, while claypans and exposures of ironstone gravels on low rises are found in the dune swales. Granite hills, domes and tor fields rise out of the sandplain in the north-west. Alluvial plains (with salt lakes, salt pans and claypans) are also

[35] Broadhurst Province is described by Northcote and Wright as being “narrow terraces bordering drainage ways and old watercourses, calcreted during late Tertiary”. They also suggest that powdery calcareous soils are dominant.

present. There are some uneven calcrete plains with small salt lakes and pans broken by variable proportions of longitudinal sand dunes.

Soils: The hills and ranges have Stony soils, Bare Rock, Red shallow loams, Red shallow sands and Red loamy earths. Sandplains are dominated by Red sandy earths, with Red deep sands on the dunes. Red loamy earths and Shallow gravels are found in swales. Salt lake soils and Saline wet soils characterise the saline plains, while Calcareous loamy earths are common on the calcrete plains.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly in the 150-200 mm range with a greater chance of summer falls, but rises to 300 mm in the north-west.

Vegetation: The dominant vegetation is hummock grassland of feathertop spinifex (*Triodia schinzii*) with scattered desert bloodwood (*Corymbia dichromophloia*) and mixed shrubs. Hard spinifex (*T. basedowii*) grasslands are found with *Acacia coriacea*, kanji (*Acacia inaequilatera*) and *Hakea* spp. Soft spinifex (*T. pungens*) grasslands are also present in places. Saline plains support samphire (*Halosarcia* spp.) succulent steppe with teatree (*Melaleuca* spp.) scrub surrounding the bare salt lakes.

Component zones: Paterson-Yeneena Province has been divided into three soil-landscape zones (Figure 4.4d)[36]:

- Rudall River Zone is based on the Rudall Complex tectonic unit of Tyler and Hocking (2001);
- Yeneena Zone is based on a combination of the Yeneena Basin and Gibson Sub-basin tectonic units of Tyler and Hocking (2001); and
- Waroo Zone is based on the Gregory Granitic Complex tectonic unit of Tyler and Hocking (2001)[37].

[36] The boundaries of this province and its component zones are poorly defined and could be reviewed with greater emphasis on geomorphic surface expressions.

[37] The Waroo Zone is a very small and narrow, but does not sit comfortably with either of its adjoining zones. It differs from the Yeneena Zone to the east due to its underlying granitic geology (as opposed to sedimentary rocks) with numerous surface expressions. To the west is the Warrawagine Zone which is predominantly hilly (on a mix of volcanic and sedimentary rocks) rather than sandplain.

151 - Rudall River Zone (6,625 km^2)	Hills and ranges (with some calcrete plains) on gneiss and sedimentary rocks of the Rudall Complex. Stony soils, Red shallow loams and Bare rock with Red shallow sands, Red loamy earths and Red sandy earths. Spinifex grassland with scattered bloodwoods and acacias. Located in the western Arid Interior between Rudall River and Well No. 24 on the Canning Stock Route.
152 - Yeneena Zone (26,650 km^2)	Sandplains and dunes (with hills, ranges and some salt lakes) on sedimentary rocks of the Yeneena Basin and Gibson Sub-basin. Red sandy earths with Red deep sands and some Salt lake soils, Stony soils, Red loamy earths, Red shallow loams and Bare rock. Spinifex grassland with scattered bloodwoods and acacias and some salt lakes. Located in the western Arid Interior from Lake Disappointment to Telfer.
153 - Waroo Zone (1,725 km^2)	Sandplains and dunes (with some stony plains and hills) on sedimentary, volcanic and granitic rocks of the Gregory Granitic Complex. Red deep sands with Red sandy earths and Red loamy earths and some Red shallow sands and Shallow gravels. Spinifex grassland with scattered bloodwood and some kanji. Located in the north-east Pilbara in a narrow strip sitting to the east of the Oakover River.

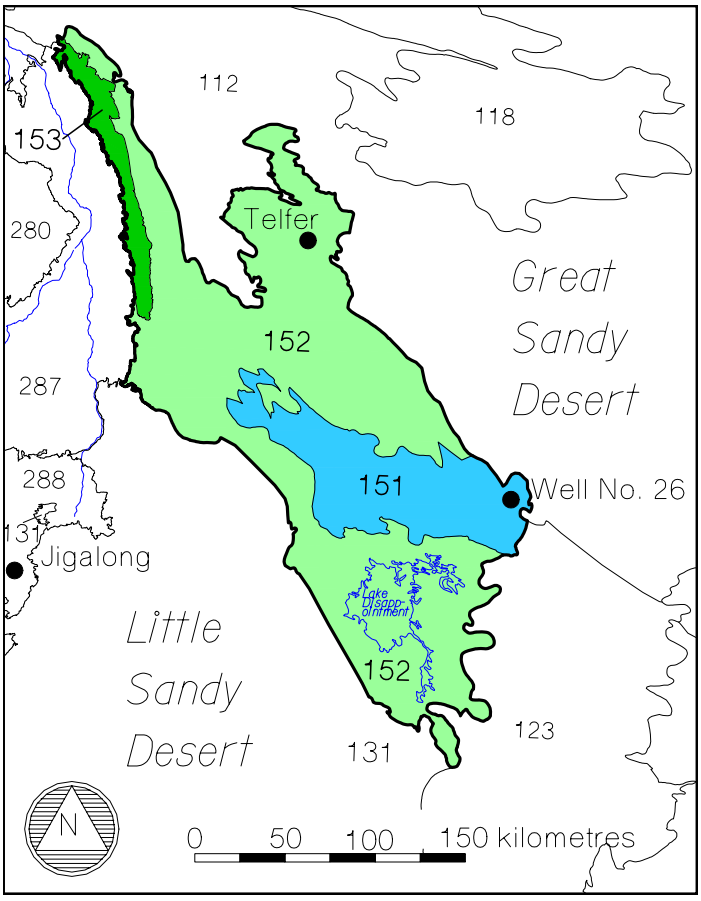

Figure 4.4d: Soil-landscape zones of the Paterson-Yeneena Province

2 Western Region

Undulating plateaux (with plains, hills and ranges and coastal plains) on the rocks of the Yilgarn and Pilbara Cratons, Capricorn and Albany-Fraser Orogens and Carnarvon and Perth Basins. Deep sands (mostly red), Loamy earths (mostly red), Shallow loams (mostly red), Sandy duplexes, Stony soils and Sandy earths (mostly red). Mulga shrublands, spinifex grasslands and eucalypt woodlands/forests with acacia shrublands (and some mallee scrub, heaths and halophytic shrublands). Located in the west of Western Australia between Port Hedland, Israelite Bay, Cape Leeuwin and Exmouth.

Location and boundaries: This occupies the west of the State, covering just under half of the total area (47.6% or1,201,400 km^2). It is west of the Sandy Desert and Central Southern Regions.

The region contains most of the population, including the cities of Perth, Bunbury, Albany and Geraldton as well as the towns of Esperance, Merredin, Northam, Kalgoorlie, Carnarvon, Karratha, Port Hedland and Newman. Along with a significant proportion of the State's Rangelands, the Western Region contains the entire Agricultural Area (22.2% of this region).

It is based on the Western Region described by Bettenay (1983) and includes the Western Coastlands, Yilgarn Plateau and Pilbara Provinces of Jennings and Mabbutt (1977)[38].

The boundary corresponds to those of several tectonic units of Tyler and Hocking (2001). It follows the northern and eastern boundary of the Pilbara Craton and the eastern boundaries of the Capricorn Orogen, Yilgarn Craton, and Albany-Fraser Orogen.

The boundary extends south-east from the mouth of the De Grey River (to the east of Port Hedland) to Shay Gap. It then follows the Vermin Proof Fence south to Jigalong before swinging south-west until it almost reaches Kumarina on the Great Northern Highway. From here it heads south-east to Lake Carnegie, then turns southwards. On its way south it passes Lake Minigwal, Zanthus (on the Trans-Australian Railway) and Balladonia before reaching the Southern Ocean near Israelite Bay. It then follows the coast westwards (past Esperance and Albany) to Cape Leeuwin, from where it heads north along the shores of the Indian Ocean (past Bunbury, Perth, Geraldton and Carnarvon) to North-west Cape near Exmouth. From here it follows the coast in a general north-easterly direction, passing Karratha and Port Hedland on its way back to the mouth of the De Grey River.

Geology: The geology is varied and complex. The region is dominated by a stable Precambrian craton. Most of the southern portion overlies the Archaean granite, gneiss and migmatite of the Yilgarn Craton. Within this craton there is a series of greenstone belts containing highly metamorphosed volcanic and sedimentary rocks.

In the north are the Archaean and Palaeoproterozoic granitic, volcanic and sedimentary rocks of the Pilbara Craton and Hamersley Basin. In between the Yilgarn and Pilbara Cratons sit the Proterozoic sedimentary rocks of the Ashburton, Collier, Edmund, Earaheedy and Yerrida Basins, and the Proterozoic granite and gneiss of the Gascoyne Complex. Some of these have been affected by the later Capricorn Orogen.

To the south and south-east of the Yilgarn Craton are the Proterozoic rocks of the Albany-Fraser Orogen. These are mostly granite and gneiss, but also include the shale, sandstone, phyllite, schist and quartzite of the Mount Barren Group and Stirling Range Formation.

Lying to the west of the Yilgarn Craton are the Cretaceous, Jurassic, Triassic, Permian, Carboniferous and Silurian sedimentary rocks of the Perth Basin. To the north of the Perth Basin, and west of the Capricorn Orogen, are the similar aged sedimentary rocks of the Southern Carnarvon Basin. The Northern Carnarvon Basin (again with similar sediments) lies to the west of the Pilbara Craton. Associated with the Perth Basin are the Proterozoic

[38] In future it may be worthwhile splitting the Western Region into three separate regions along these lines.

gneiss and granite of the Pinjarra Orogen, most notably the Northampton Complex (near Geraldton) and the Leeuwin Complex (around Margaret River).

Landforms: Over the last 100 million years the Yilgarn Craton has been subjected to subsurface weathering. This has worn most of it down, largely reducing it to a low plateau of little relief where there has been extensive development of ironstone duricrust associated with deep weathering (Bettenay 1983).

The upland areas on the central Yilgarn Craton are dominated by lateritic plateaux and sandplains. Gentle slopes have developed on stripped weathered mantle while the valley floors tend to be broad and sluggish, often containing chains of salt lakes. To the south-west the plateau becomes more dissected. Fresh rock is exposed on the slopes of major valleys but extensive areas of lateritic duricrust remain between the valleys (e.g Darling Range). A similar pattern of dissection is found on the western Albany-Fraser Orogen, while in the east lateritic sandplains have developed on Eocene sediments overlying granitic rocks of the Orogen.

In the south-east of the Yilgarn Craton (southern Goldfields) plains with many playa lakes have formed on calcareous aeolian dust (known as parna). Very gently inclined alluvial surfaces, in which a continuous cemented layer of red-brown hardpan has formed, are common to the north (and particularly north-west) of the Craton (Murchison). These surfaces carry sheet flows and are known as hardpan wash plains.

North of the Yilgarn Craton, hardpan wash plains are found in association with low hills. To the north of the Gascoyne Valley, the landscape tends to be dominated by rugged hills, ranges and plateaux formed on the rocks of various sedimentary basins and Pilbara Craton.

In the west, coastal plains have developed on the Perth and Carnarvon Basins. Here there are a mixture of alluvial plains, sandplains and dunefields. There are also areas of low hills and gently undulating lateritic uplands that have developed on uplifted sedimentary rocks.

Soils: Due to the wide range of parent materials and climatic conditions, soils are very varied. Red soils dominate the Rangelands. Red deep sands cover most of the sandplains formed over the Carnarvon Basin in the Gascoyne. They are also common on the sandplains of the northern Yilgarn Craton (Murchison), in association with Red sandy earths. Red deep sands and Red sandy earths are also found in the Pilbara sandplains.

Red loamy earths and Red-brown hardpan shallow loams are found on the plains and wash plains of the northern Yilgarn Craton and Capricorn Orogen (northern Murchison and eastern Gascoyne). Stony soils, Red shallow loams and Red shallow sands are common on hills and ranges throughout the Pilbara, Gascoyne, Murchison and Goldfields. Red deep sandy duplexes are found the alluvial plains of the Pilbara and Gascoyne. Red/brown non-cracking clays, Red shallow sandy duplexes and Red shallow loamy duplexes are also present on plains, alluvial plains, stony plains and low hills across the north.

Calcareous loamy earths are mostly found on the south-eastern Yilgarn Craton (in the Goldfields and eastern Wheatbelt). Salt lake soils are also common here as well as in the Murchison.

Yellow deeps sands dominate the sandplains of the Perth Basin in the Mid-west. The sandplains of the southern Yilgarn Craton (Wheatbelt) have Yellow deep sands and Yellow sandy earths. Pale deep sands are most common on sandplains of the South Coast, where they occur in association with Grey Deep sandy duplexes. They are also prominent on the Swan Coastal Plain. Grey deep sandy duplexes and Alkaline grey shallow sandy duplexes are common on the slopes over stripped mantle of the south-western Yilgarn Craton (Wheatbelt). Duplex sandy gravels, Loamy gravels and Shallow Gravels are associated with the lateritic uplands of the south-west.

Climate: The bioclimate is described by Beard (1990) as ranging from Sub-Eremaean (tropical semi-desert with 9-11 dry months) in the Pilbara to Eremaean (desert with 12 dry months) in central east and Thermoxeric (moderate Mediterranean with 3-4 dry months) in the south-west. Mean annual rainfall is winter-dominant in the south and summer-dominant in the north. It ranges from over 1400 mm in the south (Northcliffe) to below 200 mm in the deserts to the north and east of Laverton then up to 400 mm on the ranges of the Pilbara.

Vegetation: Like the soils, the natural vegetation is highly variable. It ranges from tall karri (*Eucalyptus diversicolor*) forests in the high rainfall south-west, to spinifex grasslands in the tropical north and proteaceous scrub-heaths along the west coast.

Spinifex (*Triodia wiseana*, *T. lanigera* and *T. pungens*) grasslands with scattered eucalypts and acacias (*E. leucophloia* , *Corymbia hamersleyana* and *Acacia inaequilatera*) are found in the hills, ranges and sandplains of the Pilbara. There are some tussock grasslands (with *Eragrostis xerophila*, *Chrysopogon fallax* and *Astrebla elymoides*) on the clays of the Pilbara's coastal plain.

Woodlands and shrublands of mulga (*A. aneura*), bowgada (*A. ramulosa*) and other acacias start to replace the spinifex grasslands in the Gascoyne. Halophytic shrublands (*Maireana* and *Atriplex* spp.) are also present on some stony plains and alluvial flats. In the Murchison, mulga woodlands and shrublands dominate the hardpan wash plains and hills, though other acacias are common. Spinifex (*T. basedowii*) grasslands with mallees (*Eucalyptus* spp.) and marble gum (*E. gongylocarpa*) grow on the Murchison sandplains while there are some halophytic shrublands on valley floors.

Sparse mulga shrubland on a hardpan wash plain (PJ Waddell)

In the Goldfields eucalypt woodlands become dominant, with species such as redwood (*E. transcontinentalis*), salmon gum (*E. salmonophloia*) and red mallee (*E. oleosa*) being common. These woodlands sometimes have an understorey of halophytic shrubs (*Maireana* and *Atriplex* spp.) or *Eremophila* spp. In the south-east these woodlands are replaced by mallee scrub (*E. eremophila*, *E. redunca* and *E. oleosa*) which in turn gives way to proteaceous mallee-heath and scrub-heath on the sandplains of the south coast.

Eucalypt woodlands were also common in the Wheatbelt before clearing. The main species were salmon gum, wandoo (*E. wandoo*), York gum (*E. loxophleba*), gimlet (*E. salubris*) and morrel (*E. longicornis*). Proteaceous scrub-heath and acacia-casuarina-melaleuca thickets occur on the sandplains. Scrub-heath with *Banksia* spp. and bowgada thickets are found on the sandplains of the Mid-west. In the south-west there are forests and woodlands of jarrah (*E. marginata*), marri (*Corymbia calophylla*) and wandoo on the lateritic gravels.

Component provinces: The Western Region has been divided into 10 soil-landscape provinces, nine of which extend beyond the Agricultural Area into the Rangelands (Figure 4.5):

- Exmouth Province (20) is based on the Northern Carnarvon Basin tectonic unit of Tyler and Hocking (2001) as well as the Carnarvon 1 IBRA sub-region of Environment Australia (2000) and the northern portion of the Carnarvon Province of Bettenay (1983);
- Greenough Province (22[39]) is based on the Greenough Province of Bettenay (1983);
- Carnarvon Province (23) is based on the Southern Carnarvon Basin tectonic unit of Tyler and Hocking (2001) and the southern portion of the Carnarvon Province of Bettenay (1983);
- Stirling Province (24) is based on the Stirling Province of Bettenay (1983);
- Avon Province (25)is based on the Avon Province of Bettenay (1983) and south-western portions of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001);
- Kalgoorlie Province (26) is based on a combination of the Kalgoorlie Province of Bettenay (1983), the Coolgardie botanical district of Beard (1990) and south-eastern portions of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001);
- Murchison Province (27) is based on a combination of the Murchison Province of Bettenay (1983), the Austin botanical district of Beard (1990) and the northern portion of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001);
- Fortescue Province (28) is based on a combination of the Pilbara Craton and Hamersley Basin tectonic units of Tyler and Hocking (2001) as well as the Fortescue botanical district of Beard (1990); and
- Ashburton Province (29) is based on the Capricorn Orogen tectonic unit of Tyler and Hocking (2001) as well as the Ashburton botanical district of Beard (1990).

[39] The code 21 has been assigned to the Swan Province that is situated entirely within the Agricultural Area and is therefore not described in this report.

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20 Exmouth Province

Alluvial plains and sandplains with coastal flats and dunes (and some ranges and stony plains) on sedimentary rocks of the Carnarvon Basin. Red deep sands with Red/brown non-cracking clays and Red deep sandy duplexes (and some Red loamy earths, Tidal soils and Hard cracking clays). Spinifex grasslands with acacia shrublands and tussock grasslands (and some halophytic shrublands and bare mudflats). Located on the north-west coast between Cape Preston, Nanutarra and Coral Bay.

Location and boundaries: Exmouth Province occupies about 25,100 km^2 (1.0% of WA). It is in the far western Pilbara, west of the Fortescue Province and north of the Carnarvon and Ashburton Provinces. Included are the towns of Exmouth, Coral Bay and Onslow.

It correlates with the northern portion of the Carnarvon botanical district of Beard (1990), the northern portion of the Carnarvon Province of Bettenay (1983), the northern tip of the Western Coastlands Province of Jennings and Mabbutt (1977), and a combination of the Carnarvon 1 IBRA sub-region and the southern part of the Pilbara 1 IBRA sub-region (Environment Australia 2000).

The northern boundaries are based on the Northern Carnarvon Basin tectonic unit of Tyler and Hocking (2001). In the south, this province extends some distance onto the Southern Carnarvon Basin tectonic unit, and its southern boundary with the Carnarvon Province approximates the southern boundaries of the Cape Yannare Coastal Plain, Giralia Anticline and Coastal Dunes vegetation systems of Beard (1975b).

The boundary extends south-west from Cape Preston, approximately following the route of the North West Coastal Highway to Winning Station. From here it heads across to the coast at Warroora Station (just north of Lake MacLeod) and then north along the coastline to North West Cape. It continues along the coast around Exmouth Gulf and then north-west past Onslow back to Cape Preston.

Geology: Exmouth Province mostly sits over the sedimentary rocks of the Northern Carnarvon Basin. To the east of the Exmouth Gulf are the Cretaceous Windalia Radiolarite and Birdrong Sandstone of the Peedamullah Shelf. These are overlain by Quaternary alluvium, colluvium and aeolian sand. Along the eastern margin of the province are scattered outliers of the Gascoyne Complex comprising Palaeoproterozoic granitoid rocks, paragneiss and metasedimentary schist. Also present are some Palaeoproterozoic conglomerates, sandstones, siltstones and mudstones of the Mount Minnie Group.

To the west of Exmouth Gulf, the Tertiary limestone of the Cape Range Group is found on top of the Triassic-Jurassic sediments of the Exmouth Sub-basin.

South of Exmouth Gulf, this province extends onto the northern end of the Southern Carnarvon Basin. This is dominated by Merlingleigh Sub-basin which has Windalia Radiolarite and Birdrong Sandstone like the Peedamullah Basin. To the east, these are mostly overlain by Quaternary deposits. Closer to the coast Tertiary deposits and the Cretaceous chalky deposits, clayey siltstone and greensand of the Toolonga Calcilutite/Alinga Formation are found. The Gascoyne Platform, mostly overlain by these calcareous marine deposits, is found in the south-west corner of this province.

Landforms: Most of the province consists of sandplains or alluvial plains. Broad sandplains (with large linear dunes) and broad sandy-surfaced plains are dominant in the south-east. Mixed in with these are some active floodplains and alluvial plains covered with sand in parts. In the north there is a complex of sandy-surfaced plains, alluvial plains, gilgaied clay plains and flood plains (with some gravelly plains and deltaic deposits).

Along the coast from Exmouth Gulf northwards tidal mudflats are backed by undulating sandplains and dunefields between clay plains. South of North West Cape, the deeply dissected limestone plateau of the Cape Range dominates the coastline. This contains hills and ridges with gorges and steep stony footslopes. From Ningaloo southwards, the range

gives way to undulating sandy plains with linear dunes, minor limestone ridges and outcrop plains. Inland from these there are limestone hills, gently sloping outwash plains and undulating stony plains.

Soils: The sandplains and dunes are dominated by Red deep sands. On the broad, sandy-surfaced plains are Red deep sandy duplexes with some Red sandy earths. Red/brown non-cracking clays, Hard cracking clays and Red deep sandy duplexes are found on the alluvial plains and floodplains, along with some Red loamy earths.

Tidal soils are found on the coastal flats while the coastal dunes have Calcareous deep sands and Red deep sands. Calcareous shallow loams, Red loamy earths and Stony soils are found on the Cape Range and other limestone hills with Red deep sands on the undulating sandy plains to the south.

Climate: The bioclimate along the coast is described by Beard (1990) as Sub-Eremaean (a bixeric Mediterranean climate with 9-11 dry months per year). Inland it becomes an Eremaean bioclimate (a desert climate, commonly with 12 dry months). Mean annual rainfall is mostly in the 250-300 mm range, with a tendency towards summer falls in the north and a mix of summer and winter falls in the south (where the rainfall drops to 200 mm).

Vegetation: The sandplains have grasslands of hard spinifex (*Triodia lanigera* and *T. basedowii*) and some soft spinifex (*T. pungens*). These grasslands have scattered emergent kanji (*Acacia inaequilatera*), prickly wattle (*A. victoriae*), *A. stellaticeps* and corkwood (*Hakea lorea* subsp. *suberea*). Feathertop spinifex (*Plechtrachne schinzii*) is found on the dunes. Hard and soft spinifex grasslands with scattered kanji, *A. ancistrocarpa*, bloodwoods (*Corymbia* spp.) and *E. aspera* are found on the sandy-surfaced plains.

The alluvial plains and floodplains have soft spinifex grasslands on the loamy soils and tussock grasslands of Roebourne Plains grass (*Eragrostis xerophila*), weeping grass (*Chrysopogon fallax*), weeping Mitchell grass (*Astrebla elymoides*), buffel grass (*Cenchrus ciliaris*) and *Eriachne* spp. Snakewood (*Acacia xiphophylla*), prickly wattle and saltbush (*Atriplex* spp.) shrublands are also present along with scattered coolabah (*Eucalyptus victrix*). The mudflats are mostly bare, but have fringing mangrove thickets and samphire (*Halosarcia* spp.) shrublands, while the dunes support soft spinifex and buffel grass.

The Cape Range has hard and soft spinifex grasslands with sparse shrubs and trees (including acacias, sennas, grevilleas and eucalypts). The surrounding sandy plains also support hard and soft spinifex grasslands with curara (*Acacia tetragonophylla*) and *A. sclerosperma*. Shrublands of Gascoyne bluebush (*Maireana polypterygia*) with snakewood and prickly wattle are found on the limestone hills and outwash plains.

Component zones: Exmouth Province has been divided into four soil-landscape zones (Figure 4.5a):

- Onslow Plain Zone is based on the Onslow Plains Section of Jennings and Mabbutt (1977) and correlates with the coastal strip of the Coastal Plains geomorphic province of Payne *et al.* (1988);
- Cane River Zone is based on the Onslow Coastal Plain vegetation system of Beard (1975b) and correlates with the northern tip of the Carnarvon Dunefields Section of Jennings and Mabbutt (1977);
- Yanrey Plains Zone is based the Coastal Plains geomorphic province of Payne *et al.* (1988) and the eastern portion of the Winning Plains geomorphic district of Payne *et al.* (1987). It correlates with the Cape Yannare Coastal Plain vegetation system of Beard (1975b) and the remainder of the northern portion of the Carnarvon Dunefields Section of Jennings and Mabbutt (1977); and
- Cape Giralia Coastal Zone is based on the Giralia Anticline geomorphic province of Payne *et al.* (1988) and a combination of the Cape Range, Coastal Dunes, Giralia

Range and (western) Winning Plains geomorphic districts of Payne *et al.* (1987). It correlates with the north of the North West Cape Ridges Section of Jennings and Mabbutt (1977).

201 – Onslow Plain Zone (3,250 km^2)	Coastal mudflats (with some sandplains and coastal dunes) on coastal deposits over Cretaceous sedimentary rocks of the Carnarvon Basin. Tidal soils with Calcareous deeps sands and some Red deeps sands, Red/brown non-cracking clays and Salt lake soils. Bare mudflats with samphire and spinifex/tussock grasslands (and some mangroves). Located in the north-west coast between Cape Preston and the Exmouth Gulf.
202 - Cane River Zone (4,325 km^2)	Alluvial plains and sandplains (with some flood plains and gravelly plains) on Cainozoic deposits over Cretaceous sedimentary rocks of the Carnarvon Basin. Red deep sandy duplexes with Red/brown non-cracking clays and Red loamy earths and some Red deep loamy duplexes, Red sandy earths and Self-mulching cracking clays. Spinifex grasslands with acacia shrublands and tussock grasslands. Located in the north-west coast between Mardie Station and the Ashburton River.
203 - Yanrey Plains Zone (9,750 km^2)	Sandplains and alluvial plains (with some floodplains) on Quaternary deposits over Cretaceous sedimentary rocks of the Carnarvon Basin. Red deep sands with Red/brown non-cracking clays and Red deep sandy duplexes and some Hard cracking clays. Spinifex grasslands with acacia shrublands and some tussock grasslands. Located in the north-west coast between the Ashburton and Lyndon Rivers.
204 - Cape Giralia Coastal Zone (7,800 km^2)	Sandy plains, alluvial plains and hills and ranges (with some stony plains) on Cainozoic deposits and marine limestone over sedimentary rocks of the Carnarvon Basin. Red deep sands and Red loamy earths with some Shallow calcareous loams, Red/brown non-cracking clays and Stony soils. Spinifex grasslands with acacia and halophytic shrublands. Located in the north-west coast between Exmouth and Warroora Station (to the north of Lake MacLeod).

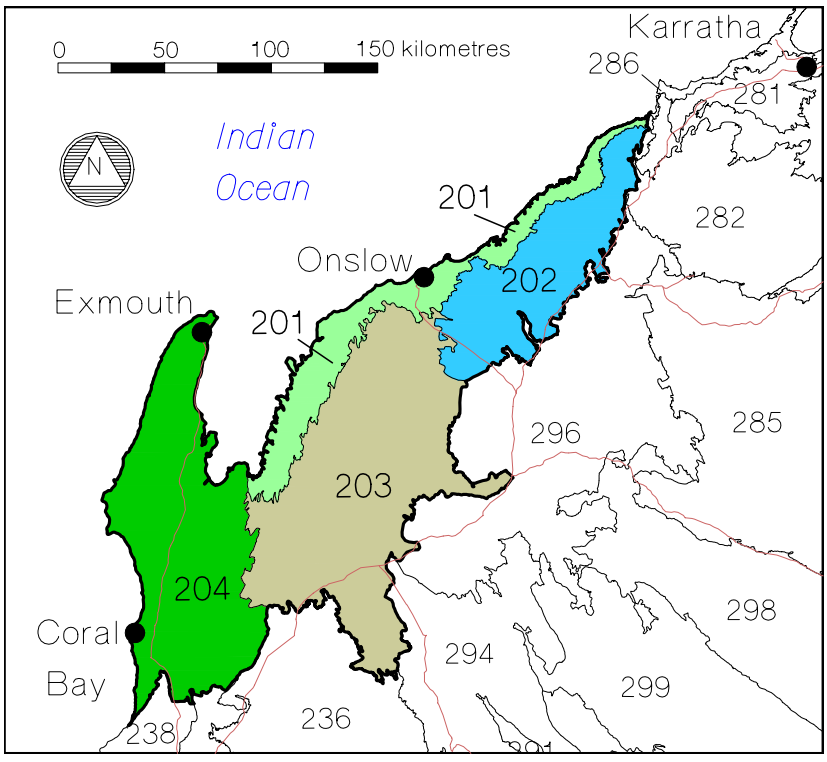

Figure 4.5a: Soil-landscape zones of the Exmouth Province

22 Greenough Province

Laterised plateau (dissected at the fringes) on the sedimentary rocks of the Perth Basin and gneiss of the Northampton Complex. Yellow deep sands with Pale deep sands and some Gravelly pale deep sands and Red-brown hardpan shallow loams. Scrub-heath with jam-York gum shrublands (and some acacia-casuarina thickets and banksia-marri-jarrah woodlands). Located in the Mid-west coast and hinterland between Gingin, Eneabba, Mullewa, Geraldton and the Murchison River.

Location and boundaries: Greenough Province occupies about 30,150 km^2 (1.2% of WA), of which the vast bulk (92.5%) is within the Agricultural Area. This province is south of the Carnarvon Province, north-east of the Swan Province, and west of the Murchison and Avon Provinces. Towns include Geraldton, Northampton, Dandaragan, Gingin, Arrino, Badgingarra, Binnu, Dongara, Eneabba, Eradu, Galena, Mingenew and Yandanooka.

It is based on the Greenough Province of Bettenay (1983). It correlates with central portion of the Western Coastlands Province of Jennings and Mabbutt (1977) and most of the Irwin botanical district of Beard (1990).

The boundary is based on the northern half of the Perth Basin tectonic unit of Tyler and Hocking (2001). This includes most of the basin north of the Mandurah Terrace and the Vlaming Sub-basin. Included is all of the Northampton Complex of the Pinjarra Orogen. Excluded is the northern portion of the Coolcalalaya Sub-basin.

The southern boundary follows the Gingin Scarp, running across the northern edge of the Beermullah Trough and matching the north-western boundaries of the Bassendean and Pinjarra vegetation systems of Beard (1981). East of the Northampton Complex, the northern boundary approximates the northern boundary of Yuna vegetation system of Beard (1976), cutting across the Coolcalalaya Sub-basin.

The boundary extends north from Horrocks (on the coast north of Geraldton) to the Murchison River and onto Eurardy Station, before doubling back to the river and heading east to Lake Nerramyne. From here it heads south along the Darling Fault, passing through (or close to) Mullewa, Three Springs, Moora and Mogumber, till it reaches Bullsbrook East. It then heads north-west, along the Gingin Scarp (past Gingin and Cataby) to Mount Lesueur, before swinging south-west to meet the coast at Jurien Bay south of Green Head. It follows the coastline north (passing Leeman, Port Denison and Geraldton) eventually returning to Horrocks.

Geology: Greenough Province principally overlies Cretaceous, Jurassic, Triassic, Permian, Carboniferous and Silurian sedimentary rocks of the northern Perth Basin. These rocks include sandstone, siltstone, shale and claystone. There is also some limestone, coal measures and conglomerate. North-east of Geraldton are the Mesoproterozoic granulite and migmatite (with numerous dolerite dykes) of the Northampton Complex. To the west of Three Springs are the Proterozoic gneiss, granite and pegmatite of the Mullingarra Inlier as well as the Neoproterozoic siltstone (with common volcanic fragments), sandstone and conglomerate of the Yandanooka Group.

Extensive laterite formation commenced in the Tertiary. In the Quaternary, Tamala Limestone developed in aeolian coastal deposits.

Landforms: Most of the province consists of gently undulating plateau surfaces formed on laterite overlying Perth Basin sedimentary rocks. There has been extensive development of sandplains on these plateaux, especially in the north-east and south-east. The northern sandplain has low dunes and some relict drainage systems with long gentle slopes and alluvial surfaces.

The western edges of the plateaux are often dissected. The two most dramatic dissections are the hills and mesas of the Moresby Range and around Badgingarra. Hilly terrain is also found on Permian glacial tillite, shale, sandstone and conglomerate near Mingenew. Gently

undulating to rolling low hills, often capped by flat topped mesas, have formed on the Northampton Complex. Undulating to steep low hills and rocky ridges are found on the Mullingarra Inlier. Between Green Head and Horrocks there is a narrow strip with coastal dunes (formed over Tamala limestone) and alluvial flats.

Soils: Yellow deep sands are most common and dominate the sandplains. Pale deep sands and Gravelly pale deep sands are also present, with some Red deep sands and Yellow sandy earths. Deep sandy gravels, Duplex sandy gravels and Shallow gravels are found on broad crests in the southern sandplains. Red-brown hardpan shallow loams appear on the relict drainage systems in the northern sandplains.

In areas of dissected plateaux, Shallow gravels occur on the ridges. Pale deep sands, Yellow deep sands, Gravelly pale deep sands and Deep sandy gravels occur on the slopes along with some Duplex sandy gravels and Grey deep sandy duplexes.

On the granitic terrain of the Northampton Complex there are Red shallow loamy duplexes, Red shallow sandy duplexes, Red loamy earths and Yellow/brown shallow sandy duplexes. Hard cracking clays are associated with the glacial deposits to the north of Mingenew. On the coastal strip there are dunes of Calcareous deep sands, with Yellow deep sands overlying the Tamala Limestone.

The relatively small proportion lying within the Rangelands is dominated by the northern sandplains. The soils are mostly Yellow deep sands with Red deep sands and some Red-brown hardpan shallow loams.

Climate: The bioclimate is described by Beard (1990) as Thermoxeric. This is a mostly an extra dry Mediterranean climate with 7-8 dry months. Mean annual rainfall is mostly about 400-600 mm, predominantly falling in the winter. To the south, this province extends into a dry Mediterranean climate with 5-6 dry months and up to 800 mm of rainfall. To the north, where rainfall decreases to 250 mm, the bioclimate tends towards Sub-Eremaean. This is a semi-desert Mediterranean climate with 9-11 dry months.

Vegetation: Much of the province is covered by scrub-heath. *Banksia attenuata* and *B. menziesii* are often present on the northern sandplains. Also present in places is a bowgada (*Acacia ramulosa*) scrub and acacia-casuarina thickets. A scrub of *Acacia* spp. and sheoaks (*Casuarina obesa*) with *Eucalyptus obtusiflora* and *E. transcontinentalis* is found on the hardpan shallow loams. York gum (*E. loxophleba*) and jam (*Acacia acuminata*) may also be present.

Southern sandplains and areas of dissected plateaux have a proteaceous scrub-heath with *Acacia*, *Banksia, Allocasuarina*, *Grevillea*, *Dryandra*, *Melaleuca* and *Verticordia* spp. Woodlands of banksias (*Banksia grandis, B. prionotes, B. attenuata, B. menziesii and B. ilicifolia*) and sheoak (*Casuarina humilis*) are found in the south along with open forests of marri (*Corymbia calophylla*), jarrah (*Eucalyptus marginata*) and some (*E. todtiana*) in the far south. In the central portion there are some areas of wandoo (*E. wandoo*) woodland as well as scattered Christmas tree (*Nuytsia floribunda*) and river red gum (*E. camaldulensis*).

The red loams and duplexes of the Northampton Complex support a scrub of jam (*Acacia acuminata*) and *Hakea* spp. with scattered York gum (*Eucalyptus loxophleba*) and river red gum (*E. camaldulensis*). In the north *Acacia tetragonophylla* and *Casuarina huegeliana* become common.

The calcareous coastal dunes and Yellow deep sands over limestone have thickets and scrub of *Acacia rostellifera*, *Banksia* spp. and *Melaleuca* spp. *Eucalyptus erythrocorys* may also be present. On the alluvial flats, river red gum is often present. A low woodland of *E. todtiana* and *Banksia* spp. is found in the Eneabba district.

Component zones: Greenough Province has been divided into eight soil-landscape zones, three of which extend beyond the Agricultural Area into the Rangelands (Figure 4.5b):

- Northern Victoria Sandplain Zone is based on the intersection of the southern portion of the Coocalaya Sub-basin tectonic unit of Tyler and Hocking (2001) and the northern portion of the Yuna vegetation system of Beard (1976). It forms the north-western portion of the Victoria Plateau soil-landscape zone[40] described by Tille *et al.* (1998) and lies within the southern portion of the Yaringa Section of Jennings and Mabbutt (1977);
- Chapman Zone is based on the Northampton Complex tectonic unit of Tyler and Hocking (2001) and is an extension of the Chapman Zone described by Tille *et al.* (1998). It lies mostly within the Greenough Hills Section of Jennings and Mabbutt (1977); and
- Tenindewa Zone is based on the eastern and central portions of the Victoria Plateau soil-landscape zone described by Tille *et al.* (1998). It largely corresponds with the northern portion of the Irwin Terrace tectonic unit of Tyler and Hocking (2001) and the southern portion of the Yuna vegetation system of Beard (1976). It also lies within the southern portion of the Yaringa Section of Jennings and Mabbutt (1977).

Wheat crop on Yellow deep sand that once supported scrub-heath in Greenough Province (A Stuart-Street)

[40] The Victoria Plateau Zone described by Tille *et al.* (1998) has recently been subdivided into three separate zones reflecting differences in the geology of the underlying sedimentary rocks. The Northern Victoria Sandplain overlies Silurian Tumblagooda sandstone, the Southern Victoria plateau overlies Yarragadee sandstone, while the Tenindewa Zone overlies Permian sediments. These geological differences are reflected in the hydrological characteristics as well as the nature of the soils.

223 - Northern Victoria Sandplain Zone (3,250 km^2) **(1,825 km^2 covered by existing mapping)**	Weakly dissected sandplain (with dune ridges) on deeply weathered mantle over Carboniferous, Permian and Silurian sedimentary rocks of the Perth Basin. Yellow deep sands with some Red deep sands and Red-brown hardpan shallow loams. Scrub-heath with acacia-casuarina thickets and some bowgada and mallee-jam-York gum shrublands. Located in the northern Mid-west between Yuna, Ajana, the Murchison River and Lake Nerramyne.
225 - Chapman Zone (4,175 km^2) **(3,675 km^2 covered by existing mapping)**	Dissected lateritic terrain (with hills, sandplains, breakaways and plateaux) on colluvium and deeply weathered mantle over gneiss of the Northampton Complex. Yellow deep sands with Red shallow loamy duplexes and some Red shallow sandy duplexes, Red loamy earths and Shallow gravels. York gum-jam shrublands and scrub-heath with some acacia-melaleuca-hakea thickets. Located in the Mid-West between Walkaway, Horrocks, Yuna and Eurardy Station.
227 – Tenindewa Zone (3,350 km^2) **(3,025 km^2 covered by existing mapping)**	Sandplains and relict hardpan wash plains on Permian and Carboniferous sedimentary rocks of the Perth Basin. Yellow deep sands and Red-brown hardpan shallow loams with some Yellow sandy earths and Red sandy earths. Scrub-heath with acacia-casuarina thickets and mallee-jam-York gum shrublands. Located in the northern Mid-west between Lake Nerramyne, Yuna, Mullewa and Mingenew.

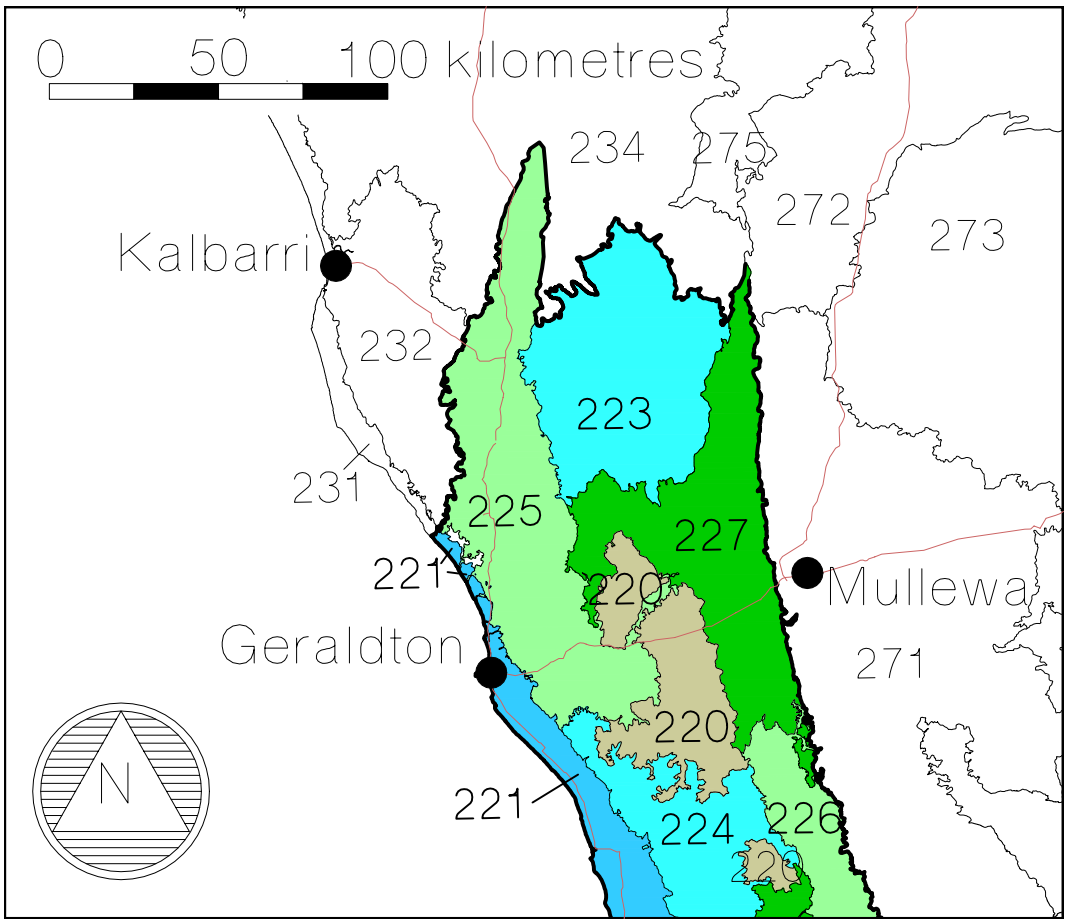

Figure 4.5b: Soil-landscape zones of the northern portion of the Greenough Province

23 Carnarvon Province

Sandplains (with alluvial plains and some stony plains, hills and mesas) on Cainozoic deposits over sedimentary rocks of the southern Carnarvon Basin. Red deep sands with Red deep sandy duplexes and some Red sandy and loamy earths. Acacia shrublands with some halophytic and currant bush shrublands, spinifex grasslands and tree-heaths. Located in the southern Gascoyne between Kalbarri, Lake MacLeod and Gascoyne Junction.

Location and boundaries: Carnarvon Province occupies about 92,475 km^2 (3.7% of WA). It covers the coastal portion of the Gascoyne district, north of the Greenough Province, west of the Murchison and Ashburton Provinces, and south of Exmouth Province. The towns of Carnarvon, Denham, Kalbarri, Useless Loop, Horrocks, Port Gregory and Gascoyne Junction are included.

It correlates with the south of the Carnarvon Province of Bettenay (1983), the bulk of the northern portion of the Western Coastlands Province of Jennings and Mabbutt (1977), and a combination of the southern portion of the Carnarvon botanical district with the northern portion of the Irwin botanical district of Beard (1990).

The boundary is based on the Southern Carnarvon Basin tectonic unit of Tyler and Hocking (2001). Excluded are the northern tip of the Merlinleigh Sub-basin and a small corner of the Gascoyne Platform. Included is the northern portion of the Coolcalalaya Sub-basin of the Perth Basin.

The boundary between this and the Exmouth Province approximates the northern boundary of both the North and South Lower Riverine Plains vegetation systems of Beard (1975b). The southern boundary follows the southern boundary of the Carnarvon Basin from the coast to the Murchison River, from where it approximates the northern boundary of the Yuna vegetation system of Beard (1976) eastwards to the edge of the Yilgarn Craton.

The boundary extends west from Warroora Station (just north of Lake MacLeod) to Lyndon Station, and then swings south-east to Glenburgh Station (to the south of the Gascoyne River). From here it heads south to Mount Narryer, and west briefly to Muggon Station before continuing south to Lake Nerramyne. It then turns west to Ajana before swinging south to the coast at Horrocks. From here it follows the coastline north to Kalbarri, then along the Zuytdorp Cliffs, around Shark Bay and past Carnarvon back to Warroora Station.

Geology: The province overlies the sedimentary rocks of the Southern Carnarvon Basin. In the west, the Cretaceous chalky deposits, clayey siltstone and greensand of the Toolonga Calcilutite-Alinga Formation are found on the Gascoyne Platform. South of the Murchison River, the Ordovician Tumblagooda Sandstone outcrops on the Gascoyne Platform along with some Jurassic sandstone and conglomerate, and Triassic shale and siltstone. In the north-east are the Permian and Carboniferous sandstone, siltstone, shale and radiolarite of the Merlinleigh Sub-basin. Devonian rocks outcrop along the eastern margin of this sub-basin and there are also some outlying granitic rocks of the Gascoyne Complex.

The Byro Sub-basin in the central east also has Permian and Carboniferous sandstone, tillite, siltstone and shale (and contains numerous glacial erratics). In the south-east, the Carnarvon Province overlies the northern extension of the Coolcalalaya Sub-basin of the Perth Basin. This has similar Permian and Carboniferous sediments to the Carnarvon Basin, with some Tumblagooda sandstone on its western margin.

Quaternary alluvium and aeolian sand are found over much of the surface. Extensive alluvial deposits are found on ancient deltas of the Lyndon, Minilya, Gascoyne and Wooramel Rivers. The aeolian deposits are largely derived from Tertiary laterite formed over the sedimentary rocks. Quaternary Tamala Limestone is found along the coast from Shark Bay southwards. Elsewhere coastal dunes overlie calcrete.

Landforms: Sandplains make up approximately half of the Carnarvon Province, covering most of the south and much of the east. These are predominantly flat to gently undulating, though sandplains with linear (and occasionally reticulate) dunes and broad depressions also occur. The floors of these depressions may be broad sandy swales, clayey interdunal plains (with discrete drainage foci), saline flats, or limestone plains.

Alluvial plains are found on the old river deltas in the west. These range from nearly flat, saline plains (with sluggish drainage tracts and prominent drainage foci) to plains with numerous low sandy banks and rises. There are also some sandy alluvial plains, stony alluvial plains and narrow, active flood plains.

Gently undulating stony plains (with sluggish drainage, stony rises, sandy banks and low summits) are found on the Permian sediments in the east. Low hills, mesas, breakaways and ridges of sandstone and siltstone are also found on the Permian sediments. These typically have extensive stony slopes. Almost flat, sandy-surfaced hardpan plains with sandy banks and sand sheets are another feature.

There are some intensely dissected plateaux, mesas and hills formed on the Permian sedimentary rocks. These typically have steep footslopes and narrow valleys. The most notable example is the Kennedy Range which has elevated sandy plains with large linear and reticulate dunes on the plateaux surface. Hills are also found on Devonian sediments in the north-west.

Gently undulating calcrete outcrop plains are most common in the Shark Bay district as well as around the saline floor of Lake MacLeod. Undulating sandy plains (with minor low dunes, limestone rises and saline flats) are also found around Shark Bay. Along the coast there are large, long walled parabolic coastal dunes and narrow swales; unstable blow-out areas; minor limestone plains; and rocky wave cut platforms. The Zuytdorp coast has undulating limestone plains with thin sand cover, sandy coastal slopes and sea cliffs.

Soils: Red deep sands dominate the sandplains, with only minor occurrences of other types. There are some Yellow deep sands in the south, while Red loamy earths, Red deep sandy duplexes, Red sandy earths, Red shallow sands and Red/brown non-cracking clays occur on the interdune flats.

On the alluvial plains there are Red deep sandy duplexes, with some Red/brown non-cracking clays, Red shallow sandy duplexes, Red loamy earths and Red sandy earths. Red deep sands are common on the alluvial plains, especially on the sandy banks and rises.

The stony plains have Red deep sandy duplexes, Red sandy earths and Red shallow loams, with some Red shallow sandy duplexes and Red/brown non-cracking clays. Red sandy earths, Red loamy earths and Red shallow loams are found on the wash plains. On hilly terrain there are Stony soils with Red shallow sandy duplexes, Red loamy earths and Red shallow sands. Calcareous shallow loams and Calcareous loamy earths are found on the calcrete plains while Calcareous Deep sands and Red deep sands are found on the coastal dunes. Salt lake soils cover the bed of Lake MacLeod.

Climate: The bioclimate is described by Beard (1990) as mainly Sub-Eremaean. This is a mostly semi-desert Mediterranean climate with 9-11 dry months and average annual rainfall of 200-250 mm. This rain is mostly concentrated in \ winter, but there is a mix of summer and winter rain along the coastal strip north of Carnarvon. In the south-west (between Shark Bay and Kalbarri) rainfall increases to 400 mm and bioclimate becomes Thermoxeric (extra dry Mediterranean climate with 7-8 dry months). In the north-east rainfall drops below 200 mm and the bioclimate becomes Eremaean (desert with 12 dry months).

Vegetation: On the north-western sandplains there are grasslands of hard spinifex (*Triodia lanigera* and *T. basedowii*) with some soft spinifex (*T. pungens*). These grasslands support scattered emergent *Acacia sclerosperma*, kanji (*A. inaequilatera*), prickly wattle (*A. victoriae*) and *Grevillea* spp. Central sandplains have tall shrublands of bowgada (*A. ramulosa*),

sandplain gidgee (*A. anastema*), *A. sclerosperma* and *A. subtessarogona*, sometimes with a hard spinifex understorey. Gidgee (*A. pruinocarpa*) and mulga (*A. aneura*) are present on loamy interdune plains. To the south, scattered eucalypts (*Eucalyptus eudesmioides* and *E. obtusiflora*) and cypress pine (*Callitris columellaris*) start appearing in the bowgada shrublands on the sandplains. Further south is scrub-heath and tree-heath with *Banksia ashbyi*, *Grevillea gordoniana*, *Melaleuca* spp. and mallee eucalypts.

On the alluvial plains are acacia shrublands with currant bush (*Scaevola spinescens*), curara (*A. tetragonophylla*), snakewood (*A. xiphophylla*), *A. sclerosperma*, prickly wattle, *Hakea preissii* and *Eremophila* spp. Also presents are shrublands of Gascoyne bluebush (*Maireana polypterygia*), *M. platycarpa*, bladder saltbush (*Atriplex vesicaria*) and Gascoyne mulla mulla (*Ptilotus polakii*). Bowgada and sandplain gidgee are found on the sandy banks and rises.

The stony plains support shrublands of snakewood and prickly wattle with bluebush (*Maireana* spp.), saltbush (*Atriplex bunburyana*) and currant bush. The wash plains have acacia shrublands with bowgada and mulga. The hilly terrain also has acacia shrublands with mulga, gidgee, curara, *A. cuspidifolia*, snakewood and *A. subtessarogona*. The calcrete plains of Shark Bay have shrublands of minniritchie (*A. grasbyi*) and *A. drepanophylla*.

Component zones: Carnarvon Province has been divided into 10 soil-landscape zones (Figure 4.5c):

- Muggon Zone is based on the Byro Sub-basin tectonic unit of Tyler and Hocking (2001). It lies on the north-west edge of the Murchison Plateau of Jennings and Mabbutt (1977);
- Port Gregory Zone is based on the Port Gregory Zone of Schoknecht *et al.* (2004) and the southern occurrence of the Tamala Limestone Plains Section of Payne *et al.* (1987);
- Kalbarri Sandplain Zone is an extension of the Kalbarri Sandplain Zone of Schoknecht *et al.* (2004). It correlates with the northern portion of the Greenough Hills Section of Jennings and Mabbutt (1977) and the Hutt and (northern) Kalbarri vegetation systems of Beard (1976);
- Yalbalgo Sandplain Zone is based on the Ridge Dunes geomorphic district of Payne *et al.* (1987) on which grassy acacia shrublands are dominant. It roughly correlates with the Sand Dune geomorphic province of Wilcox and McKinnon (1972) and the south of the Carnarvon Dunefield Section of Jennings and Mabbutt (1977);
- Victoria Red Sandplain Zone is based on the Victoria Sandplain geomorphic district of Payne *et al.* (1987) and correlates with the northern portion of the Yaringa Sandplain Section of Jennings and Mabbutt (1977);
- Lower Gascoyne Alluvial Plains Zone is based on the Alluvial Plains geomorphic district of Payne *et al.* (1987) while it correlates with the southern portion of the Carnarvon Plain Section of Jennings and Mabbutt (1977);
- Wandagee-Byro Plains and Hills Zone is based on a combination of the Mardathuna Plains, Wandagee Permian Plains and the Ridge Dunes (those on which spinifex grassland are dominant) geomorphic districts of Payne *et al.* (1987) as well as the Permian Basin geomorphic province of Wilcox and McKinnon (1972). It roughly correlates with the northern portion of the Carnarvon Dunefield Section of Jennings and Mabbutt (1977);
- Shark Bay Zone is based on the Shark Bay Peninsula Section of Jennings and Mabbutt (1977). It contains a combination of the Carbla Plateau geomorphic district of Payne *et al.* (1987) with the portions of their Victoria Sandplain, Coastal Dunes and Tamala Limestone Plains districts that adjoin Shark Bay;

- Lake MacLeod Coastal Zone is based on the Lake MacLeod and Saline Plains geomorphic district (with addition of the adjoining occurrences of the Coastal Dunes and Giralia Range geomorphic districts) of Payne *et al.* (1987). It correlates with the southern portion of the North West Cape Ridges Section of Jennings and Mabbutt (1977); and
- Kennedy Range Zone is based on the Kennedy Range Section of Jennings and Mabbutt (1977) and a combination of the Permian Hills and Ridge Dunes geomorphic districts of Payne *et al.* (1987).

230 - Muggon Zone (4,250 km^2)	Sandplains (with stony plains and some saline depressions) on Permian and Carboniferous sedimentary rocks of the Carnarvon Basin (Byro Sub-basin). Red deep sands with some Red deep sandy duplexes, Red shallow sandy duplexes and Red shallow loams. Bowgada scrub and mulga shrublands with halophytic shrublands. Located in the western Murchison between Murchison Settlement and the Wooramel River.
231 - Port Gregory Zone (1,150 km^2) **(375 km^2 covered by existing mapping)**	Coastal plains (with coastal dunes and some sandplain, alluvial plains and sea cliffs) on limestone and sand over Cretaceous sedimentary rocks of the Carnarvon Basin. Red shallow sands with Deep sands, Stony soils and Calcareous deep sands and some Yellow deep sands and Yellow/brown shallow sands. Coastal acacia-banksia-hakea scrub-heath with some acacia thickets. Located in the northern Mid-West and south-west Gascoyne coast between Horrocks and the northern Zuytdorp Cliffs.
232 – Kalbarri Sandplain Zone (2,550 km^2) **(1,100 km^2 covered by existing mapping)**	Moderately dissected sandplain (with plateaux, valleys and gorges) on deeply weathered mantle and colluvium over Cretaceous (and some Silurian) sedimentary rocks of the Carnarvon Basin. Pale deep sands and Yellow deep sands with Red deep sands and some Pale shallow sands and Bare rock. Scrub-heath with some jam-sheoak woodlands. Located in the northern Mid-West from between Horrocks, Ajana and Kalbarri.
233 - Yalbalgo Sandplain Zone (9,275 km^2)	Sandplains (with some dunes and hardpan wash plains) on Quaternary deposits over Cretaceous and Permian sedimentary rocks of the Carnarvon Basin. Red deep sands with some Red loamy earths. Grassy bowgada shrublands and acacia scrub. Located in the western Gascoyne between the Wooramel River and Lake MacLeod.
234 - Victoria Red Sandplain Zone (22,950 km^2) **(50 km^2 covered by existing mapping)**	Sandplains (with occasional dunes) on Quaternary deposits over Permian, Carboniferous and Cretaceous sedimentary rocks of the Carnarvon Basin (and northern Perth Basin). Red deep sands. Bowgada scrub with some scrub-heath and banksia tree-heath. Located in the south-western Gascoyne between the Wooramel and Murchison Rivers.
235 - Lower Gascoyne Alluvial Plains Zone (13,975 km^2)	Alluvial plains (with saline plains and sandplains and some floodplains) on Quaternary alluvial and aeolian deposits over Cretaceous sedimentary rocks of the Carnarvon Basin. Red deep sandy duplexes and Red deep sands with some Red/brown non-cracking clays and Red sandy earths. Currant bush shrublands and acacia scrub with halophytic shrublands. Located in the western Gascoyne from Wooramel and Minilya Roadhouses to Mooka Station.
236 – Wandagee-Byro Plains and Hills Zone (21,350 km^2)	Stony plains, sandplains and alluvial plains (with some mesas, hills and hardpan wash plains) on Quaternary deposits over Permian and Carboniferous sedimentary rocks of the Carnarvon Basin. Red deep sandy duplexes and Red deep sands with Red sandy earths and some Red loamy earths, Stony soils and Red shallow sandy duplexes. Snakewood-prickly wattle-mulga shrublands (with some spinifex grasslands and halophytic shrublands). Located in the Gascoyne between the Lyndon and Wooramel Rivers.

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237 - Shark Bay Zone (8,475 km^2)	Sandplains (with coastal flats and dunes, calcrete plains and alluvial plains) on marine shoreline and aeolian deposits and Cretaceous marine limestone of the Carnarvon Basin. Red deep sands with some Calcareous deep sands, Calcareous shallow loams and Red deep sandy duplexes. Acacia shrublands (often grassy) with some scrub-heaths, halophytic shrublands and spinifex grasslands. Located in the south-western Gascoyne between the Zuytdorp Cliffs, Dirk Hartog Island and Wooramel.
238 - Lake MacLeod Coastal Zone (5,450 km^2)	Lake bed, saline flats and calcrete plains (with some sandplains and dunes) on marine shoreline and aeolian deposits and marine limestone of the Carnarvon Basin. Salt lakes soils with Red deep sands and some Calcareous loamy earths and Red deep sandy duplexes. Bare salt lake with halophytic shrublands, spinifex grasslands and acacia scrub. Located in the north-west coast from Carnarvon to Waroora Station.
239 - Kennedy Range Zone (3,025 km^2)	Dissected plateaux, mesas, hills and elevated sandplains on Eocene marine limestone and sandstone over Permian sedimentary rocks of the Carnarvon Basin. Stony soils and Red deep sands with some Red shallow sands and loams and Red shallow sandy duplexes. Snakewood-prickly wattle scrub with spinifex grasslands. Located in the Gascoyne to the north of Gascoyne Junction.

Flooding of alluvial flats along the Gascoyne River (PJ Waddell)

24 Stirling Province

Undulating plains and laterised plateau (dissected at fringes and with some emergent quartzite ranges) on deeply weathered mantle and Bremer Basin sediments over granitic rocks of the Yilgarn Craton and Albany-Fraser Orogen (with some metasediments and greenstone). Grey shallow sandy duplexes (mostly alkaline), Calcareous loamy earths, Grey deep sandy duplexes and Pale deep sands (with some Salt lakes soils and Alkaline grey shallow loamy duplexes). Mallee scrub with mallee heath and eucalypt woodlands (and some scrub-heath). Located in the South Coast district between Albany, Gnowangerup, Norseman and Israelite Bay.

Location and boundaries: Stirling Province occupies about 66,050 km^2 (2.6% of WA) along the southern coastline. The bulk (77%) of it lies within the Agricultural Area. It is south of the Kalgoorlie Province, south-east of Avon Province, and west of the Nullarbor Province. Included are the towns of Albany, Esperance, Cranbrook, Borden, Jerramungup, Ravensthorpe, Gnowangerup, Bremer Bay, Hopetoun and Salmon Gums.

It is based on the Stirling Province of Bettenay (1983). It correlates with most of the Eyre and Roe botanical districts of Beard (1990), and southern portion of the Yilgarn Plateau Province of Jennings and Mabbutt (1977).

The western boundary follows the western edge of the Bremer Basin tectonic unit of Tyler and Hocking (2001). In the north (between Gnowangerup and Pyramid Lake north of Munglinup) the boundary between the Stirling and Avon Provinces approximates the Jarrahwood Axis. This axis marks the catchment divide between rivers flowing directly to the Southern Ocean and the upper catchments of the Blackwood and Avon Rivers (as well as some internally drained basins). The Jarrahwood Axis indicates the upper extent of the dissection of the lateritic plateau of the Avon Province by these south flowing rivers.

Between Pyramid Lake and Norseman, the boundary between the Stirling Province and the Kalgoorlie Province is somewhat arbitrary[41]. Here it currently follows the outside edge of the *Atlas of Australian Soils* units abutting the Salmon Gums-Esperance-Ravensthorpe soil-landscape survey (Nicholas and Gee, in prep.).

East of Norseman, the boundary follows the northern boundary of the Clear Streak vegetation system of Beard (1975a), then the eastern edge of the Albany-Fraser Orogen tectonic unit of Tyler and Hocking (2001).

It extends north from Torbay (to west of Albany), past Mt Barker to Cranbrook, then north-east to Gnowangerup, and east to Ongerup. From here it swings north-east, passing to the north of Jerramungup and Ravensthorpe before reaching Pyramid Lake. It then heads north-east to Lake Dundas (south of Norseman) and swings east to Nanambinia Station, from where it head south to Mt Ragged in the Cape Arid National Park. From here it follows the Wylie Cliffs north-east a short distance before doubling back along the coastline, past Israelite Bay to Cape Arid. From here it follows the coastline west, passing Esperance, Hopetoun, Bremer Bay and Albany before returning to Torbay.

Geology: Most of the Stirling Province is underlain by a basement of either Mesoproterozoic rocks of the Albany-Fraser Orogen, or the Archean rocks of the Yilgarn Craton. The Biranup and Nornalup Complexes of the Albany-Fraser Orogen dominate the southern, eastern and western portions of this province. The Biranup Complex consists mainly of granitic augen gneiss and heterogeneous granitoid gneiss. The Nornalup Complex consists of even-grained or porphyritic recrystallised granite that has been weakly to strongly deformed.

[41] In reality the Stirling and Kalgoorlie Provinces grade into each other. In drawing a boundary between the two effort has been made identify the change from the terrain in the south that has a significant influence of Tertiary marine sediments and supports a predominantly mallee vegetation (with a melaleuca understorey) to the terrain formed on parna in the north that supports predominantly eucalypt woodland (with a halophytic understorey). It would be worth reviewing this boundary in the future.

The Mesoproterozoic shale, sandstone, phyllite, schist, quartzite and dolomite of the Mount Barren Group and Mesoproterozoic sandstone, quartzite, slate and phyllite of the Stirling Range Formation are prominent features in the western portion of the Albany-Fraser Orogen.

In the north, the basement is dominated by granitoid rock (monzogranite dominant) and foliated gneissic and migmatitic granitoid rocks of the Yilgarn Craton. Greenstone belts are found around Ravensthorpe.

Overlying much of this basement unconformably are Tertiary marine and continental deposits of the Onshore Bremer Basin. These include Plantagenet siltstone, sandstone and spongolite.

Landforms: In the north-east there is a level to gently undulating plain formed on the Eocene sediments of the Bremer Basin. On the surface of the plain there is a mantle of wind blown carbonate (parna). This plain is occasionally broken by small valleys, low narrow rocky hills and ridges, and granitic tors and bosses. Although defined drainage courses are largely absent over most of the plain, areas of internal drainage are a prominent feature. Salt lakes, claypans, kopi dunes and sand dunes are found on these broad valleys floors.

This calcareous plain merges in the south with a level lateritic sandplain that has formed on the Plantagenet sediments in the Esperance hinterland. This plain is approximately 50 km wide and extends discontinuously from Israelite Bay to Albany. While the sandplain has been dissected by a number of rivers (forming shallow valleys and scarps), defined drainage courses are absent over much of the plain's surface. In places there are winter waterlogged depressions. Low sand dunes and isolated granitic domes are also present. Below the sandplain is a narrow coastal plain with extensive dune fields and swampy flats. Dunes, dramatic granitic headlands and limestone cliffs are found along the coast.

In the north-west, a gently undulating plain (formed on the granitic rocks of the southern edge of the Yilgarn Craton) lies inland from the sandplain. The plain has been dissected by a number of short rivers. In the west it gives way to an undulating terrain of shallow valleys with granitic rock outcrop and dolerite dykes.

Hills and ranges are a prominent feature of the western half, providing dramatic contrast to the gently undulating plains. Around Ravensthorpe greenstone hills rise up to 400 m above sea level. Between Hopetoun and Bremer Bay are the Barren Ranges formed on Mesoproterozoic sediments. Even more dramatic are the Stirling Ranges, inland from Albany. They are formed on similar sedimentary rocks and rise to over 1000 m above sea level. The Porongurup Ranges and Mount Manypeaks are granitic hills.

Soils: On the plains in the north-east Calcareous loamy earths and Alkaline shallow sandy duplexes are dominant, with Alkaline grey shallow loamy duplexes and Alkaline grey deep sandy duplexes also present. These soils have high levels of soluble salts and calcium carbonate is often present in the profile. The duplex soils are often sodic. Salt lake soils are common on the valley floors, with Pale deep sands on the dunes.

Grey deep sandy duplexes (with some Grey shallow sandy duplexes) cover much of the sandplains. These soils usually have a gravelly layer between the sandy topsoil and the clayey subsoil. Pale deep sands are found on sand sheets and low dunes. Grey shallow sandy duplexes and Alkaline shallow sandy duplexes are found on the slopes of the shallow valleys dissecting the sandplain. Duplex sandy gravels and Deep sandy gravels also occur on slopes in the west. On the narrow coastal plains there are Pale deep sands, Wet soils and Semi-wet soils, with Calcareous deep sands on the coastal dunes.

The plains and valleys on granite in the north-west have a variety of soils including Grey shallow and deep sandy duplexes (sometimes alkaline), Yellow/brown shallow and deep sandy duplexes, hardsetting Grey shallow loamy duplexes, Alkaline grey shallow loamy duplexes and Duplex sandy gravels. Stony soils are common on the Stirling and Barren Ranges. Shallow gravels and Red/brown non-cracking clays are mostly found on Ravensthorpe Ranges.

The portion lying outside the existing coverage of soil-landscape mapping for the Agricultural Area falls predominantly on the north-east plains. Here Calcareous loamy earths dominate, and Alkaline grey shallow sandy duplexes and Salt lake soils are common. In the south there are Grey deep and shallow sandy duplexes and Pale deep sands on the east of the Esperance sandplain.

Climate: The bioclimate is described by Beard (1990) as Thermoxeric. This is predominantly a dry Mediterranean climate with 5-6 dry months. Mean annual rainfall is mostly in the 300-600 mm range, tending to fall in the winter. It increases to 900 mm in the south-west where the climate becomes moderate Mediterranean with 3-4 dry months. In the north-east this province extends into an extra dry Mediterranean climate (with 7-8 dry months). In the far north, where rainfall drops below 250 mm, the bioclimate tends towards Sub-Eremaean (semi-desert Mediterranean with 9-11 dry months).

Vegetation: On the plains of the north-east, a mallee scrub with *Eucalyptus eremophila*, black marlock (*E. redunca*), Forrest's marlock (*E. forrestiana*) and red mallee (*E. oleosa*) are found in association with woodlands of merrit (*E. floctoniae*), coral gum (*E. torquata*), salmon gum (*E. salmonophloia*) and red mallee. There is also some redwood (*E. transcontinentalis*) and Dundas blackbutt (*E. dundasii*).

Mallee-heath and scrub-heaths dominate the Esperance sandplains. Common species here include tallerack (*E. tetragona*), *E. incrassata*, chittick (*Lambertia inermis*), *Banksia* and Christmas tree (*Nuytsia floribunda*). In the west, jarrah (*E. marginata*) and Albany blackbutt (*E. staeri*) are found in the sandplain mallee-heaths, while jarrah, marri (*Corymbia calophylla*) and casuarina (*Allocasuarina fraseriana*) woodlands and forests are also present in dissected terrain. Banksia scrub-heath is found on the coastal plains, with the coastal dunes supporting mallee and acacia scrub. Sedge communities and paperbark (*Melaleuca* spp.) woodland characterise the poorly drained lowlands.

On the plains and valleys of the north-west there is mallee scrub with *Eucalyptus eremophila* and black marlock. Woodlands of flat-topped yate (*E. occidentalis*), York gum (*E. loxophleba*), salmon gum, morrel (*E. longicornis*) and wandoo (*E. wandoo*) are also present, and areas of tallerack mallee-heath. The Ravensthorpe Ranges support mallee scrub and salmon gum-yate woodlands. Scrub-heath and tallerack mallee-heath are found on the Barren Ranges, with tallerack and jarrah mallee-heath (and jarrah, marri and wandoo woodland) on the Stirling Ranges. Pockets of karri (*E. diversicolor*) forest occur on the Porongurup Ranges.

Component zones: Stirling Province has been divided into seven soil-landscape zones, two of which extend beyond the Agricultural Area into the Rangelands (Figure 4.5d):

- Esperance Sandplain Zone is largely as described by Tille *et al.* (1998). It corresponds with the eastern Eyre botanical district[42] of Beard (1990) and includes the Esperance Hills and Israelite Plains Sections of Jennings and Mabbutt (1977) with portions of their Stirling-Barren Hills and Narrogin-Ongerup Plateau Sections; and
- Salmon Gums Mallee Zone is largely as described by Tille *et al.* (1998). It corresponds with the eastern Roe botanical district[43] of Beard (1990) and the south-eastern protrusion of the Narrogin-Ongerup Plateau Section of Jennings and Mabbutt (1977), along with portions of their Coonana-Ragged Plateau Section.

[42] The Eyre botanical district includes the Esperance and Fanny Cove vegetation systems of Beard (1975a, 1981) where it intersects the Esperance Sandplain Zone.

[43] The Roe botanical district includes the Clear Streak, Ridley, Oldfield, Lort, Salmon Gums and (south-eastern) Lake Hope vegetation systems of Beard (1975a, 1981) where it intersects the Salmon Gums-Mallee Zone.

245 – Esperance Sandplain Zone (12,825 km^2) **(10,175 km^2 covered by existing mapping)**	Weakly dissected sandplain (with some coastal plain, dunes and headlands) on deeply weathered mantle and colluvium over Bremer Basin sediments on granite and gneiss of the Albany-Fraser Orogen. Grey deep sandy duplexes and Pale deep sands with Grey shallow sandy duplexes and some Calcareous deep sands. Mallee-heath with banksia scrub-heath (with some mallee scrub and coastal heath). Located in the South Coast district from Hopetoun to Israelite Bay.
246 – Salmon Gums Mallee Zone (29,650 km^2) **(18,800 km^2 covered by existing mapping)**	Flat to undulating plains (with some salt lakes) on deeply weathered mantle and alluvium over Bremer Basin sediments on granite and gneiss of the Yilgarn Craton and Albany-Fraser Orogen. Calcareous loamy earths and Alkaline grey shallow sandy duplexes with Salt lake soils and some Alkaline grey shallow loamy duplexes and Pale deep sands. Merrit-coral gum-salmon gum-red mallee woodlands with mallee scrub and some mallee heath. Located in the South Coast district between Pyramid Lake, Scaddan, Norseman and Mt Ragged.

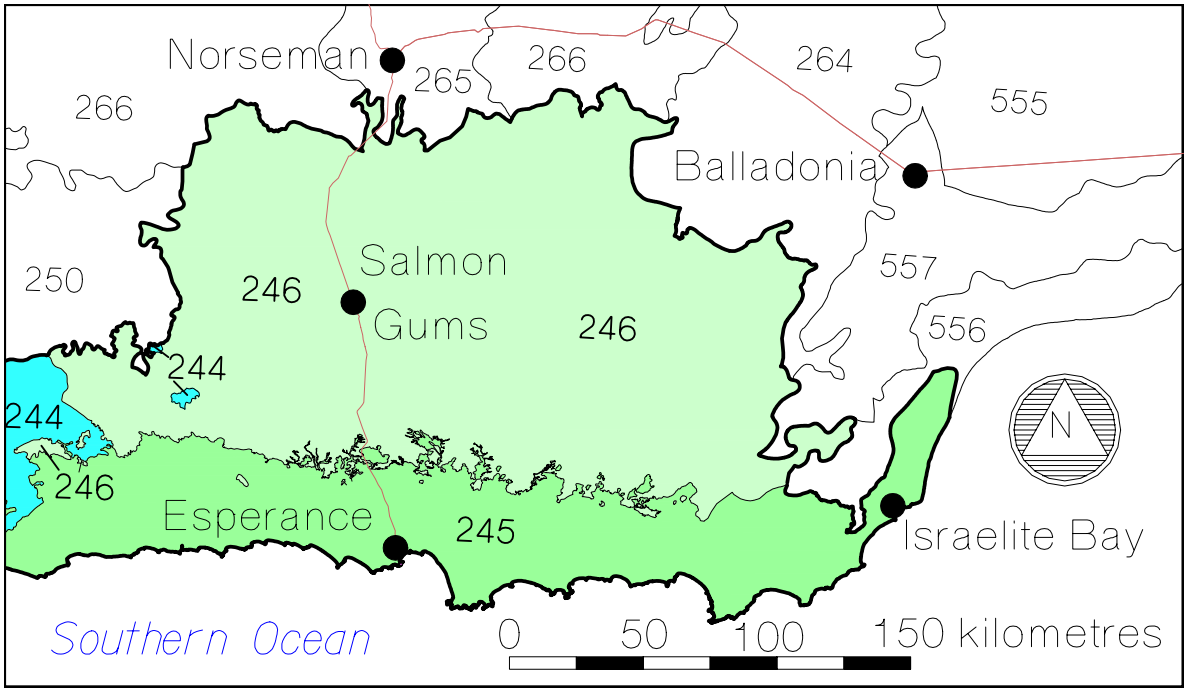

Figure 4.5d: Soil-landscape zones of the eastern portion of the Stirling Province

25 Avon Province

Laterised plateau (dissected at fringes and with saline drainage lines inland) on deeply weathered mantle and alluvium over granitic rocks of the Yilgarn Craton (and Albany-Fraser Orogen). Sandy duplexes soils and Ironstone gravelly soils with Loamy earths, Loamy duplexes, Sandy earths, Deep sands and Wet soils. York gum-wandoo-salmon gum-morrel-gimlet woodland and jarrah-marri-karri-wandoo woodlands/forests (with some mallee scrub, tammar-wodjil thickets and scrub-heath). Located in the south-west, between Nannup, Denmark, Jerramungup, Southern Cross, Lake Moore, Carnamah and the Perth Hills.

Location and boundaries: Avon Province occupies about 169,325 km^2 (6.7% of WA), of which the vast bulk (93%) lies in the Agricultural Area. It extends from the eastern Wheatbelt to the south coast near Denmark and Northcliffe, and includes the Darling Range. It includes the towns of Northam, Merredin, Dalwallinu, Carnamah, Wongan Hills, Bencubbin, Narrogin, Corrigin, Hyden, Lake Grace, Katanning, Kojonup, Collie, Boyup Brook, Bridgetown, Manjimup, Pemberton, Walpole and Denmark.

It is based on the Avon Province of Bettenay (1983). It correlates with the bulk of the Avon and Dale botanical districts of Beard (1990), the south-western portions of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001) and the south-western portions of the Yilgarn Plateau Province of Jennings and Mabbutt (1977).

The boundary is based on a combination of the south-west quarter of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001) with the western portion of the Albany-Fraser Orogen tectonic unit (i.e. the portion not overlain by the Bremer Basin).

East of Tambellup, its boundary with the Stirling Province approximates the Jarrahwood Axis, following the southern edge of the Blackwood and Avon River catchments. The boundary with the Kalgoorlie Province largely follows the eastern edge of the Coolgardie botanical district of Beard (1990).

To the north, the eastern boundary with the Murchison Province follows the boundary between the Avon and Austin botanical districts. West of Mongers Lake, the boundary with the Murchison Province follows the southern extent of Shallow red-brown hardpan loams as mapped by Grose (in prep.) and Griffin and Frahmand (in prep.).

The boundary extends north from Torbay (to the west of Albany), past Mt Barker to Cranbrook, then swings north-east to Gnowangerup, and east to Ongerup. From here it heads north-east, passing to the north of Jerramungup and Ravensthorpe before reaching Pyramid Lake. It then turns north to Lake Hope before swinging north-west (past Mount Holland, Marvel Loch, Southern Cross and Bullfinch) to Hamersley Lakes. From here it follows the Vermin Proof Fence west to Lake Moore, then detours north for a short distance before swinging south-west to Wubin, north-west to Perenjori and west to Carnamah. From here it follows the Darling Fault south through Moora, Chittering, Armadale, Harvey, Donnybrook and Nannup to the south coast, which it then follows eastwards (past Walpole and Denmark) before returning to Torbay.

Geology: Most overlies the South West Terrane of the Yilgarn Craton. This is composed of Archaean granitic rocks, predominantly monzogranite with significant areas of gneiss, granulite and migmatite. These rocks contain numerous faults, shear zones and dolerite dykes. The Archaean granitiod rocks of the Youanmi Terrane are in the north-east (Murchison Domain) and south-east (Southern Cross Domain). Within the Avon Province, greenstones form only a minor component of this terrane.

In the south-west, the Albany-Fraser Orogen contains the Archaean-Mesoproterozoic gniess of Biranup Complex, and the Mesoproterozoic gneiss and granite of the Nornalup Complex. On the western margin of the province, between Moora and Morawa, there are the Neoproterozoic siltstone, quartzite, chert, sandstone and conglomerate of the Moora Group.

The Archaean basement has been subject to deep weathering (to 50 m depth) and laterite formation. There are also extensive Tertiary and Quaternary alluvial deposits.

Landforms: Avon Province is dominated by an undulating plateau, rising from the Southern Ocean coastline in the south-west to 450 m above sea level in the north-east. The north-eastern half is an area of low relief. Here broad lateritic uplands (typically with extensive sandplain) give way to long gentle slopes formed on the truncated weathering profile. Basement rock outcrops on these slopes in some places. The valley floors are broad with very low gradients. They only carry flows in very wet years and contain chains of salt lakes.

A significant change in the landscape occurs west of a line that runs approximately between Moora, Quairading and Katanning known as the Meckering Line. It marks a change from the subdued landscape inland (with palaeochannels on the valley floors) to a more dissected terrain with rejuvenated drainage. West of the Meckering Line the plateau becomes increasingly dissected, initially resulting in a landscape of rounded, moderately to gently inclined rises and low hills. The hills are sometimes capped by lateritic remnants with breakaways, while rock outcrop is more common on the valley slopes than it is to the east. The valley floors become narrower and the drainage lines (although sometimes sluggish) flow in clearly incised courses in the winter months.

In the south-west, the valleys are quite deeply incised with steep slopes. These valleys are separated by large areas of gently undulating uplands that extend between New Norcia, Manjimup and Mt Barker. Lateritic duricrust is common on these uplands and broad flat areas of raised Eocene sedimentary deposits can also be found. The western margin is marked by the sudden drop (40-200 m) of the Darling Scarp. South of the Blackwood River, the plateau drops gradually towards the coast, giving way to a landscape of swampy plains interspersed with hills and rises formed on granite and gneiss of the Albany-Fraser Orogen. Along the coast are large dunefields separated by rocky headlands and limestone cliffs.

Soils: The sandplains in the north and north-east have Yellow deep sands and Yellow sandy earths, with Red sandy earths, Acid yellow sandy earths and Shallow gravels also being present. To the south-east, Grey deep sandy duplexes, Deep sandy gravels and Duplex sandy gravels replace the deep sands and sandy earths on the lateritic uplands.

The long gentle slopes on truncated weathering profile have Alkaline grey shallow sandy duplexes, Alkaline grey deep sandy duplexes, Alkaline grey shallow loamy duplexes and Yellow/brown shallow loamy duplexes. The clayey subsoils are usually sodic and often calcareous, while loamy topsoils are often hardsetting. Where the granitic basement is exposed, Red loamy earths and Yellow/brown shallow sandy duplexes are found. Calcareous loamy earths, Alkaline red shallow loamy duplex, Alkaline grey shallow loamy duplexes, Alkaline grey shallow sandy duplexes, Salt lake soils and Saline wet soils are all found on the valley floors.

West of the Meckering Line, Grey deep sandy duplexes are common on sloping terrain. Also present are Grey shallow sandy duplexes. Granitic slopes have Brown loamy earths, Red deep loamy duplexes and Red shallow loamy duplexes. On lateritic caps there are Duplex sandy gravels, with Yellow sandy earths occurring on sandplain remnants. Saline wet soils are found on the valley floors along with Brown sandy earths, Yellow/brown deep sandy duplexes and Grey shallow sandy duplexes.

The lateritic plateaux of the south-west have Loamy gravels, Duplex sandy gravels, Deep sandy gravels and Shallow gravels, while the valley slopes have Brown loamy earths, Brown deep loamy duplexes and Friable red/brown loamy earth. Wet soils, Semi-wet soils, Grey deep sandy duplexes and Pale deep sands are associated with the flats on Eocene sediments as well as coastal flats in the far south.

Climate: The bioclimate is described by Beard (1990) as Thermoxeric. This is a mostly dry to extra dry Mediterranean climate with 5-8 dry months. Mean annual rainfall is mostly in the 300-500 mm range, tending to fall mainly in the winter months. In the south-west the rainfall

increases up to 1400 mm and the climate becomes moderate Mediterranean with only 3-4 dry months. In the north, where the rainfall drops below 300 mm, the bioclimate tends towards Sub-Eremaean (semi-desert Mediterranean climate with 9-11 dry months).

Vegetation: Much has been cleared for agricultural development. In their natural state, the northern sandplains support acacia-casuarina-melaleuca thickets. Species present include tammar (*Allocasuarina campestris*), *Melaleuca uncinata*, *M. cordata*, *Acacia neurophylla*, *A. beauverdiana*, *A. resinomarginea* and bull mallee (*Eucalyptus pyriformis*). In the south is a proteaceous scrub-heath of *Dryandra*, *Allocasuarina*, *Banksia*, *Hakea*, *Grevillea* and *Acacia* spp. Scrub-heaths with *Banksia* and *Xylomelum angustifolium* also occur on these sandplains.

Common species of the woodlands east of the Meckering Line are salmon gum (*Eucalyptus salmonophloia*), wandoo (*E. wandoo*) and gimlet (*E. salubris*). Woodland of York gum (*E. loxophleba*), jam (*Acacia acuminata*) and sheoak (*Allocasuarina heugeliana*) are found on rocky slopes, while the Calcareous loamy earths on valley floors support morrel (*E. longicornis*). There are also areas of mallee scrub, with *E. sheathiana* in the north and *E. eremophila*, black marlock (*E. redunca*) and redwood (*E. transcontinentalis*) to the south.

West of the Meckering line are woodlands of York gum and wandoo with salmon gum, morrel and gimlet. York gum and jam are found on the loamy soils over fresh rock. To the south, marri (*Corymbia calophylla*) becomes common on valley slopes, while powderbark wandoo (*E. accedens*) and parrotbush (*Dryandra* spp.) are found on gravelly uplands. There is also some tammar thickets, proteaceous scrub-heaths and mallee on the lateritic residuals, with mallet (*E. astringens*) found below breakaways. On saline valley floors thickets of *Melaleuca thyoides* over samphire (*Halosarcia* spp.) can occur.

In the south-west, woodlands and forests or jarrah (*E. marginata*) and marri are found on the lateritic plateau, with wandoo also sometimes present. On loamy soils in the valleys, marri is most common, with karri (*E. diversicolor*) forests occurring in the high rainfall area to the south of Manjimup. Sedge communities, heath shrublands and paperbark (*Melaleuca* spp.) woodlands are found in sandy and poorly drained terrain.

Component zones: The Avon Province has been divided into eight soil-landscape zones, two of which extend beyond the Agricultural Area into the Rangelands (Figure 4.5e):

- South-eastern Zone of Ancient Drainage is a subdivision of the Zone of Ancient Drainage of Tille *et al.* (1998) that is described by Percy (2003) and Verboom and Galloway (2004). It corresponds with the western Roe botanical district[44] of Beard (1990) within the Narrogin-Ongerup Plateau Section of Jennings and Mabbutt (1977); and
- Northern Zone of Ancient Drainage is a subdivision of the Zone of Ancient Drainage of Tille *et al.* (1998) that is described by Verboom and Galloway (2004). It corresponds with the north-eastern Avon botanical district[45] of Beard (1990) and lies within the Narrogin-Ongerup Plateau Section of Jennings and Mabbutt (1977).

[44] Where it intersects the South-eastern Zone of Ancient Drainage, the Roe botanical district includes the Hyden, Chidnup and (central) Lake Hope vegetation systems of Beard (1981).

[45] Where it intersects the Northern Zone of Ancient Drainage, the Avon botanical district includes the Muntadgin, Mt Caroline, Moorine Rock, Jibberding, (eastern) Guangan, (eastern) Goomalling, (eastern) Marchagee and (southern) Perenjori vegetation systems of Beard (1981).

250 - South-eastern Zone of Ancient Drainage (30,650 km^2) **(23,725 km^2 covered by existing mapping)**	Gently undulating terrain (with some salt lake chains and areas of prominent granitic outcrops) on deeply weathered mantle and alluvium over granitic rocks of the Yilgarn Craton. Sandy duplexes (often alkaline) with Ironstone gravelly soils and Loamy earths (often calcareous) and some Loamy duplexes, Sandy earths, Deep sands and Saline wet soils. Mallee scrub and salmon gum-gimlet-morrel woodlands (and some scrub-heath). Located in the southern Wheatbelt between Kondinin, Lake Grace, Gnowangerup, Frank Hann National Park and Mt Holland.
258 - Northern Zone of Ancient Drainage (60,350 km^2) **(55,200 km^2 covered by existing mapping)**	Gently undulating terrain (with some sandplains and salt lakes chains) on deeply weathered mantle and alluvium over granitic rocks of the Yilgarn Craton. Sandy earths (mostly yellow and red), Loamy earths (often calcareous), Sandy duplexes, Loamy duplexes, Deep sands and Ironstone gravelly soils. Salmon gum-gimlet-morrel-wandoo-York gum woodlands with mallee scrub (and some acacia-casuarina thickets, scrub-heath and samphire flats). Located in the eastern Wheatbelt between Quairading, Hyden, Bullfinch, Bonnie Rock, Lake Moore, Carnamah and Wongan Hills.

Open Page 76 map

26 Kalgoorlie Province

Undulating plains (with some sandplains, hills and salt lakes) on the granitic rocks and greenstone of the Yilgarn Craton. Calcareous loamy earths and Red loamy earths with some Salt lake soils, Red deep sands, Yellow sandy earths, Shallow loams and Loamy duplexes. Eucalypt woodlands with some acacia-casuarina thickets, mulga shrublands, halophytic shrublands and spinifex grasslands. Located in the southern Goldfields between Paynes Find, Menzies, Southern Cross and Balladonia.

Location and boundaries: Kalgoorlie Province occupies about 148,400 km^2 (5.9% of WA). It covers the southern Goldfields to the north of the Stirling Province; north-west of the Avon Province; south of the Murchison Province; and east of the Nullarbor Province. Although most (98%) lies within the Rangelands, its western edge extends into the Agricultural Area. Included are the towns of Kalgoorlie, Coolgardie, Kambalda, Norseman, Menzies, Southern Cross, Marvel Loch, Koolyanobbing and Bullfinch.

It is based on the Kalgoorlie Province of Bettenay (1983). It correlates with the bulk of the Coolgardie botanical district of Beard (1990) and Coolgardie IBRA region of Environment Australia (2000), the south-east of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001), and the south-east of the Yilgarn Plateau Province of Jennings and Mabbutt (1977).

The boundary is based approximately on the boundary of the Coolgardie botanical district of Beard (1990). It excludes the tongue of Beard's district protruding east along the Great Australian Bight. The eastern boundary follows the edge of the Albany-Fraser Orogen. The boundary with the Murchison Province has been placed along the northern extent of the *plains with eucalypt woodlands with non-halophytic undershrubs* and *sandplains with acacia, mallees and heath* rangeland land types (Van Vreeswyk and Godden 1998, Pringle 1994). This line lies approximately 40-80 km north of the boundary between the Austin and Coolgardie botanical districts.

The boundary extends from the western shore of Lake Moore (south of Paynes Find) north-east to the southern shore of Lake Barlee, then east (past Menzies) to Lake Rebecca. From here it swings south-west to Cundeelee (north of Zanthus on the Trans-Australian Railway) before heading south, past Balladonia to Nanambinia Station. It then heads north-west to Southern Hills Station before swinging west, past Norseman to Lake Hope. From here it heads north-west, past Mount Holland, Marvel Loch, Southern Cross, Bullfinch to Hamersley Lakes before following the Vermin Proof Fence back to Lake Moore.

Geology: Kalgoorlie Province is on the central eastern portion of the Yilgarn Craton, mostly overlying Archaean rocks of the Southern Cross Domain and the Eastern Goldfields Superterrane. To the north-west is the Murchison Domain. The basement rocks are a mix of granite, gneiss and greenstone. Even-grained porphyritic granitic rocks (intruded by quartz veins and dolerite dykes) are most common across the north as well as in the western half and the north-east. The largest areas of migmatite and gneiss are found in the south-west.

The greatest concentration of greenstone belts is in the centre of the eastern half, between Norseman and Kalgoorlie. They are also common along the south-western margin and to the south of Lake Barlee. These greenstone belts contain a mixture of metamorphosed mafic to ultra-mafic volcanic rocks (including basalt, amphibolite, dolerite and gabbro), felsic volcanic rocks, and metasedimentary rocks (including cherts and banded iron formations).

Mesoproterozoic rocks of the Albany-Fraser Orogen are found in the south-eastern corner. These include the gneiss of the Biranup Complex and the weakly to strongly deformed granite of the Nornalup Complex. Overlying much of the Albany-Fraser Orogen is a veneer of Eocene sediments belonging to the Balladonia Shelf of the Eucla Basin.

Also present north-east of Norseman is an outcrop of Mesoproterozoic arenaceous and argillaceous metasedimentary sandstone and shale of the Woodline Formation.

The bedrock has been extensively weathered and laterised. Much is obscured by Tertiary and Quaternary alluvial, colluvial and aeolian deposits.

Landforms: Kalgoorlie Province consists of an extensive plateau of low relief. Flat to undulating plains with small valleys (occasionally broken by low narrow rocky hills, ridges, tors and bosses) are most commonly found on granitic terrain. On these plains may be found some silcrete duricrust, claypans, salt lakes with dunes and lunettes, gilgai areas, small remnants of sand plain, and small dune tracts. Low breakaways with short saline footslopes are also occasionally present.

Below these plains are some broad, flat to undulating, shallow valley plains formed on Quaternary alluvium and colluvium. These plains show little defined drainage and some seasonal lakes and claypans with isolated granitic and basic rock outcrops. Slightly lower down in the landscape are broad, flat valleys with chains of salt lakes. Also present on these valley floors are saline flats, claypans, kopi dunes, sand dunes, and sometimes tors and bosses of outcropping granites.

Higher up in the landscape are gently sloping to gently undulating plateau areas on granites and gneisses. These have long gentle slopes and, in places, abrupt erosional scarps. Some granitic bosses and tors are present.

Rocky ranges, hills and ridges have formed on the greenstone, along with some undulating to low hilly country. Associated with this hilly terrain are gently undulating stony plains and low rises on limonite.

Level to gently undulating sandplains and gravelly sandplains are mostly found over lateritic residuals and granitic basement. There are also some extensive loamy plains with sandy surfaces.

Soils: The undulating plains on granite have extensive areas of Calcareous loamy earths with Red loamy earths, Red deep loamy duplexes and Red shallow loamy duplexes. Red-brown hardpan shallow loams, Yellow loamy earths, Salt lake soils, Red shallow sands and Cracking clays are present, and Red shallow sandy duplexes on breakaways.

The broad valley plains have Red loamy earths and Calcareous loamy earths, with Red-brown hardpan shallow loams and Red/brown non-cracking clays. There are also some Alkaline grey shallow and deep sandy duplexes and Yellow loamy earths. Saline valley floors have Salt lake soils with Saline wet soils and Red deep sandy duplexes. Red deep sands are found on lunettes associated with the lakes.

The gently sloping uplands on granite have Yellow sandy earths and Yellow loamy earths, with some Yellow deep sands and Ironstone gravelly soils. The hilly terrain on greenstone has Red loamy earths, Calcareous loamy earths and Calcareous shallow loams, along with Stony soils and Red shallow loams.

Sandplains have Red deep sands, with some Yellow deep sands in the west. On the sandy-surfaced plains there are Red deep sands and Red loamy earths with Red sandy earths.

Climate: The bioclimate is described by Beard (1990) as mainly Sub-Eremaean. This is mostly a semi-desert Mediterranean climate with 9-11 dry months. Mean annual rainfall is in the 250-300 mm range, tending to fall in winter. In the south-west (around Southern Cross) rainfall rises to 350 mm and the bioclimate tends towards Thermoxeric (an extra dry Mediterranean climate with 7-8 dry months). In the north and east where rainfall drops to 200 mm the bioclimate tends towards Eremaean (desert with 12 dry months, mostly non-seasonal in the east but tending to a mix of summer and winter rain in the north).

Vegetation: The undulating plains on granite support woodlands of redwood (*Eucalyptus transcontinentalis*), red mallee (*E. oleosa*), Dundas blackbutt (*E. dundasii*), merrit (*E. floctoniae*) and salmon gum (*E. salmonophloia*). There are also some hummock grasslands with red mallee over spinifex (*Triodia scariosa*) and thickets of *Acacia*, *Casuarina*

and *Melaleuca* spp. Plains on greenstone have woodlands of York gum (*E. loxophleba*), salmon gum and gimlet (*E. salubris*).

The valley plains have woodlands of salmon gum, red mallee, Goldfields blackbutt (*E. lesouefii*), gimlet, York gum and morrel (*E. longicornis*). These sometimes have an understorey of saltbush (*Atriplex* spp.), pearl bluebush (*Maireana sedifolia*), sago bluebush (*M. pyramidata*) and *Eremophila* spp. There are areas of spinifex grasslands with red mallee, mallees (e.g. *E. youngiana*) and marble gum (*E. gongylocarpa*). Low woodlands of mulga (*Acacia aneura*) and black sheoak (*Casuarina cristata*) over bluebush and saltbush are also present.

Apart from the bare salt lake surfaces, saline valley floors have shrublands of samphire (*Halosarcia* spp.) and *Frankenia* spp. in lower areas, shrublands of saltbush and bluebush on Red deep sandy duplexes, and woodlands of salmon gum, merrit, red mallee, gimlet and York gum.

Acacia neurophylla, *A. beauverdiana* and *A. resinomarginea* thickets grow on gently sloping uplands on granite, with thickets of acacia, casuarina and melaleuca. There are also scrub-heaths and York gum-salmon gum-gimlet woodlands on these uplands.

The hilly terrain on greenstone supports woodlands of salmon gum, Goldfields blackbutt, coral gum (*E. torquata*), York gum, gimlet, morrel, Dundas blackbutt and black sheoak. Thickets of granite wattle (*Acacia quadrimarginea*) are also present. The stony plains support scattered woodlands of Goldfields blackbutt, gimlet and salmon gum, along with shrublands of saltbush and bluebush.

Sandplains in the west have acacia (*A. coolgardiensis, A. ramulosa, A. aneura, A. burkittii* and *A. tetragonophylla*) shrublands, commonly with patchy native pine (*Callitris glaucophylla C. preissii*) and mallees (*E. leptopoda, E. longicornis* and *E. loxophleba*). Native box (*Bursaria occidentalis*), *Melaleuca uncinata* and *Hakea recurva* may also be present. Hard spinifex (*T. basedowii*) grasslands with mulga, marble gum and mallees (e.g. *E. kingsmillii*) are found on sandplains to the east.

The sandy-surfaced plains support acacia, casuarina and melaleuca thickets; woodlands of York gum, cypress pine (*Callitris columellaris*), salmon gum, gimlet and mulga; and shrublands of bowgada (*A. ramulosa*).

Component zones: Kalgoorlie Province has been divided into six soil-landscape zones (Figure 4.5f):

- Southern Cross Zone is based on the Southern Cross Zone of Schoknecht *et al.* (2004) and overlies the greenstones of the Southern Cross Granite-Greenstone Terrane tectonic unit of Tyler and Hocking (2001). It lies within the Salinaland Plateau Sections of Jennings and Mabbutt (1977) and the Southern Cross Granite-Greenstone Terrane tectonic unit of Tyler and Hocking (2001);
- Bimbijy Sandplain Zone overlies granitic rocks within the Murchison and Southern Cross Granite-Greenstone Terrane tectonic units of Tyler and Hocking (2001). It lies within the Salinaland Plateau Section of Jennings and Mabbutt (1977) and is differentiated from the Mount Jackson and Norseman Zones by the preponderance of the *sandplains with acacia, mallees and heath* rangeland land type (Van Vreeswyk and Godden 1998);
- Mount Jackson Plains and Hills Zone overlies the greenstone of the Southern Cross Granite-Greenstone Terrane tectonic unit of Tyler and Hocking (2001). It lies within the Salinaland Plateau Section of Jennings and Mabbutt (1977) and is differentiated from the Bimbijy Sandplains Zone by the preponderance of the *stony plains with acacia shrublands and halophytic shrublands* and *hills and ranges with acacia shrublands* rangeland land types (Van Vreeswyk and Godden 1998);

- Nanambinia Zone is based on the Harms vegetation system of Beard (1975a) and occurs where the Balladonia Shelf sediments overlie the Albany-Fraser Orogen tectonic unit of Tyler and Hocking (2001). It is located within the Coonana-Ragged Plateau Sections of Jennings and Mabbutt (1977);
- Kambalda Zone overlies the greenstone of the Eastern Goldfields and Southern Cross Granite-Greenstone Terrane tectonic units of Tyler and Hocking (2001). It lies within the Salinaland and Coonana-Ragged Plateau Sections of Jennings and Mabbutt (1977) and is differentiated from the Norseman Zone due to the preponderance of the *stony plains with acacia shrublands and halophytic shrublands*, *low hills with eucalypt or acacia woodlands with halophytic undershrubs*, *stony plains with acacia shrublands* and *alluvial plains with eucalypt woodlands and halophytic undershrubs* rangeland land types (Pringle 1994); and
- Norseman Zone predominantly overlies granitic rocks within the Eastern Goldfields and Southern Cross Granite-Greenstone Terrane tectonic units of Tyler and Hocking (2001). It lies within the Salinaland and Coonana-Ragged Plateau Sections of Jennings and Mabbutt (1977) and is differentiated from the Bimbijy and Kambalda Zones by the preponderance of the *sandplains and occasional dunes with spinifex grasslands* rangeland land type (Pringle 1994).

NOTE: The patchwork of differing soil/rangeland mapping styles, combined with the general lack of clear patterns of geological differentiation and subdued terrain, made identification of soil-landscape zones in the Kalgoorlie Province difficult. The mapping of this province requires review. The boundary between this province, the Gunbarrel Province (12) and the Leemans Sandplain Zone (274) of the Murchison Province also requires review. The portion of the Norseman Zone (266) overlying the Albany-Fraser Orogen might be better included in Nanambinia Zone (264).

261 – Southern Cross Zone (8,550 km^2) **(2,375 km^2 covered by existing mapping)**	Undulating plains and uplands (with some salt lake and low hills) on deeply weathered mantle, colluvium and alluvium over greenstone and granitic rocks of the Yilgarn Craton. Calcareous loamy earths, Red and yellow loamy earths and Alkaline deep and shallow sandy duplexes with some Yellow sandy earths, Salt lake soils, Yellow deep sands and Red shallow loamy duplexes. Salmon gum-gimlet-morrel-York gum woodlands with acacia-casuarina thickets (and some mallee, scrub-heath and halophytic shrublands). Located in the eastern Wheatbelt/south-western Goldfields between Bullfinch and Mt Holland.
262 – Bimbijy Sandplains Zone (19,875 km^2)	Sandplains (with plains and some salt lakes and mesas) on granitic rocks of the Yilgarn Craton. Red deep sands with Red loamy earths and some Red shallow loams, Red shallow sands, Salt lake soils, Yellow loamy earths and Yellow deep sands. Mulga shrublands, acacia-casuarina thickets, spinifex grasslands and York gum-salmon gum-gimlet woodlands (with some mallee, acacia scrub and halophytic shrublands). Located in the Goldfields between Lake Moore, Lake Barlee and Mt Jackson.
263 – Mount Jackson Plains and Hills Zone (6,350 km^2)	Undulating plains (with some hills and stony plains) on greenstone and granitic rocks of the Yilgarn Craton. Red loamy earths with Red-brown hardpan shallow loams and some Red sandy earths, Red shallow loams and Loamy gravels. York gum-salmon gum-gimlet woodland with acacia thickets and mulga scrub. Located in the Goldfields between Lake Barlee and Mt Jackson.
264 – Nanambinia Zone (9,975 km^2)	Undulating plains (with some salt lakes and granitic outcrops) on Eocene sediments over granite and gneiss of the Albany-Fraser Orogen. Calcareous loamy earths with some Red shallow and deep loamy duplexes, Red loamy earths and Salt lake soils. Redwood-red mallee-merrit woodlands. Located in the south-eastern Goldfields between Fraser Range and Balladonia.

265 – Kambalda Zone (35,825 km^2)	Flat to undulating plains (with hills, ranges and some salt lakes and stony plains) on greenstone and granitic rocks of the Yilgarn Craton. Calcareous loamy earths and Red loamy earths with Salt lakes soils and some Red-brown hardpan shallow loams and Red sandy duplexes. Red mallee-blackbutt-salmon gum-gimlet woodlands with mulga and halophytic shrublands (and some spinifex grasslands). Located in the south-eastern Goldfields between Menzies, Norseman and the Fraser Range.
266 – Norseman Zone (67,325 km^2)	Undulating plains and uplands (with some sandplains and salt lakes) on granitic rocks of the Yilgarn Craton. Calcareous loamy earths, Yellow sandy and loamy earths, Red loamy earths, Red deep sands and Salt lake soils. Salmon gum-redwood-merrit-red mallee-gimlet woodland with acacia-casuarina thickets (and some mulga shrublands and spinifex grasslands). Located in the southern Goldfields between Koolyanobbing, Menzies, Zanthus (Trans-Australian Railway), Norseman and Lake Hope.

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Figure 4.5f: Soil-landscape zones of the Kalgoorlie Province

27 Murchison Province

Hardpan wash plains and sandplains (with some stony plains, hills, mesas and salt lakes) on the granitic rocks and greenstone of the Yilgarn Craton. Red loamy earths, Red sandy earths, Red shallow loams, Red deep sands and Red-brown hardpan shallow loams (with some Red shallow sands and Red shallow sandy duplexes). Mulga shrublands with spinifex grasslands (and some bowgada shrublands, eucalypt woodlands and halophytic shrublands). Located in the inland Mid-west and northern Goldfields between Three Springs, the Gascoyne River, Wiluna, Cosmo Newberry and Menzies.

Location and boundaries: Murchison Province occupies about 304,875 km^2 (12.1% of WA), covering the eastern Mid-West and northern Goldfields. It lies \ north of the Avon and Kalgoorlie Provinces, west of the Gunbarrel Province, south of the Ashburton Province, and east of the Greenough and Carnarvon Provinces. Most (97%) lies within the Rangelands and Arid interior, with the western edge extending into the Agricultural Area. Included are the towns of Cue, Laverton, Leinster, Leonora, Meekatharra, Morawa, Mount Magnet, Mullewa, Perenjori, Paynes Find, Sandstone, Wiluna and Yalgoo.

It is based on the Murchison Province of Bettenay (1983) and the bulk of the Austin botanical district of Beard (1990). It correlates with the northern central portion of the Yilgarn Plateau Province of Jennings and Mabbutt (1977) and the Murchison and Yalgoo IBRA regions of Environment Australia (2000).

The boundary is based on the northern half of the Yilgarn Craton tectonic unit of Tyler and Hocking (2001). East of Lake Monger, it approximates the southern edge of the Austin botanical district of Beard (1990). The boundary actually sits some 40-80 km north of Beard's line, following the northern extent of the *plains with eucalypt woodlands with non-halophytic undershrubs* and *sandplains with acacia, mallees and heath* rangeland land types (Pringle 1994, Van Vreeswyk and Godden 1998). Further west, the southern boundary has been based on the southern extent of Shallow red-brown hardpan loams as mapped by Grose (in prep.) and Griffin and Frahmand (in prep.).

The boundary extends north from Three Springs, past Mullewa, to Lake Nerramyne. It then turns north-east, past the Woodrarrung and Errabiddy Ranges, almost to Glenburgh Station. From here it heads east (firstly following the catchment divide between the Wooramel and Gascoyne River), passing to the south of Landor Station before swinging south-east near Yarlarweelor Station and continuing past Meekatharra to Wiluna. It then heads north to Lake Gregory, then south east to Lake Wells. From here it strikes south, passing to the east of Cosmo Newberry and Lake Minigwal, till it almost reaches Cundeelee (north of Zanthus on the Trans-Australian Railway). It now swings northwards to Lake Rebecca and then west (passing to the north of Menzies and the south of Lakes Ballard and Barlee) to the northern shore of Lake Moore (just south of Paynes Find). From here it heads south-west, almost to Wubin, before swinging north-west to Perenjori, and then west back to Three Springs.

Geology: Murchison Province is spread across the northern third of the Yilgarn Craton. The underlying rocks are predominantly Archaean even-grained porphyritic granitic rocks. These are intruded by quartz veins and dolerite dykes. Throughout the Craton are areas of Archaean migmatite and gneiss. These rocks are especially common along the western margin, as well as in the north-west where the Narryer Terrane and Yarlarweelor Gneiss Complex are located. The latter consists of migmatite, gneiss, schist and quartzite.

Areas of gneiss are associated with Archaean greenstone belts which are prominent. These belts have a north-west trend and become more common to the east. They contain a mixture of metamorphosed mafic to ultra-mafic volcanic rocks (including basalt, amphibolite, dolerite and gabbro), felsic volcanic rocks, and metasedimentary rocks (including cherts and banded iron formations).

This Archaean bedrock has been extensively weathered and laterised. Much is obscured by Tertiary and Quaternary alluvial, colluvial and aeolian deposits. In the south-western corner

(between Morawa and Three Springs) are the Neoproterozoic siltstone, quartzite, chert, sandstone and conglomerate of the Moora Group. In the north-west corner is the Neoproterozoic sandstone of the Badgeradda Group.

Landforms: Murchison Province consists of an extensive plateau of low relief. Laterite or silcrete mesas are usually found at the top of the landscape in areas of granitic basement. These mesas have lateritic breakaways, kaolinised footslopes (often saline) and are surrounded by gently sloping plains. There are also some low hills, domes and tor fields of granite, gneiss and quartz found in upper parts of the landscape.

The bulk of the terrain consists of gently undulating wash plains and sandplains sitting below the mesas and hills. Although wash plains are most common in the north-west, they occur throughout the province with the exception of its eastern margin. These wash plains consist of very gently inclined alluvial surfaces that carry sheet flows. Typically, an almost continuous cemented layer of red-brown hardpan has formed in these deposits. There are often small sandy banks and groves across the wash plains and gravelly mantles are sometimes present. Narrow saline drainage tracts may also be found.

Not all wash plains have red-brown hardpans, there are some sandy-surfaced and loamy wash plains. Other quartz-strewn plains and plains with stony and gravelly mantles and low rises are also present. These are often associated with low rises and may contain outcrops of granite, gneiss and schists.

Along the western margin the plateau has been dissected by the Greenough, Irwin and Lockier Rivers. Here is an undulating landscape with shallow valleys divided by stony ridges.

Extensive gently undulating sandplains (locally with reticulate or parallel sand dunes) are most common to the east of the province, dominating its eastern margin. In the north-west the sandplains tend to occur on top of the lateritic residuals. In the south-west there are level to gently undulating sand sheets with gravel mantles in lower parts of the landscape. Most of the sandplains have loamy plains associated with them.

The lowest point in the landscape is occupied by valley floors filled with Tertiary and Quaternary alluvium. In the north-west these take the form of broad, active floodplains along the course of the Murchison River and its tributaries. These saline and non-saline floodplains are very gently inclined and flank channelled watercourses. Red-brown hardpans and calcrete platforms may be present. Elsewhere, the valley floors tend to contain stagnant palaeo-drainage systems. In these valleys salt lakes fringe alluvial plains and dunes of kopi or sand.

In the greenstone belts there are rounded low hills and rocky ridges, with occasional lateritic breakaways and broad stony slopes. Some rugged ranges have also formed over the greenstone. Sandplains are not usually associated with greenstone, but hardpan wash plains and stony plains are commonly found downslope from the hills. Rises in ferruginous saprolite are often found on the stony plains.

Soils: On the wash plains there are Red loamy earths and Red-brown hardpan shallow loams, with some Red shallow loams. Red sandy earths and Red deep sands are found on sandy banks.

The sandplains have Red sandy earths and Red deep sands, with some Red loamy earths and Calcareous loamy earths in low lying areas. Yellow deep sands are found on the sandplains in the south-west.

On the mesas there are Red shallow loams, Red shallow sandy duplexes and Red shallow sands, with some Stony soils and Red/brown non-cracking clays also present. The hilly terrain has Red shallow loams, Stony soils and Red shallow sands, with some Bare rock and Red shallow sandy duplexes. The sandy soils tend to be more common on granitic hills. On the stony plains there are Red shallow loams with Red shallow sandy duplexes. Red shallow

sands occur on gritty plains over granite. Red-brown hardpan shallow loams, Calcareous loamy earths and Red loamy earths are also present.

On the valley floors there are Salt lake soils with some Red deep sands. Red deep sandy duplexes, Red/brown non-cracking clays, Red shallow sandy duplexes and Red-brown hardpan shallow loams are also present, especially on floodplains in the north-west. Calcareous shallow loams are found on the calcrete platforms.

Climate: The bioclimate is described by Beard (1990) as mainly Eremaean. This is a desert climate, commonly with 12 dry months a year. Most rainfall is in the 200-250 mm range. Typically there is an even chance of summer or winter precipitation, though there is a tendency to summer rain in the north where precipitation drops below 200 mm. To the south-west of Mt Magnet, where the rainfall rises to 300 mm, the province extends into a Sub-Eremaean bioclimate zone (semi-desert Mediterranean 9-11 dry months). In the far south-west (around Morawa), up to 400 mm rainfall is received and the bioclimate tends to Thermoxeric (extra dry Mediterranean climate with 7-8 dry months).

Vegetation: Mulga (*Acacia aneura*) shrublands and woodlands with gidgee (*A. pruinocarpa*), curara (*A. tetragonophylla*), *A. linophylla,* bowgada (*A. ramulosa*), jam (*A. acuminata*), minniritchie (*A. grasbyi*), Senna spp. and *Eremophila* spp. dominate the hardpan wash plains. Denser, taller mulga woodlands are found on groves while the sandy banks support mulga, bowgada and curara shrublands with an understorey of wanderrie grasses (*Eragrostis* and *Eriachne* spp. and *Monachather paradoxa*). Snakewood (*A. xiphophylla*), bluebush (*Maireana* spp.) and saltbush (*Atriplex* spp.) grow on the saline drainage tracts.

The sandplains in the east support grasslands of hard spinifex (*Triodia basedowii*). These grasslands occur with an open tree and shrub steppe of mulga, marble gum (*Eucalyptus gongylocarpa*), mallees (*E. kingsmillii*, *E. trichopoda*, *E. brachycorys* and *E. youngiana*), bowgada and spinifex wattle (*A. coolgardiensis*). In places denser woodlands of mulga, spinifex wattle or mallee are found over the spinifex. On western sandplains shrublands are dominated by bowgada with cypress pine (*Callitris columellaris*), mallees (e.g. *E. leptopoda* and *E. kingsmillii*), mulga and *Grevillea* spp. On the yellow sandplains in the south-west are closed mixed shrublands with *Melaleuca*, *Hakea*, *Calothamnus*, *Baeckea*, *Banksia prionotes*, *Allocasuarina*. and *Acacia* spp.

The mesas have bowgada, mulga and *A. linophylla* shrublands above the breakaways, while the footslopes support shrublands with saltbush (*Atriplex* spp.), *Frankenia* spp., *Ptilotus* spp. and *Eremophila pterocarpa*. The hilly terrain has shrublands of mulga, minniritchie, *Eremophila* spp. and cotton bush (*Ptilotus obovatus*). Hills in the far west have woodlands of York gum (*Eucalyptus loxophleba*), salmon gum (*E. salmonophloia*) and jam. The stony plains support shrublands of mulga, gidgee, granite wattle (*Acacia quadrimarginea*), minniritchie, prickly wattle, snakewood, jam and *Eremophila* spp.

On the valley floors there are shrublands of samphire (*Halosarcia* spp.), saltbush, sage (*Cratystylis subspinescens*) and *Frankenia* spp. surrounding salt lakes. Floodplains along the Murchison and its tributaries have shrublands of bluebush (*Maireana* spp.), saltbush and *Frankenia* spp., as well as mulga, prickly wattle and *Acacia distans*.

Component zones: The Murchison Province has been divided into seven soil-landscape zones (Figure 4.5g):

- Karrara Hills, Plains and Lakes Zone[46] is separated from the Yalgoo Plain and Irwin River Zones due to a preponderance of the *hills and ranges with acacia shrublands*, *low hills with eucalypt or acacia woodlands with halophytic undershrubs* and *sandy plains with acacia shrublands and wanderrie grasses* rangeland land types (Van Vreeswyk and Godden 1998). Greenstone is a prominent feature of the underlying geology (as opposed to the other two zones that are dominated by granite intrusions and gneiss);
- Irwin River Zone is based on the Irwin River Zone of Schoknecht *et al.* (2004) and has been separated from the Yalgoo Plain Zone where the *stony plains with acacia and halophytic shrublands* rangeland land type (Van Vreeswyk and Godden 1998) gives way to the *gritty-surfaced plains and granite tors and domes with acacia shrublands*. It correlates to the Woodrarrung Hills Section of Jennings and Mabbutt (1977);
- Upper Murchison Zone is based on the Murchison Plains geomorphic province of Mabbutt *et al.* (1963) and the central portion of Murchison Plateau Section of Jennings and Mabbutt (1977). It correlates with the bulk of the (northern) Upper Murchison and (eastern) Byro vegetation systems of Beard (1976) and is characterised by the *alluvial plains with halophytic shrublands*, *stony plains with acacia shrublands* and *wash plains and sandy banks on hardpan, with mulga shrublands and wanderrie grasses or spinifex* rangeland land types (Van Vreeswyk and Godden 1998);
- Yalgoo Plains Zone is separated from the Upper Murchison Zone due to a preponderance of the *gritty-surfaced plains and granite tors and domes with acacia shrublands*, *sandplains and occasional dunes with grassy acacia shrublands* and *wash plains on hardpan with mulga shrublands* rangeland land types (Van Vreeswyk and Godden 1998). It lies on the boundary between the Murchison and Salinaland Plateau Sections of Jennings and Mabbutt (1977);
- Leemans Sandplain Zone is based on the Leemans Sandplain Section of of Jennings and Mabbutt (1977). It lies on the intersection between the Great Victoria Desert vegetation system of Beard (1974b, 1975a) and the Yilgarn Craton tectonic unit of Tyler and Hocking (2001);
- Woodrarrung Hills and Plains Zone is based on the Badgeradda Group tectonic unit of Tyler and Hocking (2001) and correlates with the southern tip of the Byro vegetation system of Beard (1976); and
- Salinaland Plains Zone is based on the Salinaland Plains geomorphic province of Mabbutt *et al.* (1963) and the northern portion of Salinaland Plateau Section of Jennings and Mabbutt (1977). It correlates with the bulk of the Wiluna, Laverton and Barlee vegetation systems of Beard (1974b, 1975a, 1976) and has a preponderance of the *sandplains and occasional dunes with spinifex grasslands* rangeland land type (Pringle 1994, Van Vreeswyk and Godden 1998).

[46] The Karrara Zone lies within the Salinaland Plateau Section Jennings and Mabbutt (1977) and Yalgoo vegetation system of Beard (1976).

270 - Karrara Hills, Plains and Lakes Zone (9,325 km^2) **(850 km^2 covered by existing mapping)**	Hills and ranges, sandy plains, hardpan wash plains, stony plains and salt lakes (with some mesas and plains) on greenstone and granitic rocks of the Yilgarn Craton. Red shallow loams, Red loamy earths, Red deep sands and Salt lake soils with some Red shallow sands, Stony soils and Red shallow sandy duplexes. Bowgada-mulga-jam woodlands (with some halophytic shrublands and York gum-salmon gum woodlands). Located in the south-western Murchison between Morawa, Paynes Find and Yalgoo.
271 -Irwin River Zone (13,475 km^2) **(8,200 km^2 covered by existing mapping)**	Dissected plateau (with shallow valleys, stony ridges and sandplain remnants) on deeply weathered mantle, colluvium and alluvium over granite and gneiss of the Yilgarn Craton. Yellow and Red deep sands with Red shallow sands, Red-brown hardpan shallow loams and Red loamy earths and some Red shallow loams. Bowgada-jam shrublands and York gum woodland (with some acacia-casuarina thickets and halophytic shrublands). Located in the southern Murchison and Northern Wheatbelt between Three Springs, Wubin Yalgoo and Lake Nerramyne.
272 – Upper Murchison Zone (55,950 km^2)	Hardpan wash plains (with stony plains, sandplains, hills and mesas) on granite and gneiss of the Yilgarn Craton (Narryer Terrane and Murchison Domain). Red-brown hardpan shallow loams and Red shallow loams with Red loamy earths and Red deep and some Red shallow sands and Red deep sandy duplexes. Mulga shrublands (with some halophytic shrublands). Located in the north-western Murchison between Lake Nerramyne, Meekatharra, Cue and the Gascoyne River.
273 – Yalgoo Plains Zone (47,950 km^2)	Hardpan wash plains (with some sandplains, stony plains, mesas and granite outcrops) on granitic rocks (with some greenstone) of the Yilgarn Craton (Murchison Domain). Red loamy earths and Red shallow loams (often with hardpans) with Red deep sands and Red shallow sands and some Red shallow sandy duplexes. Mulga shrublands with bowgada shrublands (and some halophytic shrublands). Located in the south-western Murchison from Paynes Find to Cue and Twin Peaks Station.
274 – Leemans Sandplain Zone (42,825 km^2)	Sandplains (with some gravel plains, mesas and salt lakes) on granitic rocks of the Yilgarn Craton (Eastern Goldfields Superterrane). Red sandy earths with Red loamy earths and some Red deep sands, Red-brown hardpan shallow loams and Calcareous loamy earths. Spinifex grasslands with marble gum, mallee and mulga shrublands (and some halophytic shrublands). Located in the south-western Arid Interior between Lakes Wells and Minigwal (to the east of Laverton).
275 – Woodrarrung Hills and Plains Zone (2,900 km^2)	Sandplains and stony plans (with alluvial plains, hills and some salt lakes and hardpan wash plains) on sedimentary rocks of the Badgeradda Group. Red deep sands with Stony soils, Red shallow loams, Red shallow sandy duplexes and Red deep sandy duplexes. Bowgada-mulga shrublands with halophytic shrublands. Located in the Gascoyne between the Yallalong and Muggon Stations (to the west of Murchison Settlement).
279 – Salinaland Plains Zone (132,450 km^2)	Sandplains (with hardpan wash plains and some mesas, stony plains and salt lakes) on granitic rocks (and some greenstone) of the Yilgarn Craton. Red sandy earths, Red deep sands, Red shallow loams and Red loamy earths with some Red-brown hardpan shallow loams, Salt lake soils and Red shallow sandy duplexes. Mulga shrublands with spinifex grasslands (and some halophytic shrublands and eucalypt woodlands). Located in the northern Goldfields from Lakes Barlee and Ballard to Wiluna and Laverton.

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28 Fortescue Province

Hills and ranges (with stony plains and some alluvial plains and sandplains) on the volcanic, granitic and sedimentary rocks of the Pilbara Craton. Stony soils with Red loamy earths and Red shallow loams (and some Red/brown non-cracking clays, Red deep sandy duplexes and Red deep sands). Spinifex grasslands with kanji and snappy gum (and some mulga shrublands and tussock grasslands). Located in the Pilbara between Dampier, Port Hedland, Jigalong, Paraburdoo and Pannawonica.

Location and boundaries: Fortescue Province occupies about 160,050 km^2 (6.3% of WA). It is located in the northern Pilbara, sitting to the north of the Ashburton Province, west of the Officer and Paterson-Yeneena Provinces, and south of the Canning Province. Included are the towns of Port Hedland, Karratha, Dampier, Roebourne, Newman, Tom Price, Paraburdoo, Pannawonica, Marble Bar, Nullagine and Jigalong.

It is based on the Fortescue botanical district of Beard (1990). It equates with the northern potion of the Pilbara Province of Bettenay (1983), the De Grey Lowlands, Nullagine Hills, Chichester Range, Fortescue Valley and Hamersley Plateaux Sections of Jennings and Mabbutt (1977), and Pilbara IBRA region of Environment Australia (2000).

The boundary is based on the Pilbara Craton tectonic unit of Tyler and Hocking (2001). Excluded are the Sylvania Inlier (in the south-east of the Craton) and the Gregory Granitic Complex (on the eastern margin). Included are the Manganese Group of the Collier Basin and the southern tip of Wallal Embayment of Canning Basin (along Oakover River).

The eastern and south-eastern boundary more closely follows the boundary of the Fortescue botanical district than that of the tectonic units. The western portion of the Fortescue botanical district (underlain by the Carnarvon and Ashburton Basin tectonic units) has not been included.

The boundary runs north from Pannawonica to Cape Preston, then north-east along the Pilbara coastline (past Dampier and Port Hedland) to the mouth of the De Grey River. From here it swings south-east, past Goldsworthy (running to north of, but parallel to, the De Grey River) till it reaches Shay Gap. It then approximately follows the route of the Vermin Proof Fence south to Jigalong, before swinging west past Newman to Paraburdoo, north-west to Wyloo Station, and then north back to Pannawonica.

Geology: This province lies over the Pilbara Craton. In the north are the Archaean rocks of the East and West Pilbara Granite-Greenstone Terranes. Included in these terranes are granitoid rocks, basic and ultrabasic volcanic rocks, and acidic volcanic rocks. Also present in the north are the Archaean shale, siltstone and wacke and granitic intrusions of the Mallina Basin; the Archaean greywacke of the Mosquito Creek Basin; and the late Archaean-Palaeoproterozoic basalt and sandstone of the Marble Bar Sub-basin.

In the south the Pilbara Craton is dominated by the Hamersley Basin. In the north of the Hamersley Basin are the Archaean basalt, shale, sandstone, conglomerate, tuff and carbonate of the Northwest and Northeast Pilbara Sub-basins. These rocks are collectively known as the Fortescue Group and, with a narrow strip of banded iron formation, they make up the Chichester Ranges.

To the south, the Hamersley Range has formed on the late Archaean-Palaeoproterozoic metamorphosed banded iron formations, shales, dolerite, carbonate, chert and rhyolite of the South Pilbara Sub-basin. These rocks belong to the Hamersley Group and make up part of the Ophthalmia Fold Belt.

In the north-east, the Carboniferous-Permian sandstone of the Wallal Embayment of the Canning Basin is found along the Oakover River. In the south-east there are the Mesoproterozoic sandstones and shales of the Manganese Group (an outlier of the Collier Basin). Calcrete and ferruginous pisolite were deposited in the Tertiary along drainage lines,

most notably in the Fortescue Valley. Quaternary alluvial and aeolian deposits are found on the coast.

Landforms: Rocky hills and stony plains dominate. Rugged hills, ridges, dissected plateaux and mountains are found on the basalt, banded iron formation and sandstone of the Hamersley Basin. The most notable of these are the Chichester and Hamersley Ranges. Long stony footslopes and plains are often associated with these hills. On the Chichester Ranges, stony gilgai plains are found on the basaltic plateau surface.

On the granites of the East and West Pilbara Granite-Greenstone Terranes, there are hills, tors and domes with minor sandy plains. Stony plains are also a feature of this granitic terrain.

Along the coast there are bare tidal mudflats backed by low dunes. Behind these lie extensive alluvial plains that are bisected by a number of active floodplains. The alluvial plains have a mixture of sandy surfaces and gilgai flats. Broad sandy plains are also common on the coastal plains, while there are sandplains with occasional dunes in the upper reaches of the Fortescue River. Alluvial plains are also present along the Fortescue River. Hardpan wash plains are found in the Fortescue Valley and Hamersley Plateau and they often have a gravelly or stony surface.

Soils: Stony soils dominate the hilly terrain, where Red shallow loams and Red shallow sands also occur. Hard cracking clays are sometimes found on basaltic plateau surfaces. On the granitic stony plains there are Red shallow loams, Red deep sandy duplexes and Red sandy earths, while Red shallow loams and Red/brown non-cracking clays are found on the stony footslopes and plains beneath basaltic hills. Stony soils, Red deep sandy duplexes and Red loamy earths are also associated with the stony plains.

The alluvial plains have Red loamy earths, Red/brown non-cracking clays, Hard cracking clays, Self-mulching cracking clays, Red deep loamy duplexes and Red shallow sandy duplexes. Alluvial deposits of Red deep sands are found on river terraces and active floodplains. The Fortescue River alluvial plains have Red/brown non-cracking clays and Red loamy earths.

The sandy coastal plains have Red deep sandy duplexes and Red sandy earths, while Red deep sands dominate the upper Fortescue sandplains. Hardpan wash plains are characterised by Red loamy earths and Red-brown hardpan shallow loams. Tidal soils are found on the coast, while Calcareous shallow loams are associated with calcrete outcrops.

Climate: The bioclimate is described by Beard (1990) as Sub-Eremaean. This is a tropical semi-desert climate with 9-11 dry months a year. Mean annual rainfall is mostly in the 250-350 mm range, with a greater chance of summer falls. On the Chichester and Hamersley Ranges the rainfall increases to 400 mm. In the east and south it drops to 200 mm and becomes Eremaean (desert with 12 dry months and a greater chance of summer rainfall).

Vegetation: The most common vegetation of the hilly terrain and granitic stony plains is hard spinifex (*Triodia wiseana*) or soft spinifex (*T. pungens*) grassland with scattered emergent snappy gum (*Eucalyptus leucophloia*) and kanji (*Acacia inaequilatera*). Other spinifex which may be present include *T. basedowii*, *T. brizioides*, *T. lanigera*, *T. longiceps*, *T. epactia* and *T. plurinervata.* Hamersley bloodwood (*Corymbia hamersleyana*), *Acacia orthocarpa*, two-veined wattle (*A. bivenosa*), *A. pruinocarpa*, *A. ancistrocarpa*, *Senna glutinosa*, *Grevillea wickhamii* and *Hakea lorea* are among other tree and shrub species. The stony plains associated with basaltic and sedimentary hills support hard and soft spinifex grasslands and low mulga (*A. aneura*) woodlands.

The coastal alluvial plains have soft spinifex grasslands on the loamy soils while clay soils support tussock grasslands of Roebourne Plains grass (*Eragrostis xerophila*) with neverfail (*E. setifolia*), barley Mitchell grass (*Astrebla pectinata*), weeping grass (*Chrysopogon fallax*), swamp grass (*Eriachne benthamii*) and scattered snakewood (*Acacia xiphophylla*) and prickly wattle (*A. victoriae*). River gum (*Eucalyptus camaldulensis*) and coolabah (*E. victrix*)

woodlands with soft spinifex and buffel grass (*Cenchrus ciliaris*) understorey are found on the active floodplains.

The coastal sandy plains have hard and soft spinifex grasslands, while hard spinifex is found on the Fortescue sandplains. The hardpan wash plains support mulga woodlands and shrublands as well as spinifex grasslands.

Component zones: Fortescue Province contains 10 soil-landscape zones (Figure 4.5h):

- Nullagine Hills Zone falls within the eastern portion of the Nullagine Hills Section of Jennings and Mabbutt (1977). It correlates to a combination of the George Ranges vegetation system with the part of the Abydos Plain-Chichester system of Beard (1975b);
- De Grey-Roebourne Lowlands Zone is based on the De Grey Lowlands Section of Jennings and Mabbutt (1977) and the Coastal Plain geomorphic unit of Payne and Tille (1992). It correlates to the Abydos Plain vegetation system of Beard (1975b), though it extends onto the Abydos Plain-Chichester system;
- Chichester Ranges Zone is based on the Chichester Plateau vegetation system of Beard (1975b). It includes the Chichester Range Section of Jennings and Mabbutt (1977), but extends to the portion of their Nullagine Hills Section that is underlain by the Hamersley Basin tectonic unit of Tyler and Hocking (2001);
- Abydos Plains and Hills Zone is based on those portions of the East Pilbara Granite-Greenstone Terrane tectonic unit of Tyler and Hocking (2001) on which granitic rocks dominate. It falls mostly within the De Grey Lowlands Section of Jennings and Mabbutt (1977) and the Abydos Plain-Chichester vegetation system Beard (1975b);
- Fortescue Valley Zone is based on the Fortescue Valley Section of Jennings and Mabbutt (1977) and the Fortescue Valley vegetation system of Beard (1975b);
- Hamersley Plateaux Zone is based on the Hamersley Plateaux geomorphic province of Payne *et al.* (1988), the South Pilbara Sub-basin tectonic unit of Tyler and Hocking (2001); the Hamersley Plateau Section of Jennings and Mabbutt (1977) and the Hamersley vegetation system of Beard (1975b);
- Karratha Coast Zone is the equivalent of the Onslow Plain Section that Jennings and Mabbutt (1977) mapped further to the south, though they did not separate these coastal flats from their De Grey Lowlands Section.
- the Warrawagine Hills Zone sits on the eastern edge of the Nullagine Hills Section of Jennings and Mabbutt (1977). It has been separated from the Nullagine Hills Zone due to the preponderance of the *plateaux, mesas and breakaways with spinifex grasslands* rangeland land type, as opposed to the *hills and ranges with spinifex grasslands* that are found to the west (Van Vreeswyk *et al*. 2004a);
- Jigalong Plains Zone is based on the south-east protrusion of Nullagine Hills Section of Jennings and Mabbutt (1977) and is situated where the Manganese Group Sub-basin tectonic unit of Tyler and Hocking (2001) intersects with the Fortescue Valley vegetation system of Beard (1975b)[47]; and
- Harding Hills and Plains Zone represents a transition between the De Grey Lowlands and Nullagine Hills Sections of Jennings and Mabbutt (1977), having a mosaic of hilly and coastal plains. It forms the core of the Transition Zone geomorphic unit of Payne and Tille (1992).

[47] With its alluvial plains and sandplains, the Jigalong Plains Zone actually has as much in common with the Fortescue Valley Section as the Nullagine Hills Section. It represents a transition between the Fortescue Valley and Little Sandy Desert Zones.

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Figure 4.5h: Soil-landscape zones of the Fortescue Province

280 – Nullagine Hills Zone (17,650 km^2)	Hills and ranges (with some stony plains) on volcanic and sedimentary rocks of the Pilbara Craton (including the Hamersley Basin). Stony soils with Red shallow loams and sands. Spinifex grasslands with kanji and snappy gum. Located in the north-eastern Pilbara around Marble Bar and Nullagine.
281 – De Grey-Roebourne Lowlands Zone (19,350 km^2)	Alluvial plains and sandplains (and some floodplains and stony plains) on alluvial and marine deposits over rocks of the northern Pilbara Craton. Red deep sandy duplexes with Red loamy earths and some Red/brown non-cracking clays, Cracking clays, Red sandy earths and Red deep loamy duplexes. Spinifex grasslands with kanji and tussock grasslands. Located in the northern Pilbara between Karratha and the De Grey River.
282 – Chichester Ranges Zone (18,300 km^2)	Hills and dissected plateaux (with some stony plains) on basalt and sedimentary rocks of the Hamersley Basin. Stony soils with some Red shallow loams and Hard cracking clays. Spinifex grasslands with kanji and snappy gum (and some tussock grasslands). Located in the northern Pilbara between Pannawonica and Nullagine.
283 – Abydos Plains and Hills Zone (15,900 km^2)	Stony plains (with some hills) on granitic rocks of the Pilbara Craton (East Pilbara Terrane). Red deep sandy duplexes and Red shallow loams with Stony soils, Red sandy earths and Red loamy earths. Spinifex grasslands with kanji (and some tussock grasslands). Located in the northern Pilbara between Yandeyarra Community, Bamboo Springs Station and Marble Bar.

284 – Fortescue Valley Zone (15,300 km^2)	Alluvial plains, hardpan wash plains and sandplains (with stony plains, floodplains and some salt lakes) on alluvial deposits over sedimentary rocks of the Hamersley Basin. Red deep sands, Red loamy earths and Red/brown non-cracking clays with some Red shallow loams and Hard cracking clays. Mulga shrublands and spinifex grasslands (with some tussock grasslands and halophytic shrublands). Located in the Pilbara along the Fortescue River between Millstream National Park and Ethel Creek Station.
285 – Hamersley Plateaux Zone (44,450 km^2)	Hills and dissected plateaux (with some stony plains and hardpan wash plains) on sedimentary and volcanic rocks of the Hamersley Basin (Opthalmia Fold Belt). Stony soils with Red shallow loams and some Red/brown non-cracking clays and Red loamy earths. Spinifex grasslands with snappy gum and kanji (and some mulga shrublands). Located in the Pilbara between Pannawonica, Newman and Paraburdoo.
286 – Karratha Coast Zone (2,150 km^2)	Coastal mudflats (with sandy coastal plains and some hills) on marine deposits (and some sedimentary and volcanic rocks of the Pilbara Craton). Tidal soils with some Calcareous loamy earths, Salt lake soils and Red/brown non-cracking clays. Bare mudflats (with some spinifex, tussock grasses, samphire and mangroves). Located along the Pilbara coast between Cape Preston and the De Grey River.
287 – Warrawagine Hills Zone (15,050 km^2)	Mesas, hills and stony plains on volcanic and sedimentary rocks of the eastern Hamersley Basin. Stony soils and Red shallow loams with some Red shallow and deep sands, Calcareous shallow loams and Red loamy earths. Spinifex grasslands with acacia shrubs (and some mulga shrublands and eucalypts). Located in the eastern Pilbara along the Oakover River between Noreena Downs and Warrawagine Stations.
288 – Jigalong Plains Zone (4,700 km^2)	Alluvial plains, sandplains, hills and ranges (with floodplains and hardpan wash plains) on sedimentary rocks of the Manganese Group (with some basalt and granite). Red deep sands with Red/brown non-cracking clays, Red loamy earths, Red deep sandy and loamy duplexes, Stony soils and Red shallow loams. Mulga woodlands/shrublands with spinifex and tussock grasslands. Located in the eastern Pilbara between Jigalong, Ethel Creek and Balfour Downs.
289 – Harding Hills and Plains Zone (7,200 km^2)	Hills and ranges with (stony plains and some alluvial and flood plains) on sedimentary, granitic and volcanic rocks of the northern Pilbara Craton. Stony soils with Red/brown non-cracking clays and Red shallow loams and some Hard cracking clays. Spinifex grasslands with kanji and snappy gum (and some tussock grasslands). Located in the northern Pilbara between Karratha, Whim Creek and Yandeyarra Community.

29 Ashburton Province

Hills and ranges (with stony plains and hardpan wash plains) on the sedimentary and granitic rocks of the Capricorn Orogen. Stony soils with Red loamy earths, Red shallow loams and Red-brown hardpan shallow loams (and some Red deep sands, Red/brown non-cracking clays and Red deep sandy duplexes). Mulga woodlands and shrublands with snakewood (and some spinifex grasslands and halophytic shrublands). Located in the southern Pilbara/ northern Gascoyne between Nanutarra, Jigalong, Gascoyne River, Wiluna and Lake Carnegie.

Location and boundaries: Ashburton Province occupies about 188,375 km^2 (7.5% of WA). It covers the southern Pilbara and north-western Gascoyne as well as extending into the north-eastern Goldfields. It lies south of the Fortescue Province, north of the Murchison Province, east of the Exmouth and Carnarvon Provinces and west of the Officer and Gunbarrel Provinces. Apart from numerous station homesteads, the only settlements are Mundiwindi and Burringurrah communities, Mt Augustus Tourist Resort and Kumarina Roadhouse.

It straddles the boundaries between the Pilbara and Murchison Provinces of Bettenay (1983) and the Pilbara, Sandland and Yilgarn Plateau Provinces of Jennings and Mabbutt (1977).

The boundary is based on the Capricorn Orogen tectonic unit of Tyler and Hocking (2001). Included is the Sylvania Inlier of the Pilbara Craton. The boundary is also closely aligned with the boundary of the Ashburton botanical district of Beard (1990), with the inclusion of the Stewart Hills vegetation system of Beard (1975b).

The boundary extends south-east from Pannawonica (along the North West Coastal Highway) to Nanutarra, then south past Lyndon to the Gascoyne River (near Mooloo Downs). From here it heads east, passing to the south of Landor Station before swinging south-east near Yarlarweelor Station, and continuing past Meekatharra to Wiluna. It then turns northwards to Lake Gregory, before swinging south-east to Lake Wells, north to Lake Carnegie, and north-west to Ten Mile Lake (located east of Kumarina Roadhouse on the Great Northern Highway). From here it heads north-west to Jigalong, then west past Newman to Paraburdoo, swings north-west to Wyloo Station, and finally north back to Pannawonica.

Geology: Ashburton Province is developed on a number of sedimentary basins that form the suture line between the Pilbara and Yilgarn Cratons. These basins were later affected by the Capricorn Orogen as the Pilbara and Yilgarn Cratons collided. In the north-west are the Palaeoproterozoic sandstone, carbonate, basalt, shale and conglomerate of the Ashburton Basin. Associated with this is the Palaeoproterozoic sandstone of the Mount Minnie and Blair Basins. In the north-east are the Archaean granitic rocks of the Sylvania Inlier. Between these lie the Palaeoproterozoic sandstone and conglomerate of the Bresnahan Basin.

Further south (running across much of the centre of the orogen) are the Mesoproterozoic sandstone, shale and carbonate (with dolerite, gabbro and ultrabasic intrusions) of the Edmund and Collier Basins. In the west and the south-west of the Orogen are the Palaeoproterozoic granite intrusions, gneiss and sedimentary rocks of the Gascoyne Complex.

To the centre of the south are the Palaeoproterozoic sandstone, shale, greywacke, conglomerate and basalt of the Padbury, Bryah and Yerrida Basins. Between these and the Collier Basin are located the Archaean granite and gneiss of the Marymia Inlier. The south-east extension of the Province is dominated by the Palaeoproterozoic sandstone, carbonate, banded iron formation and shale of the Earaheedy Basin.

Eocene deposits of calcrete and partially consolidated colluvium are found along the Ashburton and Gascoyne Rivers along with Quaternary alluvial deposits. Similar deposits occur around Lake Carnegie in the east.

Landforms: Much of the Ashburton Province is comprised of a mosaic of hilly terrain and stony plains. Rugged ranges, hills, ridges and plateaux are found on the sedimentary rocks of the Ashburton, Edmund and Collier Basins. There are also rugged hills and ridges on the schist, gneiss, granite and quartz on the Gascoyne Complex. Undulating stony uplands and plains are often associated with these hills, having formed over similar parent materials. There are also some basalt hills, as well as mesas capped with laterite, silcrete and calcrete.

Downslope from the hilly terrain, there are extensive flat and gently sloping plains on depositional surfaces in which red-brown hardpan has formed. These wash plains typically have a pattern of groves and inter-groves, and they are sometimes covered with a surface mantle of gravel or stones. Sandy banks are also common in places. Hills, hardpan wash plains and stony plains have also formed on the sedimentary rocks of the Edmund, Earaheedy, Yerrida, Bryah and Padbury Basins.

Sandplains, sometimes with linear dunes, are a relatively minor component of the landscape. They are scattered throughout the province but are most common near the margins. Alluvial plains and floodplains are associated with the Ashburton and Gascoyne Rivers. Restricted areas of low calcrete platforms and plains are found throughout the province, being most common in the Gascoyne Valley. Salt lakes are only really a significance feature in the south-east.

Soils: Stony soils dominate the hilly terrain, with some Red loamy earths, Red shallow loams, Red shallow sands and Red shallow loamy duplexes being also present. On the stony plains there are Red shallow loams, Red/brown non-cracking clays, Red loamy earths and Red deep sandy duplexes. The hardpan wash plains have Red loamy earths and Red-brown hardpan shallow loams, with some Red shallow loams, Red deep sands and Red shallow sandy duplexes.

Red deep sands, Red sandy earths and Red deep sandy duplexes are found on the sandplains. The alluvial plains have Red loamy earths, Calcareous loamy earths and Red deep sands while Calcareous shallow loams are found on the calcrete plains.

Climate: The bioclimate of the Ashburton Province is described by Beard (1990) as Eremaean. This is a desert climate commonly with twelve dry months a year. Mean annual rainfall is mostly in the 200-250 mm range, with a greater chance of summer rain in the north and an even chance of summer or winter rain in the south. The bioclimate tends towards Sub-Eremaean in both the north (tropical semi-desert with 9-11 dry months and rainfall of up to 350 mm) and south-west (Mediterranean semi-desert with 9-11 dry months) of the region.

Vegetation: The most common vegetation of the hilly terrain is sparse shrublands of mulga (*Acacia aneura*). Other shrubs include curara (*A. tetragonophylla*), gidgee (*A. pruinocarpa*), kanji (*A. inaequilatera*), *A. linophylla*, *A. eremea*, *A. kempiana*, flannel bush (*Solanum lasiophyllum*) and *Eremophila* spp. In the north, these acacia shrublands are often found in association with hard spinifex (*Triodia wiseana* and *T. lanigera*) grasslands. Soft spinifex (*T. pungens*) grasslands are also present in places.

Similar mulga shrublands are found on the stony plains, along with shrublands of snakewood (*A. xiphophylla*). Also present on stony plains are prickly wattle (*A. victoriae*), minnirichi (*A. rhodophloia*), *Senna* spp., poverty bushes (*Eremophila* spp.), cottonbush (*Ptilotus obvatus*), ruby saltbush (*Enchylaena tomentosa*) and tall saltbush (*Rhagodia eremaea*).

On the hardpan wash plains, sparse mulga shrublands are found on the intergrove areas with dense mulga shrublands or woodlands in the groves. Other species present are similar to those found on the snakewood shrublands of the stony plains. Wanderrie grasses, such as *Eriachne* spp. and *Monochather paradoxa*, are found on sandy banks.

Hard and soft spinifex grasslands, sometimes with scattered kanji, mulga and other acacias, are found on the sandplains. The alluvial plains support a variety of vegetation including shrublands of prickly and other acacias, saltbush (*Atriplex bunburyana*) and bluebush (*Maireana pyramidata*) shrublands, *Senna* spp. and *Eremophila* spp. shrublands, and tussock grasslands of buffel grass (*Cenchrus ciliaris*) with coolabah (*E. victrix*) and river gums (*E. camaldulensis*). Samphire (*Halosarcia* spp.) is associated with the salt lakes.

Component zones: Ashburton Province has been divided into nine soil-landscape zones (Figure 4.5i):

- Bulloo Plains and Hills Zone is based on the Eastern Plains geomorphic province of Payne *et al.* (1988). It correlates with the Kumarina Hills vegetation system of Beard (1975b) while straddling the boundary between the Augustus Ranges and Stanley Hills and Dunes Sections of Jennings and Mabbutt (1977);
- South Bangemall Hills Zone[48] is based on the Bangemall geomorphic province of Wilcox and McKinnon (1972) while falling within the Augustus Ranges Section of Jennings and Mabbutt (1977);
- Frere Uplands Zone is based on the North Eastern Uplands geomorphic province of Mabbutt *et al.* (1963) and the Earaheedy Basin tectonic unit of Tyler and Hocking (2001). It incorporates the Carnegie Hills Section and southern Stanley Hills and Dunes Section of Jennings and Mabbutt (1977);
- Paroo Uplands Zone is based on the Eastern Uplands geomorphic province of Wilcox and McKinnon (1972), the Central Uplands geomorphic province of Mabbutt *et al.* (1963) and the Yerrida, Padbury and Bryah Basin tectonic units of Tyler and Hocking (2001). It incorporates the Glengarry Hills Section (and parts of the Augustus Ranges and Murchison Plateau) of Jennings and Mabbutt (1977);
- Yaragner Hills and Plains Zone is based on a combination of the Maroonah Plains geomorphic province of Payne *et al.* (1988), the northern part of the Archaean geomorphic province of Wilcox and McKinnon (1972) and the Towera Stony Plains and Lyndon Proterozoic Hills geomorphic districts of Payne *et al.* (1987). It corresponds to the Gascoyne Complex tectonic unit of Tyler and Hocking (2001) and falls within the Murchison Plateau Section of Jennings and Mabbutt (1977);
- Gascoyne Valley Zone is based on the Eastern Tributary geomorphic province of Wilcox and McKinnon (1972). It straddles the boundary between the Augustus Ranges and Murchison Plateau Sections of Jennings and Mabbutt (1977);
- Stuart Plains and Hills Zone is based on the Stuart Hills geomorphic province of Payne *et al.* (1988) and the Stewart Hills vegetation system of Beard (1975b). It falls within the Augustus Ranges Section of Jennings and Mabbutt (1977);
- Ashburton Valley Zone is based on the Ashburton Valley geomorphic province of Payne *et al.* (1988). It correlates to the Ashburton Valley vegetation system of Beard (1975b) and the southern portion of the Ashburton Basin tectonic unit of Tyler and Hocking (2001), while falling within the Augustus Ranges Section of Jennings and Mabbutt (1977); and
- North Bangemall Hills Zone is based on the Bangemall geomorphic province of Payne *et al.* (1988). It falls within the Augustus Ranges Section of Jennings and Mabbutt (1977).

[48] The South Bangemall zone is differentiated from the North Bangemall because hardpan wash plains are a major component of the former but are relatively rare in the latter.

290 - Bulloo Plains and Hills Zone (29,325 km^2)	Hardpan wash plains, stony plains, hills and ranges (with some sandplains) on sandstone and shale of parts of the Collier and Bresnahan Basins and granite of the Sylvania Inlier. Red shallow loams (often with hardpans), Red loamy earths, Stony soils and Red deep sands with some Red shallow sands. Mulga shrublands (with some spinifex grasslands). Located in south-eastern Pilbara between Newman, Jigalong and Three Rivers (Upper Gascoyne).
291 - South Bangemall Hills Zone (12,200 km^2)	Hardpan wash plains (with hills, ranges and stony plains) on sedimentary rocks of the Edmund Basin. Stony soils, Red loamy earths and Red/brown non-cracking clays with some Red shallow loams and Red deep sands. Mulga shrublands with snakewood (and some halophytic shrublands). Located in the northern Gascoyne between Maroonah Station and the Gascoyne River.
292 - Frere Uplands Zone (32,875 km^2)	Hills, hardpan wash plains and salt lakes (with some sandplains and stony plains) on sedimentary rocks of the Earaheedy Basin. Red-brown hardpan shallow loams, Red shallow loams, Salt lake soils, Red loamy earths, Stony soils and Calcareous loamy earths. Mulga shrublands with samphire flats (and some spinifex grasslands). Located in northern Wiluna district between Lakes Gregory and Carnegie.
293 - Paroo Uplands Zone (21,175 km^2)	Hills, hardpan wash plains and stony plains (with sandplains) on Yerrida, Bryah and Padbury Basins sedimentary rocks and Marymia Inlier granitic and volcanic rocks. Red-brown hardpan shallow loams with Red loamy earths and Stony soils and some Red shallow sands, Red shallow loams, Red sandy earths and Red deep sands. Mulga shrublands (with some spinifex, eucalypts and halophytic shrubs). Located in the North-eastern Goldfields between Meekatharra, Wiluna and Kumarina Roadhouse (Great Northern Highway).
294 – Yaragner Hills and Plains Zone (27,425 km^2)	Undulating stony uplands, stony plains, hills and ranges on Gascoyne Complex granitic and sedimentary rocks. Stony soils with Red shallow loamy duplexes with Red deep sandy duplexes and Red shallow loams and some Red shallow sandy duplexes and Red/brown non-cracking clays. Mulga-snakewood-prickly wattle shrublands (with some spinifex grasslands and halophytic shrublands). Located in the northern Gascoyne between Nanutarra and the Gascoyne River (Landor Station).
295 – Gascoyne Valley Zone (16,575 km^2)	Hardpan wash plains (with hills, stony plains and some calcrete plains and floodplains) on alluvial deposits over gneiss and volcanic rocks of the southern parts of the Gascoyne Complex and Edmund and Collier Basins. Red-brown hardpan shallow loams with Red deep sands, Red shallow sandy duplexes and Red loamy earths and some Red/brown non-cracking clays and Stony soils. Mulga shrublands (with some wanderrie grasses and chenopods). Located in the Upper Gascoyne between Landor Station and the Great Northern Highway.
296 - Stuart Plains and Hills Zone (11,375 km^2)	Hills, ranges, stony plains and sandplains on sedimentary rocks (with some granite) of the northern Ashburton Basin and Gascoyne Complex. Stony soils and Red deep sandy duplexes with Red loamy earths and Red shallow loams and some Red sandy earths. Spinifex grasslands with snakewood and kanji. Located in the northern Gascoyne from the Robe River to Nanutarra.
298 – Ashburton Valley Zone (15,725 km^2)	Hills and ranges (with some floodplains and stony plains) on sandstone, shale and conglomerate of the Ashburton Basin. Stony soils with Red loamy earths and Red shallow loams. Mulga-snakewood shrublands with mixed scrub and spinifex grasslands (and some halophytic shrubs and tussock grasses). Located in the southern Pilbara along the Ashburton River between Nanutarra, Paraburdoo and Turee Creek Station.

299 – North Bangemall Hills Zone (21,675 km^2)	Hills, ranges and plateaux (with some stony plains) on sandstone, shale and volcanic rocks of the Edmund and Collier Basins. Stony soils with some Red loamy earths and Red shallow loams. Mulga-snakewood shrublands (with some spinifex grasslands). Located in southern Pilbara (south of the Ashburton) from Glen Florrie Station to Tangadee Station.

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3 Kimberley Region

Hills, ranges and plateaux (with undulating plains and uplands and some alluvial plains and sandplains) on the rocks of the Kimberley Basin and King Leopold and Halls Creek Orogens. Stony soils with Red deep sands and Yellow deep sands and some Red and Yellow loamy earths, Red and Yellow sandy earths and Self-mulching cracking clays. Eucalypt woodlands with spinifex and tall grasses (and some pindan shrublands, spinifex grasslands and tussock grasslands). Located in northern WA between Broome, Wolfe Creek and Lake Argyle.

Location and boundaries: The Kimberley occupies 9.9% of WA (about 250,200 km^2). This includes most of the north of the State, except for a narrow strip along the Northern Territory border. It lies north of the Sandy Desert Region and west of the North Australian Plateaux Region.

Kimberley Region is based on the Kimberley Province of Jennings and Mabbutt (1977), but also includes the Dampier Tableland Section of the Sandland Province. It correlates to the western portion of the Kimberley-Arnhem-Cape York Region described by Isbell (1983), extending onto the Ayres-Canning Province of the Great Sandy Desert Region between Derby and Broome.

The southern boundary extends from Broome east to Bohemia Station and Wolfe Creek. It then extends northwards to Lake Argyle and the Carr Boyd and Cockburn Ranges, then onto the eastern shore of the Joseph Bonaparte Gulf before following the Kimberley coastline back to Broome. Besides Broome, towns include Derby, Fitzroy Crossing, Halls Creek and Warmun.

Geology: The northern and central portion is dominated by the unfolded Palaeoproterozoic sandstone, siltstone, shale, mudstone and basalt of the Kimberley Basin. Running in an inverted arc to the south of the basin are the deformed Proterozoic granitic, sedimentary and volcanic rocks of the King Leopold and Halls Creek Orogens. In the south and south-west are the Devonian to Triassic sandstone, shale, siltstone and limestone of the Lennard Shelf and Fitzroy Trough (northern Canning Basin).

Landforms: In the north is a rugged, dissected plateau on the sandstone and basalt of the Kimberley Basin. Running in an inverted arc to the south of the basin there are rugged hills and ranges formed on the folded rocks of the King Leopold and Halls Creek Orogens. In the south and south-west there are sandplains and alluvial plains (with some hills) overlying the sedimentary rocks of the Canning Basin.

Soils: Stony soils dominate the plateaux and ranges. Yellow deep sands, Yellow sandy earths and Yellow loamy earths also occur on the plateau surfaces. Red deep sands, with some Yellow sandy earths and Red sandy earths, are found on the southern sandplains. Red loamy earths are associated with basaltic terrain. Self-mulching cracking clays and Red/brown non-cracking clays are found on the alluvial plains, with Yellow sandy earths.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate, with 7-8 dry months in winter. Mean annual rainfall is mostly 400-1000 mm, but increases to 1450 mm in the north-west. In the south, the bioclimate becomes Sub-Eremaean, a tropical semi-desert with 9-11 dry months and rainfall as low as 350 mm.

Vegetation: The northern and central portions are dominated by eucalypt savanna woodlands with tall grasses and spinifex. Tree species include stringybark (*Eucalyptus tetrodonta*), woollybutt (*E. miniata*), snappy gum (*E. brevifolia*), grey box (*E. tectifica*), cabbage gum (*E. grandiflora*) and bloodwoods (*Corymbia* spp.). Grass species include upland tall grass (*Sorghum stipoideum*), curly spinifex (*Triodia bitextura*), hard spinifex (*T. intermedia* and *T. wiseana*) and white grass (*Sehima nervosum*).

The sandplains of the south-west support a pindan shrubland with *Acacia tumida, A. eripoda,* other acacias, grey box and bloodwoods over an understorey of ribbon grass

(*Chrysopogon* spp.), curly spinifex and soft spinifex (*T. pungens*). On the alluvial plains of the Fitzroy and Lennard Rivers is a tall bunch grass savanna of Mitchell grass (*Astrebla* spp.), blue grass (*Dichanthium fecundum*) and ribbon grass, with bauhinia (*Bauhinia cunninghamii*), coolibah (*E. microtheca*), ghost gum (*E. papuana*) and *Acacia suberosa*.

Component provinces: Kimberley Region has been divided into three soil-landscape provinces (Figure 4.6):

- Southern Kimberley Ranges Province (31) overlying the folded rocks of the King Leopold and Halls Creek Orogen tectonic units of Tyler and Hocking (2001) in the middle;
- Fitzroy Province (33[49]) overlying the sedimentary rocks of the Canning Basin tectonic unit of Tyler and Hocking (2001) in the south; and
- Kimberley Plateau Province (34) overlying the unfolded sedimentary rocks of the Kimberley Basin tectonic unit of Tyler and Hocking (2001) in the north.

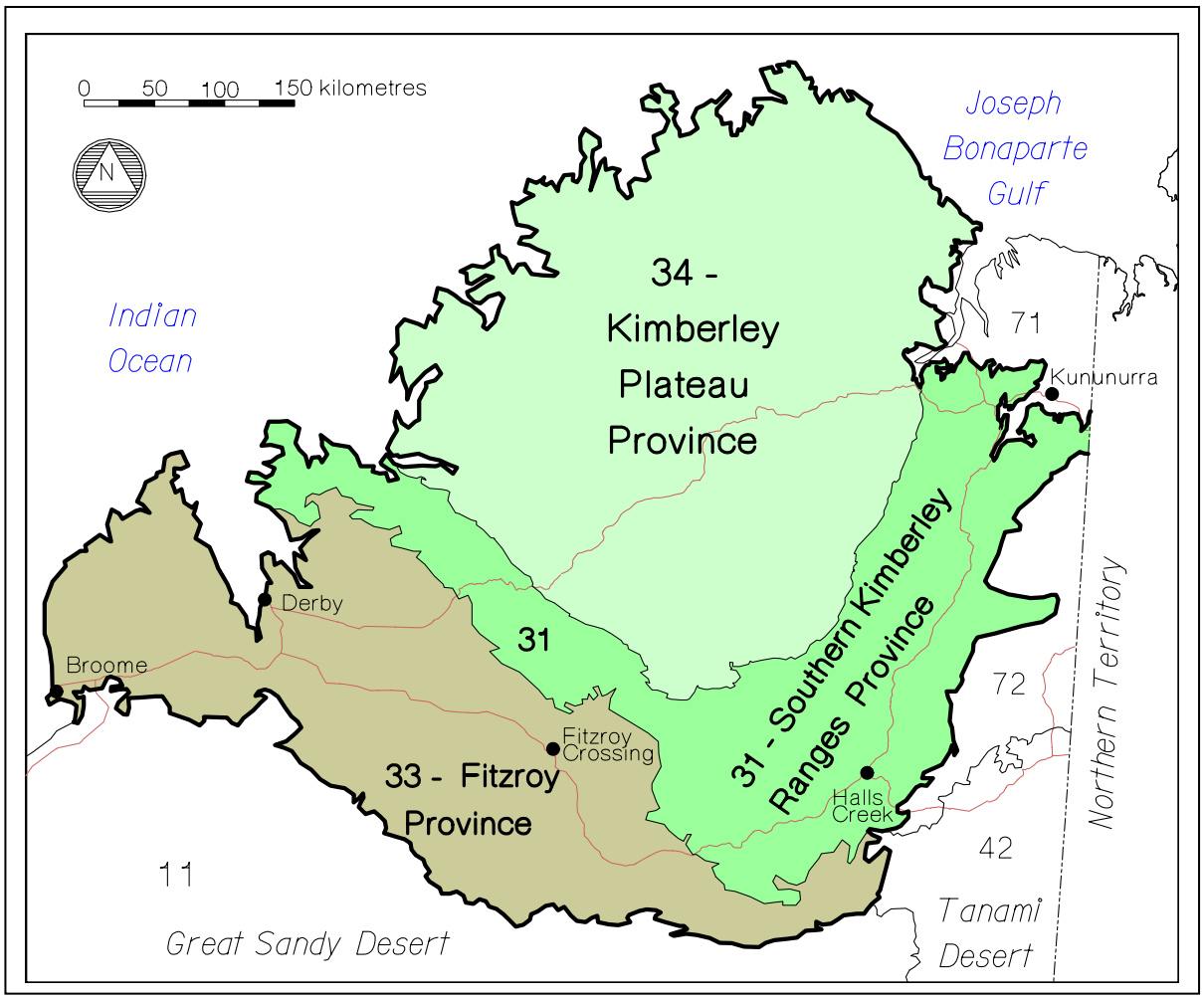

Figure 4.6: Soil-landscape provinces of the Kimberley Region

[49] Currently there is no province allocated to the hierarchy code 32.

Grassy eucalypt savanna in the Kimberley (N Schoknecht)

Kimberley rock hole (N Schoknecht)

31 Southern Kimberley Ranges Province

Hills, ranges and plateaux (with some undulating plains and lowlands) on the granitic, volcanic and sedimentary rocks of the King Leopold and Halls Creek Orogens. Stony soils with some Red deep sands, Red/brown non-cracking clays and Yellow loamy earths. Eucalypt woodlands with spinifex and mixed grasslands. Located in the Kimberley, extending from the Yampi Peninsula south-east to Louisa Downs Station and then north-east through Halls Creek to Lake Argyle.

Location and boundaries: Southern Kimberley Ranges Province occupies about 63,600 km^2 (2.5% of WA). It is between the Fitzroy and Kimberley Plateau Provinces and west of the Ord-Victoria Plateau Province.

The Southern Kimberley Ranges form an inverted arc in the central and southern Kimberley, extending from the Yampi Peninsula south-east to Louisa Downs Station and then north-east to Lake Argyle. The province continues a few kilometres into the Northern Territory, just north-east of Lake Argyle. It includes the towns of Halls Creek and Warmun as well as the King Leopold, Durack and Carr Boyd Ranges.

The province is based a combination of the Yampi Peninsula, King Leopold Ranges, North-eastern Mountain Ranges, Eastern Ranges and Eastern Uplands geomorphic provinces of Wright (1964) and the Halls Creek Ridges geomorphic sub-region of Patterson (1970). It correlates to the Yampi Peninsula, Richenda Foothills, Springvale Foothills, Hall Creek Ridges and Leopold-Durack Ranges Sections of Jennings and Mabbutt (1977).

The northern boundary follows the northern boundaries of Wright's Kimberley Foreland geomorphic province, while the southern boundary follows the southern edge of his North-east Mountain Ranges and Eastern Ranges geomorphic regions. In the east the boundary is similar to that of Patterson's Hall Creek Ridges geomorphic sub-region. The boundary with the eastern edge of the Kimberley Plateau Province approximates the western margin of the Durack Fold Belt tectonic unit of Tyler and Hocking (2001)[50] and the eastern boundary of the Karunjie Plateau–Fitzgerald vegetation system of Beard (1979).

The boundary extends from Home Valley Station (at the head of the West Arm of the Cambridge Gulf) east along the foot of the Cockburn Range to Ivanhoe Station. From here it heads south (taking in the flats of the Dunham River) as far as Sugarloaf Hill before doubling back along the foot of the Carr Boyd Range and swinging west to cross the Northern Territory border near the Victoria Highway. It only extends a short distance into the Territory before returning into Western Australia and cutting down the middle of Lake Argyle before heading south to Texas Downs station. From here it turns east before doubling back around Mt Deception and heading south-west along Osmond Creek to Bungle Bungle Outcamp. It then swings south to Ruby Plains Station, crossing Duncan Road near Fox River, and follows the foot of the McClintock range south-west before swinging west along the course of Christmas Creek, cutting across to the Louisa River near Larrawa Station. From here it heads north along the foot of the Mueller Range to the Leopold River, then north-west past Leopold Downs Station (and along the northern edge of the Oscar and Napier Ranges) to Oobagooma Station. It follows the coastline of the Yampi Peninsula north and then east to the southern shore of Walcott Inlet. From here it strikes south-east (running between the King Leopold and Precipice Ranges and past Mornington Station) until it reaches Landsdowne Station, from where it swings north-east along the base of the Durack Range to Bedford Downs Station. It then follows the Pentecost River (flowing at the base of the Elgee Cliffs) north back to Home Valley Station. Included are the islands of the Yampi Peninsula.

Geology: The Southern Kimberley Ranges have formed on the deformed Proterozoic rocks of the King Leopold and Halls Creek Orogens.

[50] It also approximates the western edge of the Bastion Basin.

The western half overlies the Palaeoproterozoic King Leopold Orogen. In the far west of this Orogen, and along its northern margin, are the folded sandstone, siltstone, mudstone, basalt, dolerite and granophyre of the Kimberley and Speewah Basins. These make up part of the Precipice-Yampi Fold Belts. Most of Orogen comprises granitoid rocks, porphyry, meta-sandstone, phyllite, rhyolite and tuff of the Hooper Complex.

The eastern half overlies the Halls Creek Orogen. This includes the Durack Fold Belt in the north-west, also containing the Palaeoproterozoic sediments of the Kimberley and Speewah Basins. The south-eastern portion of the Orogen is dominated by the Palaeoproterozoic monzogranite, granodiorite, granulite, porphyry and metamorphosed basalt, mudstone, siltstone, sandstone and carbonate rock of the Lamboo Complex. To the south, the Neoproterozoic siltstone, sandstone, conglomerate, shale, dolomite, limestone and tillite of the Louisa Basin form part of the Precipice-Yampi Fold Belts. To the east, the Neoproterozoic siltstone, mudstone, sandstone, dolomite, and conglomerate of the Wolfe Creek Basin form part of the Hardman Fold Belt. To the north-east, the Orogen includes some Mesoproterozoic sandstone, siltstone and mudstone of the Carr Boyd Basin, Phanerozoic sediments of the Southern Bonaparte Basin, and Mesoproterozoic sediments and volcanics of the Osmond Basin.

To the north of the Halls Creek Orogen this province extends onto the sandstones of the Kimberley and Bastion Basins.

Landforms: A rugged terrain has developed over these fold belts with hilly country dominating. Elevations range from sea level to over 600 m AHD, with up to half of the landscape in the south sitting above 400 m. There are rocky ridges, hogbacks, cuestas and structural plateaux of sandstone, siltstone, and shale; mountainous sandstone country with narrow or restricted basalt valleys; mountains with narrow valleys and lower slopes on crystalline and metamorphic rocks; mountains, mesas, buttes and rounded hills on basalt or dolerite; massive granite domes with colluvial lower slopes; and broad quartzite ridges.

Also present is a more subdued terrain that includes stony plains and undulating granite country with scattered hills; low lateritic plateaux and scattered hills on granite and gneiss; extensive lower slopes and undulating country on shale; and stony gently undulating basalt country. Alluvial and river plains are a minor component of the landscape, as are sandplains and the coastal flats around the Yampi Peninsula.

Soils: Stony soils dominate most of the hilly terrain. Red/brown non-cracking clays are found on the basalt hills. Other minor soils include Yellow loamy earths, Red deep sands, Yellow deep sands, Red loamy earths, Self-mulching cracking clays and Red shallow loams.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Mean annual rainfall is mostly 400-800 mm, but increases to 1000 mm on the Yampi Peninsula. To the south it tends to be Sub-Eremaean, a tropical semi-desert with 9-11 dry months and rainfall as low as 350 mm.

Vegetation: Low tree savanna with snappy gum (*Eucalyptus brevifolia*) over curly spinifex (*Triodia bitextura*) is the most common vegetation association. *Corymbia perfoliata* and other bloodwoods (*Corymbia* spp.) are sometimes found in this association. Areas of baobabs (*Adansonia gregorii*) over spinifex (*T. bynoei*) are also present. Elsewhere, snappy gums, and some times bloodwoods, are found over short grass (*Enneapogon* spp.) or hard spinifex (*T. intermedia* and *T. wiseana*).

Tall grass savanna woodlands of bloodwoods (*Corymbia* spp.), woollybutt (*Eucalyptus miniata*) and stringybark (*E. tetrodonta*) over curly spinifex and upland tall grasses (e.g. *Sorghum stipoideum*) are found in upland areas as are woodlands of grey box (*E. tectifica*) and cabbage gum (*E. grandiflora*) over white grass (*Sehima nervosum*) or ribbon grass (*Chrysopogon* spp.).

Component zones: Southern Kimberley Ranges Province has been divided into seven soil-landscape zones (Figure 4.6a):

- Yampi Peninsula Zone is based on the Yampi Peninsula of Wright (1964) and the Yampi Peninsula Section of Jennings and Mabbutt (1977);
- Springvale Foothills Zone is based on the Springvale Foothills Section of Jennings and Mabbutt (1977). It corresponds to the western portion of the Halls Creek Ridges geomorphic sub-region of Paterson (1970) and the north-western portion of the Eastern Uplands of Wright (1964);
- Van Emmerick Ranges Zone is based on the North-eastern Mountain Ranges of Wright (1964) and corresponds the Richenda Foothills Section of Jennings and Mabbutt (1977);
- Hall Creek Ridges Zone is based on the Hall Creek Ridges Section of Jennings and Mabbutt (1977). It corresponds to the east of the Halls Creek Ridges geomorphic sub-region of Paterson (1970) and the east of the Eastern Uplands of Wright (1964);
- Carr Boyd Ranges Zone is based on the northern portion of the Leopold-Durack Ranges of Jennings and Mabbutt (1977) and corresponds to northern portion of the Halls Creek Ridges geomorphic sub-region of Paterson (1970) as well as the eastern portion of their Kimberley Plateau[51];
- Durack Ranges Zone is based on the central portion of the Leopold-Durack Ranges Section of Jennings and Mabbutt (1977). It corresponds to the Eastern Ranges of Wright (1964) and part of the Kimberley Plateau geomorphic region of Paterson (1970)[52]; and
- King Leopold Ranges Zone is based on the King Leopold Ranges of Wright (1964) and corresponds to the western portion of the Leopold-Durack Ranges Section of Jennings and Mabbutt (1977).

The Ragged Range (N Schoknecht)

[51] The Carr Boyd Ranges were recognised as a separate zone due to the occurrence of the Pinkerton and Pompey land systems not encountered elsewhere in the Southern Kimberley Ranges Province.

[52] The portion of the Kimberley Plateau overlying the main occurrence of the Bastion Basin and associated occurrences of the Kimberley Basin.

311 – Yampi Peninsula Zone (3,350 km^2)	Hills, ranges and plateaux (with some lowlands and coastal mudflats) on sandstone and volcanic rocks of the King Leopold Orogen (Yampi Fold Belt). Stony soils with some Red/brown non-cracking clays, Yellow deep sands and Tidal soils. Eucalypt woodlands and spinifex grasslands (with some tall grasses and mangroves). Located in the western Kimberley between King Sound and Collier Bay.
312 – Springvale Foothills Zone (14,200 km^2)	Hills and plateaux (with some undulating plains) on granitic, volcanic and sedimentary rocks of the Halls Creek Orogen (western Lamboo Complex). Stony soils with some Red shallow loams and Deep sands. Eucalypt woodlands with spinifex and mixed grasslands. Located in the south-east Kimberley between Warmun, Halls Creek and Louisa Downs Station.
313 – Van Emmerick Ranges Zone (9,175 km^2)	Hills and ranges (with undulating plains) on granitic, volcanic and sedimentary rocks of the King Leopold Orogen (Hooper Complex). Stony soils with some Bare rock, Deep sands and Loamy duplexes. Eucalypt woodlands with spinifex and mixed grasslands. Located in the south-western Kimberley between the Yampi Peninsula and Leopold River.
314 – Halls Creek Ridges Zone (8,350 km^2)	Hills, ranges and plateaux on sedimentary (and some volcanic) rocks of the Halls Creek Orogen (eastern Lamboo Complex). Stony soils with Yellow loamy earths and Red deep sands. Eucalypt woodlands and spinifex grasslands. Located in the south-east Kimberley between Texas Downs Station, Halls Creek and Ruby Plains Station.
316 – Carr-Boyd Ranges Zone (12,350 km^2)	Hills, ranges and plateaux (with some undulating plains) on volcanic and granitic rocks of the northern Halls Creek Orogen and sandstone of the Kimberley and Bastion Basins. Stony soils with some Yellow loamy earths and Yellow deep sands. Eucalypt woodlands and tall grasses and spinifex (and some tussock grasslands). Located in the north-east Kimberley between Lake Argyle, Bow River and the Cockburn Range.
317 – Durack Ranges Zone (12,450 km^2)	Hills, ranges and plateaux (with some undulating plains) on volcanic rocks and sandstone of the Halls Creek Orogen (Durack Fold Belt). Stony soils with some Red/brown non-cracking clays. Eucalypt woodlands and spinifex grasslands with tall (and some tussock) grasses. Located in the south-eastern Kimberley between Margaret River Station, Lansdowne Station and Kachana Station (Chamberlain River).
318 - King Leopold Ranges Zone (3,700 km^2)	Hills, ranges and plateaux on sandstone and volcanic rocks of the King Leopold Orogen (Precipice Fold Belt). Stony soils and Red/brown non-cracking clays with some Red loamy earths. Eucalypt woodlands and spinifex and tall grasses. Located in the south-western Kimberley from Walcott Inlet to Conners Gap (Fossil Downs Station).

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33 Fitzroy Province

Sandplains and dunes (with some alluvial plains, floodplains, hills and stony plains) on the sedimentary rocks of the northern Canning Basin. Red deep sands with Self-mulching cracking clays and Yellow sandy earths (and some Stony soils, Red loamy earths and Red sandy earths). Pindan shrublands, spinifex/tussock grasslands and grassy eucalypt and other low woodlands. Located in the south-west Kimberley between Broome, Derby, Fitzroy Crossing and Christmas Creek.

Location and boundaries: The Fitzroy Province occupies about 73,600 km^2 (2.9% of WA) in the south-west of the Kimberley, extending east from the Dampier Peninsula to Wolfe Creek. It is situated north-east of the Canning Province, south-west of the Southern Kimberley Ranges Provinces and west of the Sturt Plateau Province. It includes the towns of Broome, Derby and Fitzroy Crossing.

The province is based on a combination of the Western Sand Plains, Fitzroy Ranges, Fitzroy-Lennard Floodplains, North Fitzroy Plains and South Fitzroy Plains geomorphic provinces of Wright (1964). It includes the Dampier Tableland, Napier Limestone Ranges, Fitzroy Plains and Fitzroy Ranges Sections of Jennings and Mabbutt (1977). It corresponds to the western occurrence of the Ord-Fitzroy Province described by Isbell (1983), but extends into the Kimberley-Arnhem-McArthur and Ayres-Canning Provinces of Northcote and Wright (1983).

The boundary extends east from Roebuck Bay (just south of Broome) across the bottom of the Dampier Peninsula to the Fitzroy River near Yakka-Munga Creek Station, before swinging south-east following the edge of the Great Sandy Desert to the Hall Range (south-east of Fitzroy Crossing). From here it heads east along the edge of the Great Sandy Desert to Wolfe Creek Meteorite Crater before turning north to Ruby Plains Station. It then follows the foot of the McClintock range south-west before swinging west along the course of Christmas Creek, cutting across to the Louisa River near Larrawa Station. From here it heads north along the foot of the Mueller Range to the Leopold River, then north-west past Leopold Downs Station, and along the northern edge of the Oscar and Napier Ranges, to Commonwealth Reserve land that was previously Oobagooma Station. It then follows the coastline of King Sound and the Dampier Peninsula back to Roebuck Bay.

Geology: Fitzroy Province mainly overlies the Phanerozoic sediments of the northern portion of the Canning Basin tectonic unit of Tyler and Hocking (2001). In the north-east are the Devonian limestone, reef carbonates and sandstones of the Lennard Shelf. To the south-west, the Lennard Shelf is composed mainly of Carboniferous to Permian sandstone, shale and siltstone. The south-western half lies predominantly on the Permian and Triassic sandstone, siltstone and shale of the Fitzroy Trough.

In the south-east are the Permian sediments of the Jones Arch and Balgo Terrace; the Neoproterozoic siltstone, sandstone, shale, greywacke, dolomite and tillite of the Louisa and Wolfe Creek Basins; and the Palaeoproterozoic granitoid rocks and metamorphosed sedimentary rocks of the Lamboo Complex (Halls Creek Orogen). Along the north-eastern margin of the province are some Palaeoproterozoic granitoid rocks and metasediments of the Hooper complex (King Leopold Orogen). Further within the province are the Neoproterozoic rocks of the Oscar Range Inlier.

Over much of this province, Quaternary alluvial and aeolian deposits form a mantle overlying the rocks described above.

Landforms: Sandplains with some dune fields are common, especially in the southern and western portions where elevations are mostly in the 10-150 m AHD range. Although these sandplains usually have little organised drainage, there are broad, shallow, gently undulating valley floors in places. Local outcrops and stony surfaces are also found in association with some of the sandplains. Elsewhere the sandplain masks a low lateritic plateau.

Alluvial plains and floodplains have developed along the Fitzroy and Lennard Rivers and sit at similar elevations to the sandplains. There are extensive dark cracking clay plains formed on limestone deposits and shale; sandy alluvial plains with broad through-going drainage floors; loamy alluvial plains with scalded tracts downslope from lateritic remnants; and active flood-plains with extensive back-plains of cracking clays or extensive levee zones.

Lateritic plateaux and hilly sandstone country are found in association with sandplains in the south-east where elevations are mostly around 250-450 m AHD. In the south-west there are extensive outcrop plains on shale and sandstone with scalded surfaces or low lateritic rises. Also present are sandstone plateaux and hills (rising to 250 m) with shaly lower slopes. To the north, rocky ranges and undulating country with scattered low hills and cracking clay plains are found on limestone. The tops of these ranges rise to almost 350 m AHD.

Mudflats have developed on coastal deposits in King Sound and along the Dampier Peninsula.

Soils: The sandplains are characterised by Red deep sands, with some Yellow sandy earths, Red sandy earths and Yellow deep sands. Self mulching cracking clays and Red/brown non-cracking clays are found on the alluvial plains, along with Yellow sandy earths and some Loamy duplexes. Stony soils are the most common soils of the hills and ranges, though Red loamy earths are also present. Yellow loamy earths, Red loamy earths and Stony soils are found on the sandstone and shale outcrop plains, while on limestone country there are Calcareous loamy earths, Calcareous shallow loams and Self-mulching cracking clays. Shallow gravels are associated with lateritic plateaux and remnants. Tidal soils are found on the coastal flats.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Average annual rainfall ranges from 800 mm on the Dampier Peninsula down to 350 mm in the south-east. Here the bioclimate tends towards Sub-Eremaean, a tropical semi-desert with 9-11 dry months.

Vegetation: On the sandplains there are pindan shrublands. These dense shrublands consist of various acacias including *Acacia platycarpa*, *A. tumida* and *A. eriopoda*. Emerging from the pindan shrublands are trees such as grey box (*E. tectifica*), bloodwoods (*Corymbia* spp.), cabbage gum (*E. grandiflora*) and woollybutt (*E. miniata*). The ground cover includes ribbon grass (*Chrysopogon* spp.), curly spinifex (*Triodia bitextura*) and sometimes soft spinifex (*T. pungens*).

The plains with sandy earths and loamy soils support tall bunch grass savanna with baobabs (*Adansonia gregorii*), bauhinia (*Bauhinia cunninghamii*) and beefwood (*Grevillea striata*) over ribbon grass. The black soil alluvial plains are characterised by tall bunch grass savanna with Mitchell grass (*Astrebla* spp.), blue grass (*Dichanthium fecundum*) and ribbon grass. Scattered trees on these black soil savannas include bauhinia, coolibah (*E. microtheca*), ghost gum (*E. papuana*) and *Acacia suberosa*.

On the sandstone hills and stony plains are hard spinifex (*Triodia intermedia* and *T. wiseana*) grasslands with beefwood, bloodwoods, snappy gum (*E. brevifolia*) and bauhinia. The limestone hills have baobabs and bloodwoods over hard spinifex (*T. wiseana*).

Component zones: Fitzroy Province has been divided into five soil-landscape zones (Figure 4.6b):

- North Fitzroy Plains Zone is based on a combination of the North Fitzroy Plains and Fitzroy-Lennard Floodplains geomorphic regions of Wright (1964) and corresponds to the Fitzroy Plains Section of Jennings and Mabbutt (1977);
- Napier-Oscar Ranges Zone is based on the Fitzroy Ranges geomorphic region of Wright (1964) and corresponds to the Napier Limestone Ranges Section of Jennings and Mabbutt (1977);
- South Fitzroy Plains and Ranges Zone is based on the South Fitzroy Plains geomorphic region of Wright (1964) and corresponds to the Fitzroy Ranges Section of Jennings and Mabbutt (1977);
- Dampier Sandplain Zone is based on the Western Sandplains geomorphic region of Wright (1964) and corresponds to the Dampier Tableland Section of Jennings and Mabbutt (1977) as well as the western portion of their Fitzroy Plains Section; and
- South Kimberley Sandplain Zone corresponds to the southern portion of the Eastern Uplands geomorphic region of Wright (1964)[53].

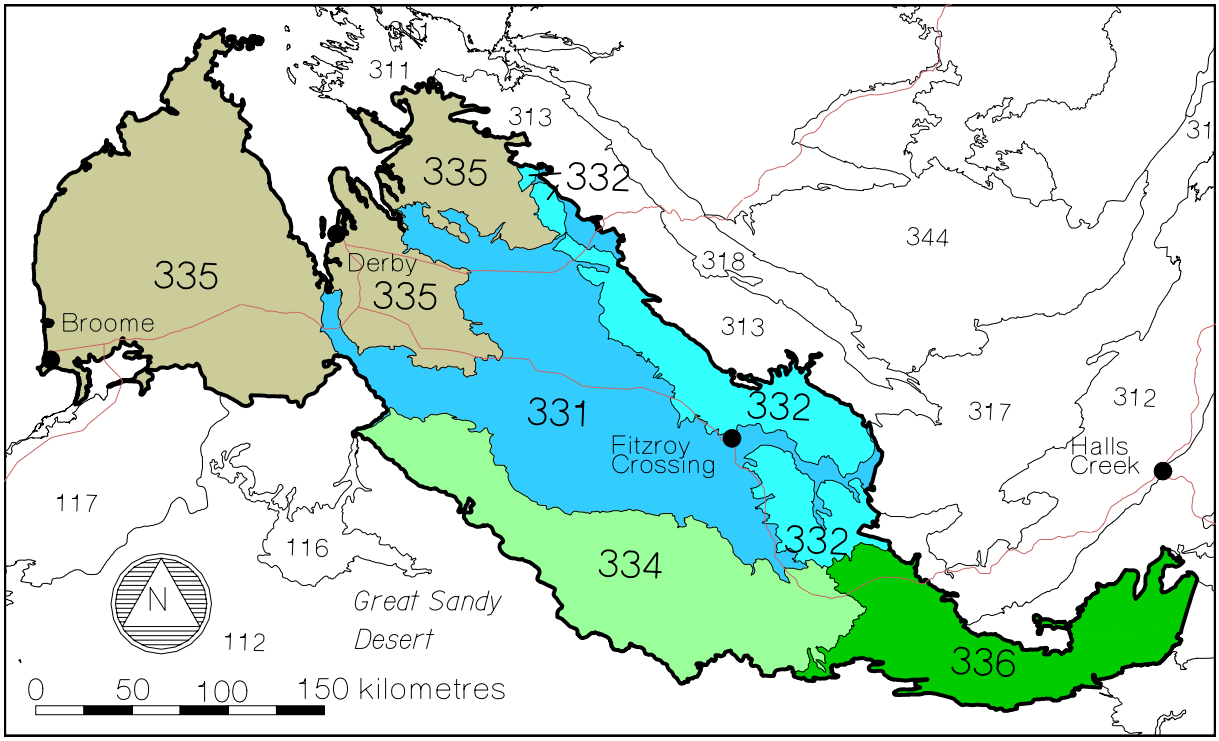

Figure 4.6b: Soil-landscape zones of the Fitzroy Province

[53] The South Kimberley Sandplain Zone forms a transition between the Kimberley Region and the Sandy Desert Region, containing systems belonging to both.

331 - North Fitzroy Plains Zone (17,925 km^2)	Floodplains and sandplains (with alluvial plains and undulating plains) on Permian sedimentary rocks of the Canning Basin. Self-mulching cracking clays with Red deep sands, Red sandy earths and Red/brown non-cracking clays and some Red loamy earths, Yellow sandy earths and Yellow loamy earths. Tussock and spinifex grasslands with woodlands of pindan, eucalypts, baobabs and bauhinia. Located in the south-western Kimberley between Camballin, Kimberley Downs Station, Fitzroy Crossing and Christmas Creek.
332 - Napier-Oscar Ranges Zone (7,750 km^2)	Undulating plains, alluvial plains and hill and ranges on Devonian limestone and other sedimentary rocks of the Lennard Shelf (Canning Basin). Self-mulching cracking clays with Calcareous shallow loams, Calcareous loamy earths and Stony soils. Eucalypt woodlands with mixed tussock and spinifex grasses (and some acacia shrublands). Located in the south-western Kimberley between Napier Downs Station and Fitzroy Crossing.
334 - South Fitzroy Plains and Ranges Zone (12,700 km^2)	Outcrop plains (with hills, sandplains and alluvial plains) on Permian sedimentary rocks of the Fitzroy Trough (Canning Basin). Red loamy earths with Stony soils and Red deep sands and some Red and yellow sandy earths. Spinifex grasslands with pindan shrublands and eucalypt woodlands (and some tussock grasses). Located in the southern Kimberley (south of the Fitzroy River) between Luluigui Station and Christmas Creek.
335 – Dampier Sandplain Zone (27,000 km^2)	Sandplains and dunes (with some sandy plateaux and coastal mudflats) on sedimentary rocks of the Canning Basin. Red deep sands with some Yellow sandy earths and Tidal soils. Pindan shrublands with spinifex/tussock grasslands (and some eucalypts). Located in the south-western Kimberley between Broome, Derby, Kimberley Downs Station and the Yampi Peninsula.
336 – South Kimberley Sandplain Zone (8,225 km^2)	Low hills and sandplains (with lateritic plateaux) on sedimentary rocks of the Canning Basin and southern Halls Creek Orogen. Loamy earths and Stony soils with Red deep sands and Shallow gravels and some Red shallow sands and Red sandy earths. Spinifex grasslands with eucalypts (and some acacia shrublands). Located in the south-east Kimberley between Bohemia Downs Station and Wolfe Creek.

Tallbunch grass savanna with baobabs on alluvial plain (N Schoknecht)

34 Kimberley Plateau Province

Hills, ranges and plateaux (with undulating plains) on the sedimentary and volcanic rocks of the Kimberley Basin. Stony soils with some Yellow deep sands, Red loamy earths, Yellow loamy earths and Red sandy earths. Eucalypt woodlands with spinifex and tall grasses (and some tussock grasses). Located in the northern Kimberley between Walcott Inlet, Landsdowne Station and Cambridge Gulf.

Location and boundaries: Kimberley Plateau Province occupies about 113,000 km^2 (4.5% of WA). It is north of the Southern Kimberley Ranges Province and west of the Bonaparte-Diemen Lowlands Province. Settlements include Kalumburu and Kuri Bay.

It is based on a combination of the Kimberley Plateau, Drysdale Lowlands and Couchman Uplands Sections of Jennings and Mabbutt (1977) and corresponds with part of the west of the Kimberley-Arnhem-McArthur Province described by Isbell (1983).

Its boundary is based on those of the Kimberley Plateaux geomorphic province of Wright (1964) and the Kimberley Plateau geomorphic region of Paterson (1970). It also follows the Kimberley Basin tectonic unit of Tyler and Hocking (2001), with the exclusion of most of the basin lying within the King Leopold and Halls Creek Orogens.

The boundary extends south from Vancouver Point on the Cambridge Gulf to Home Valley Station, then south along the Pentecost River (flowing at the base of the Elgee Cliffs) to Bedford Downs Station. From here it swings south-west (along the base of the Durack Range) to Landsdowne Station, and on to the northern edge of the King Leopold Ranges. It then strikes north-west (running between the King Leopold and Precipice Ranges and past Mornington Station) until it reaches the southern shore of Walcott Inlet. From here it follows the coastline north to Montague Sound, then east to Admiralty Gulf, the Bougainville Peninsula and Cape Londonderry, before swinging south-east along the shore of Joseph Bonaparte Gulf to Cambridge Gulf. It then follows the western shore of Cambridge Gulf south to Cape Vancouver. Numerous islands off the northern Kimberley coast are included.

Geology: Most of the Kimberley Plateau has developed on the unfolded Palaeoproterozoic sandstone and pebbly sandstone of the Kimberley Basin. Also present in the Kimberley Basin are siltstone, shale and mudstone. Basalt, dolerite and granophyre are mostly found in the western half of the plateau, with extensive areas of basalt being present in places. There are restricted outcrops of dolomite in the east.

Along its south-eastern margin, the plateau extends onto Kimberley Basin sediments within the Durack Fold Belt. In the south, and along its south-west margin, the province also includes Kimberley Basin sediments and volcanics within the Precipice-Yampi Fold Belts. Also present in the south are the Neoproterozoic sedimentary rocks of Mount House Group Basin, while in the east are some Mesoproterozoic sandstone, siltstone and mudstone belonging to outliers of the Bastion Basin.

Landforms: Much of this province comprises very rugged terrain with extensive dissection of the sandstone plateau leading to the development of precipitous gorges, benches, mesas, cuestas and ridges, along with areas of gently inclined uplands. The ruggedness is reflected by the wide range in elevations throughout this province, from sea level to over 600 m AHD near Mt Elizabeth Station. Much of the plateau surface sits at 250-500 m AHD.

Lateritic duricrust has developed on some areas of the plateau surface. This is most commonly associated with basalt, although there is also undulating shale-sandstone country with lateritic surfaces.

The dissection of the plateau is greatest in the east, west and south. In the central and northern portions of the plateau are considerable areas of low relief, with both uplands and lowlands formed on sandstone and volcanic rocks. Hilly volcanic terrain is most common in the central and western portions of the province. Tidal flats are a minor component along the coastal fringes.

Soils: Stony soils (mostly sandy) dominate the rugged sandstone terrain. Yellow deep sands, Yellow sandy earths and Yellow loamy earths are found on the sandstone and shale lowlands and plateau surface. Red loamy earths, Red sandy earths and Shallow gravels often associated with basalt uplands and lowlands, while the volcanic hills have Stony soils and Loamy earths (often red). Tidal soils are found on the coastal fringe.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Mean annual rainfall is mostly in the 600-1000 mm range, but increases to 1450 mm in the north-west.

Vegetation: Tall grass savanna woodlands dominate. On sandstone terrain there are woodlands of stringybark (*Eucalyptus tetrodonta*) and woollybutt (*E. miniata*) over upland tall grass (*Sorghum stipoideum*), curly spinifex (*Triodia bitextura*) and black spear grass (*Heteropogon contortus*). In the south scarlet gum (*E. phoenicea*) and bloodwoods (*Corymbia* spp.) with scattered *Callitris intratropica*, replace the stringybark and woolybutt. Also present on sandstone are long fruited bloodwood (*Corymbia polycarpa*) on the deeper sands, and other bloodwoods on laterite or sandstone outcrops. On laterite over sandstone, bloodwoods are often found in association with the palm tree (*Livistona humilis*), while on rugged sandstone terrain they occur with *Brachychiton*, *Terminalia* and *Gardenia* spp. Snappy gum (*E. brevifolia*) is sometimes found with bloodwoods over curly spinifex.

Woodlands of cabbage gum (*E. grandiflora*), *Corymbia foelscheana* and silver-leaved box (*E. pruinosa*) are found on shale and sandstone, while the volcanic soils support woodlands of grey box (*E. tectifica*), cabbage gum and *C. foelscheana* over white grass (*Sehima nervosum*), *Sorghum plumosum* and *Chrysopogon* spp.

Component zones: Kimberley Plateau Province has been divided into four soil-landscape zones (Figure 4.6c):

- Central Kimberley Plateau and Lowlands Zone is dominated by the gently sloping sandstone, shale and basaltic terrain of the Pago, Karunjie, Barton and Kennedy land systems of Speck *et al.* (1960), with significant areas of hilly basaltic terrain of the Napier system. It corresponds to the Drysdale Lowlands and Couchman Uplands of Jennings and Mabbutt (1977);
- Southern Kimberley Plateau Zone has a fairly even mix of dissected and gently sloping terrain on sandstone, shale and basalt[54]. It corresponds to the southern portion of the Kimberley Plateau of Jennings and Mabbutt (1977) and the Western Plains and Eastern Plateau of Wright (1964); and
- Eastern Kimberley Plateau Zone is dominated by the dissected sandstone terrain of the Pinkerton land system of Stewart *et al.* (1970). It corresponds to the eastern portion of the Kimberley Plateau of Jennings and Mabbutt (1977) and the western portion of the Kimberley Plateau described by Paterson (1970); and
- Western Kimberley Plateau Zone is dominated by the dissected sandstone terrain of the Buldiva land system of Speck *et al.* (1960), with significant areas of hilly basaltic terrain of the Napier system. It corresponds to the western portion of the Kimberley Plateau of Jennings and Mabbutt (1977).

[54] It also has significant areas of the *Hills, ranges and plateaux with eucalypt woodlands and spinifex* rangeland land type where as the remainder of this province mostly has *Hills, ranges and plateaux with eucalypt woodlands and tall grasses*

343 - Central Kimberley Plateau and Lowlands Zone (41,425 km^2)	Plateaux, hills, ranges and undulating plains and uplands on Kimberley Basin sandstone (with some basalt). Stony soils and Yellow deep sands with some Red sandy earths, Red loamy earths, Yellow loamy earths and Shallow gravels. Eucalypt woodlands with spinifex and tall grasses (and some tussock grasses). Located in the central-northern Kimberley from Kalumburu to Gibb River Stations.
344 – Southern Kimberley Plateau Zone (15,175 km^2)	Hills, ranges and plateaux (with undulating plains and lateritic uplands) on Kimberley Basin sedimentary and volcanic rocks. Stony soils with some Red/brown non-cracking clays, Shallow gravels, Red loamy earths, Yellow deep sands and Red shallow sands. Eucalypt woodlands with spinifex and tall grasses (and some tussock grasses). Located in the central Kimberley between Gibb River, Mount Barnett and Landsdowne Stations.
347 – Eastern Kimberley Plateau Zone (22,425 km^2)	Hills, ranges and plateaux on Kimberley Basin sandstone. Stony soils with some Yellow and Red loamy earths. Eucalypt woodlands with tall and spinifex grasses. Located in the northern Kimberley from Drysdale River National Park to the Chamberlain River.
348 – Western Kimberley Plateau Zone (33,950 km^2)	Hills, ranges and plateaux (with some undulating plains) on Kimberley Basin sandstone (with some basalt). Stony soils with some Yellow deep sands, Red sandy earths and Red loamy earths. Eucalypt woodlands with tall grasses (and some tussock and spinifex grasses). Located in the north-western Kimberley between Admiralty Gulf, Walcott Inlet and Mount House Station.

Hilly volcanic terrain (N Schoknecht)

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4 Lander-Barkly Plains Region

Sandplains and dunes (with undulating uplands and some hills and salt lakes) on sedimentary rocks (and some granite and volcanics) of the Birrindudu and Wolfe Creek Basins, Redcliff Pound Group, Granites-Tanami Complex and Arunta Orogen. Red sandy earths and Red deep sands with Loamy earths (mostly red) and some Stony soils, Red loamy earths and Self-mulching cracking clays. Spinifex grasslands with scattered eucalypts and acacias and some salt lakes and tussock grasslands. Located in the north-eastern Arid Interior and south-eastern Kimberley between Duncan Road and Lake McDonald.

Location and boundaries: The Lander-Barkly Plains Region is mostly in the Northern Territory. It covers much the centre of the Territory (including Daly Waters, Tennant Creek and Barrow Creek), and extends almost to Mt Isa in Queensland. Within WA this region occupies around 56,250 km^2 (2.2% of WA) along the Territory border. It lies east of the Sandy Desert Region, south of the North Australian Plateaux Region, and north of the Central Australian Ranges Region.

The boundary extends south-east from Nicholson Station on the Duncan Road (which runs east from Hall Creek) past to Flora Valley Station to Ruby Plains Station. From here it heads south to Wolfe Creek Meteorite Crater then south along the western edge of the Tanami Desert (passing just east of Balgo Community) to the Pollock Hills (situated south-west of Lake McKay). It then turns east to the Northern Territory border, passing Mt Webb, Dovers Hills and Buck Hills. Few settlements occur within this region in WA apart from a few station homesteads in the north and the Kiwirrkurra Aboriginal Community in the south.

The region is based on the Lander-Barkly Plains Province of Jennings and Mabbutt (1977), but has been altered so that its western boundary follows the eastern edge of the Canning Basin tectonic unit of Tyler and Hocking (2001). This involved the Redvers Dunefield Section, and part of the Stansmore Dunefield and Ranges Section, from Jennings and Mabbutt's Sandland Province. Excluded are the Sturt Creek Floodout Section, and the portion of the Birrundudu Section overlying the Canning Basin[55].

The northern boundary follows the southern boundary of the Halls Creek Orogen tectonic unit. The southern boundary is based on the southern boundaries of the Arunta Orogen tectonic unit of Tyler and Hocking (2001) and the Redvers Dunefield Section of Jennings and Mabbutt (1977).

In WA, the Lander-Barkly Plains Region sits within the Sandy Desert Region described by Northcote and Wright (1983), mostly within their Ayres-Canning Province.

Geology: Within WA, much of the region overlies the sedimentary and granitic rocks of the Centralian Superbasin, Granites-Tanami Complex and Arunta Orogen.

To the north, it includes the Cambrian volcanic rocks and conglomerate of that part of the Ord Basin which does not fall within the Halls Creek Orogen. To the south are the Neoproterozoic siltstone, mudstone, sandstone, dolomite and conglomerate of the Wolfe Creek Basin and the Mesoproterozoic sandstone of the Birrindudu Basin.

The central portion contains the Palaeoproterozoic monzogranite and metamorphosed greywacke, sandstone, siltstone and mudstone of the Granites-Tanami Complex; the Neoproterozoic quartz sandstone and greywacke of the Murraba Basin (Redcliffe Pound Group); and the Devonian sedimentary rocks of the Lucas Outlier of the Canning Basin.

[55] The boundaries of the Lander-Barkly Region could be altered to more closely reflect the mapping of Jennings and Mabbutt rather than the edge of the Canning Basin. This would involve incorporating the Sturt Creek Zone (114), as well as the portion of the Stansmore Dunefield and Range Zone (115) sitting directly to the east of Sturt Creek, into the Lander-Barkly Region. The Redvers Dunefield Zone (425) could be removed to the Sandy Desert Region (1).

In the south are Palaeoproterozoic-Mesoproterozoic sediments and metasediments of the Arunta Orogen. On the south-west of the region are Neoproterozoic sandstone and carbonate of an outlier of the Amadeus Basin.

Landforms: The Lander-Barkly Region mostly sits at an elevation of 320-450 m AHD. Approximately half consists of gently undulating sandplains. Many are dominated by linear or longitudinal dunes. Among the sandplains there are areas of calcrete (kunkar) of variable extent, low gravelly rises, pans, lakes, depressions, springs and isolated hilly residuals.

Elevated above the sandplains are some broad, very gently undulating tablelands (often with lateritic caps) on sedimentary rocks. Also present are stony hills and ranges that are largely derived from sandstone, and usually have flanking sandplains. In the north there are some lateritic plains and upland 'black soil' plains on alluvium derived from basalt.

Lower in the landscape are plains studded with salt pans, seasonal lakes, calcrete (kunkar) platforms and fringing dunes. Lake Mackay in the south is the most prominent salt lake.

Soils: Sandplain soils are predominantly Red sandy earths, with Red deep sands on the dunes. Red loamy earths are also present on sandplains and inter-dune flats. Red sandy earths and Loamy earths (often red) are found on the tablelands, along with some Shallow gravels. On the hills and ranges there are Stony soils and Red shallow sands and loams, with Red deep sands and Red sandy earths on the flanking sandplains. Self-mulching cracking clays dominate the alluvial black soil plains in the north. Salt lake soils and Calcareous loamy earths are associated with the salt lakes.

Climate: The bioclimate is described by Beard (1990) as mainly Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly 150-300 mm with a greater chance of summer falls. The north extends into the Sub-Eremaean bioclimate zone, a tropical semi-desert with 9-11 dry months and rainfall rising to 500 mm near the Duncan Road.

Vegetation: Although this region is mostly arid desert, there is little (apart from the salt lake surfaces) which is not at least sparsely vegetated. Hummock grasslands of soft spinifex (*Triodia pungens*) and feathertop spinifex (*T. schinzii*) dominate. These are often associated with low open tree and shrub steppes with species including desert bloodwood (*Corymbia dichromophloia*), snappy gum (*Eucalyptus brevifolia*), acacias, corkwood (*Hakea suberea*) and mulga (*A. aneura*). Associated with the salt lakes is a ti-tree (*Melaleuca* spp.) scrub overlying samphire (*Halosarcia* spp.). The black soil plains in the north support tall bunch grass savanna of Mitchell grass (*Astrebla pectinata*) and blue grass (*Dichanthium* spp.).

Component provinces: The Lander-Barkly Plains Region is yet to be subdivided into soil-landscape provinces in Western Australia[56]. As in interim measure, the whole region in WA has been placed in Sturt Plateau Province, based on the Sturt Plateau described by Paterson (1970).

[56] It is likely that more than one province exists within this region within Western Australia. This will not be identified until level 2 mapping of the ASRIS hierarchy is complete for the Northern Territory.

42 Sturt Plateau Province

Sandplains and dunes (with undulating uplands and some hills and salt lakes) on sedimentary rocks (and some granite and volcanics) of the Birrindudu and Wolfe Creek Basins, Redcliff Pound Group, Granites-Tanami Complex and Arunta Orogen. Red sandy earths and Red deep sands with Loamy earths (mostly red) and some Stony soils, Red loamy earths and Self-mulching cracking clays. Spinifex grasslands with scattered eucalypts and acacias and some salt lakes and tussock grasslands. Located in the north-eastern Arid Interior and south-eastern Kimberley between Duncan Road and Lake McDonald.

As Sturt Plateau Province currently comprises the entire Lander-Barkly Plains Region within Western Australia, the detailed description for that region also applies to this province.

Component zones: The province has been divided into five soil-landscape zones (Figure 4.7):

- Tanami Sandplain Zone is based on the Tanami Sandplain and Ranges Section of Jennings and Mabbutt (1977), though the western portion of this section overlying the Canning Basin has been excluded;
- Birrindudu Plain Zone is based on the Birrundudu[57] Plain Section of Jennings and Mabbutt (1977);
- Wiso Sandplain Zone is based on the Wiso Sandplain Section of Jennings and Mabbutt (1977);
- Stansmore Zone is based on the eastern portion of the Stansmore Dunefield and Ranges Section (Jennings and Mabbutt 1977) that overlies the Redcliff Pound Group and Lucas Outlier (rather than the Canning Basin); and
- Redvers Dunefield Zone is based on the Redvers Dunefield Section of Jennings and Mabbutt (1977).

Hummock grasslands and snappy gum on undulating tableland (N Schoknecht)

[57] The spelling of this name has been changed from that used by Jennings and Mabbutt to reflect that favoured by Tyler and Hocking (2001).

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421 - Tanami Sandplain Zone (14,025 km^2)	Sandplains and dunes with (hills, ranges, lowlands and some alluvial plains) on sedimentary rocks of the Birrindudu Basin and Redcliff Pound Group. Red deep sands with Stony soils and some Red sandy earths and Loamy earths. Spinifex grasslands with acacia-corkwood shrublands and some eucalypt woodlands. Located in the north-eastern Arid Interior between Duncan Road, Balgo and the Lewis Range.
422 – Birrindudu Plain Zone (6,850 km^2)	Alluvial and lateritic plains (with some hills and lowlands) on volcanic and sedimentary rocks of the Wolfe Creek and southern Ord Basins. Self-mulching cracking clays and Loamy earths with some Hard cracking soils and Ironstone gravels. Tussock and spinifex grasslands with eucalypt woodlands. Located in the south-eastern Kimberley on the Great Antrim Plateau (from Ruby Plains Station to Nicholson Station).
423 - Wiso Sandplain Zone (16,700 km^2)	Sandplains and salt lakes with undulating uplands and some hills on sedimentary rocks and granite of the Granites-Tanami Complex and Arunta Orogen. Red sandy earths with some Red deep sands, Salt lake soils and Red loamy earths. Spinifex grasslands with acacia shrublands, salt lakes and ti-tree salt flats. Located in the north-eastern Arid Interior to the east of Balgo (between the Gardner and Phillipson Ranges) and around Lake Mackay.
424 – Stansmore Zone (13,350 km^2)	Sandplains and dunes (with some hills, ranges, calcrete plains and salt lakes) on sedimentary rocks of the Redcliff Pound Group and Lucas Outlier. Red sandy earths and Red deep sands with some Red loamy earths and Calcareous loamy earths. Spinifex grasslands with eucalypts and shrubs and some salt lakes. Located in the north-eastern Arid Interior around Lake Willis (between Lake Mackay and the Stansmore and Phillipson Ranges).
425 – Redvers Dunefield Zone (5,350 km^2)	Sandplains and dunes (with some hills and ranges) on sedimentary rocks of the Arunta Orogen and Amadeus Basin. Red sandy earths with Red deep sands and some Red loamy earths and Shallow gravels. Spinifex grasslands with eucalypts and shrubs and some salt lakes and ti-tree salt flats. Located in the north-eastern Arid Interior between the Pollock Hills, Buck Hills and Lake Mackay.

5 Central Southern Region

Limestone and calcrete plains on the marine limestone of the Eucla Basin. Calcareous shallow loams and Calcareous loamy earths, with some Calcareous stony soils. Bluebush and saltbush shrublands, with some acacia and eucalypt woodlands and mallee scrub. Located in the south-east of Western Australia between Mt Ragged, Balladonia, the Great Victoria Desert and Eucla.

Location and boundaries: Within WA, the Central Southern Region occupies about 167,700 km^2 (6.6% of the State). It is centered on the Nullarbor Plain in the far south-east, between the Great Victoria Desert and the Great Australian Bight, and extends eastwards into South Australia. This region lies to the south of the Sandland Region and east of the Western Region. The only settlements are along the Eyre Highway (Balladonia, Caiguna, Cocklebiddy, Madura, Eucla etc.) and along the Trans-Australian Railway (Rawlina, Forrest, Reid, Deakin etc.).

The region is based on the Nullarbor Plain Province of Jennings and Mabbutt (1977) and forms the western portion of Central Southern Region described by Northcote (1983). It covers most of the Eucla botanical district of Beard (1990), as well as the eastern tongues of the Coolgardie and Roe districts.

The boundary is based on the boundary of the Eucla Basin tectonic unit of Tyler and Hocking (2001). It extends westwards from Mt Ragged (in the Cape Arid National Park) till it reaches the coast of the Great Australian Bight to the north of Israelite Bay. From here it extends eastwards (past Eyre and Eucla) into South Australia and the Head of the Bight, before turning north-east to Lake Tallacootra and on to Watson on the Trans-Australian Railway. It then heads north-west to Forrest Lakes on the WA-SA border, west past Jubilee Lakes to Plumridge Lakes. From here it extends south (passing between Zanthus and Kitchener on the Railway), past Balladonia, and back to Mt Ragged.

Geology: The region overlies the Eucla Basin which mostly comprises Oligocene marine limestone with some minor continental and marine sandstone. The surface of this limestone was covered by calcrete in the late Cainozoic. Along the coast to the east, there are marine shoreline and aeolian deposits, while Eocene marine limestone is found in the south-west. In the north are small outliers of sedimentary rocks from the Gunbarrel and Officer Basins, while in the west there are outliers of the Albany-Fraser Orogen.

Landforms: This region is dominated by an extensive flat plain formed on limestone and calcrete. This plain rises gradually from around 80 m AHD in the south to an elevation of 250 m some 350 km to the north. Closed depressions and karst topography are the main features of this otherwise monotonous plain. To the north, there are low rises with some dunes and salt lakes associated with the plain. In the south this plain ends abruptly in the Perpendicular Cliffs, dropping 80-100 m to the Great Australian Bight, and as scarps running east and west of these cliffs. Below the scarps are coastal plains with extensive dunes, sitting at 10-40 m AHD.

Soils: Calcareous shallow loams and Calcareous loamy earths dominate the limestone plain. Calcareous stony soils are also present, along with some areas of Red/brown non-cracking clays in depressions. Calcareous deep sands and some Pale deep sands are found on coastal dunes, with Calcareous shallow loams on the associated flats. Some Red loamy earths are found in the south-west, while Red sandy earths and Red deep sands appear near the margins of the Great Victoria Desert.

Climate: The bioclimate is described by Beard (1990) as mainly Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly in the 100-250 mm range with no seasonal tendency. The south extends into the Sub-Eremaean bioclimate zone, a Mediterranean semi-desert with 9-11 dry months and rainfall rising up to 300 mm on the Great Australian Bight. In the south-west (near Israelite Bay) the bioclimate

tends towards Thermoxeric, extra dry to dry Mediterranean with 6-8 dry months and up to 400 mm of winter-dominant rainfall.

Vegetation: This region is dominated by chenopod shrublands of bluebush (*Maireana sedifolia*) and saltbush (*Atriplex vesicaria*). To the north, steppe and woodlands of mulga *(Acacia aneura*), myall (*A. papyrocarpa*) and *Allocasuarina cristata* are associated with the chenopod shrublands, while spinifex (*Triodia scariosa* and *T. basedowii*) grasslands may be present on the dunes. A mallee scrub of blue mallee (*Eucalyptus socialis*), white mallee (*E. cooperiana*) and *E. gracilis* is found on the coastal plains.

Component provinces: Central Southern Region has been divided into two soil-landscape provinces (Figure 4.8):

- Nullarbor Province (55) occupying the bulk of the region is based on the Nullarbor Province of Northcote (1983); and
- Tarcoola-Quondong Province (58) along the northern margin is based on the Tarcoola-Quondong Province of Northcote (1983).

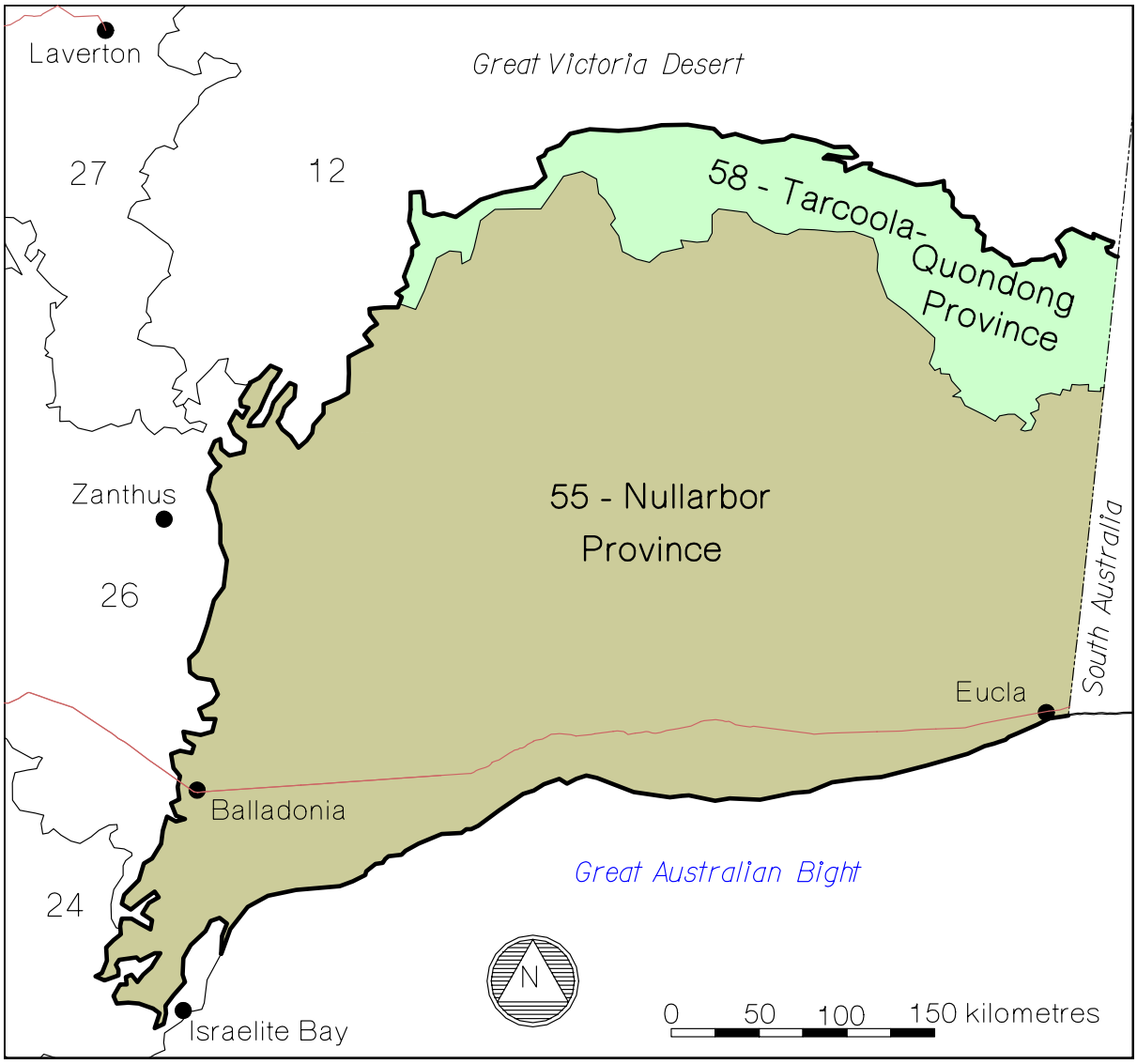

Figure 4.8: Soil-landscape provinces of the Central Southern Region

55 Nullarbor Province

Limestone plains (with some calcrete plains) on the marine limestone of the Eucla Basin. Calcareous shallow loams and Calcareous loamy earths, with some Calcareous stony soils. Bluebush and saltbush shrublands, with some acacia and eucalypt woodlands and mallee scrub. Located in the south-east of Western Australia between Mt Ragged, Balladonia, Plumridge Lakes, Deakin and Eucla.

Location and boundaries: Nullarbor Province occupies most of the Central Southern Region, covering about 145,350 km^2 in WA (5.8% of the State). It is south of the Tarcoola-Quondong Province and east of the Kalgoorlie and Stirling Provinces.

It comprises a combination of the Bunda Plateau and Roe Plain Sections of Jennings and Mabbutt (1977). It corresponds with the Nullarbor Province described by Northcote (1983) and the Nullarbor environmental association mapped in SA by Laut *et al.* (1977a). This province covers most of the Eucla botanical district of Beard (1990), as well as the eastern tongues of the Coolgardie and Roe districts.

The boundary extends westwards from Mt Ragged (in the Cape Arid National Park) until it reaches the coast of the Great Australian Bight to the north of Israelite Bay. From here it extends eastwards (past Eyre and Eucla) into South Australia and the Head of the Bight, before turning north-east to Watson on the Trans-Australian Railway, before turning north-west, re-crossing the State border and almost reaching Jubilee Lakes. From here it heads west to Plumridge Lakes, then south to Balladonia and back to Mt Ragged. The only settlements are along the Eyre Highway (Balladonia, Caiguna, Cocklebiddy, Madura, Eucla etc.) and along the Trans-Australia Railway (Rawlinna, Forrest, Reid, Deakin etc.).

Geology: Nullarbor Province overlies the Nullarbor Shelf of the Eucla Basin which mostly comprises Oligocene marine limestone with some minor continental and marine sandstone. The surface of this limestone was covered by calcrete in the late Cainozoic. Along the coast to the east are marine shoreline and aeolian deposits, while Eocene marine limestone is found in the south-west. In the west are outliers of the Albany-Fraser Orogen.

Landforms: This province is dominated by the Nullarbor Plain, a very gently to gently undulating plain with broad flats and low broad rises. It rises gradually from around 80 m AHD in the south to an elevation of 250 m some 350 km to the north. Gently undulating stony plains with numerous claypans and karst topography (large dongas and prominent annuli) are common. In the south this plain ends abruptly in the Perpendicular Cliffs, dropping 80-100 m to the Great Australian Bight, and as scarps running to the east and west of these cliffs. Below the scarps are coastal plains with extensive dunes at 10-40 m AHD.

Soils: Calcareous shallow loams and Calcareous loamy earths dominate the Nullarbor Plain. Calcareous stony soils are also present, with some areas of Red/brown non-cracking clays in depressions. Calcareous deep sands and some Pale deep sands are found on coastal dunes, with Calcareous shallow loams on the associated flats. Some Red loamy earths are found in the south-west.

Climate: The bioclimate is described by Beard (1990) as mainly Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly 150-250 mm (dropping to 100 mm in the north) with no seasonal tendency. The south of the province extends into the Sub-Eremaean bioclimate zone, a Mediterranean semi-desert with 9-11 dry months and rainfall rising to 300 mm on the Great Australian Bight. In the south-west (near Israelite Bay) the bioclimate tends towards Thermoxeric, extra dry to dry Mediterranean with 6-8 dry months and up to 400 mm of winter-dominant rainfall.

Vegetation: This province is dominated by chenopod shrublands of bluebush (*Maireana sedifolia*) and saltbush (*Atriplex vesicaria*). In the north, open low woodlands of myall (*Acacia papyrocarpa*), mulga (*A. aneura*), and sheoak (*Casuarina pauper*) sometimes occur in association with this shrub steppe. Woodlands of merrit (*Eucalyptus floctoniae*), red

mallee (*E. oleosa*), salmon gum (*E. salmonophloia*) and gimlet (*E. salubris*) grow in the west. A mallee scrub (*E. oleosa*, *E. diversifolia* and *E. gracilis*) covers the coastal plains.

Component zones: It has been divided into six soil-landscape zones (Figure 4.8a):

- Roe Plain Zone is based on the Roe land zone of Mitchell *et al.* (1988) and correlates with the Roe Plain Section of Jennings and Mabbutt (1977) and the Roe Plain vegetation system of Beard (1975a);
- Hampton Zone is based on the Hampton land zone of Mitchell *et al.* (1988) and correlates with the Coastal Hampton Tableland vegetation system of Beard (1975a);
- Nullarbor-Dimer Zone is based on a combination of the Nullarbor and Dimer land zones of Mitchell *et al.* (1988);
- Nyanga Zone is based on the Nyanga land zone of Mitchell *et al.* (1988) and includes residual clay and calcrete largely absent from the Nullarbor-Dimer Zone;
- Bilbunya Zone is based on a combination of the Nanambinia-Mallee vegetation system of Beard (1975a) with the eastern half of his Cooper system; and
- Gambanca Zone is based on the Beard's Nanambinia-Coolgardie vegetation system (1975a).

NOTE: *The zones of this province and their boundaries are under review as part of the Western Nullarbor survey. It is possible that too many zones have been identified, inferring greater variation than actually exists. Some zones may be amalgamated in the future.*

551 – Roe Plain Zone (6,650 km^2)	Coastal limestone plain (with coastal dunes and some limestone and calcrete plains) on marine shoreline and aeolian deposits over rocks of the Eucla Basin. Calcareous shallow loams with Calcareous deep sands and Calcareous loamy earths. Mallee and acacia shrublands with saltbush and bluebush shrublands. Located in the Great Australian Bight coast between Eyre, Madura and Eucla.
552 – Hampton Zone (5,325 km^2)	Limestone and calcrete plains on Oligocene marine limestone of the Eucla Basin. Calcareous shallow loams with Calcareous loamy earths and some Red/brown non-cracking clays. Mallee scrub with bluebush and saltbush shrublands and some acacia woodlands. Located in the south-eastern Nullarbor between Madura and Eucla.
553 – Nullarbor-Dimer Zone (56,550 km^2)	Limestone plains on Oligocene marine limestone of the Eucla Basin. Calcareous shallow loams with Calcareous loamy earths and some Calcareous stony soils and Red/brown non-cracking clays. Bluebush and saltbush shrublands. Located in the central Nullarbor between Cocklebiddy, Rawlinna and Deakin.
555 – Nyanga Zone (62,625 km^2)	Calcrete plains with residual clay on Oligocene marine limestone of the Eucla Basin. Calcareous loamy earths and Calcareous shallow loams with some Calcareous stony soils. Bluebush shrublands with some mulga, acacia, eucalypts and spinifex. Located in the northern and western Nullarbor between Balladonia, Kitchener, Haig and Tjuntjuntarra (Carlisle Lakes).
556 – Bilbunya Zone (5,625 km^2)	Limestone and calcrete plains (with some cliffs and coastal dunes) on Eocene and Oligocene marine limestone of the Eucla Basin. Calcareous shallow loams with Calcareous loamy earths and some Pale deep sands and Calcareous deep sands. Mallee scrub with some mallee heath. Located in the Great Australian Bight coast between Mt Ragged and Cocklebiddy.

557 – Gambanca Zone (8,575 km^2)	Calcrete plains (with undulating plains) on Eocene and Oligocene marine limestone of the Eucla Basin. Calcareous shallow loams and Calcareous loamy earths with some Red loamy earths. Merrit-red mallee woodland with some saltbush shrublands and mallee scrub. Located in the south-western Nullarbor between Balladonia Road and Cocklebiddy.

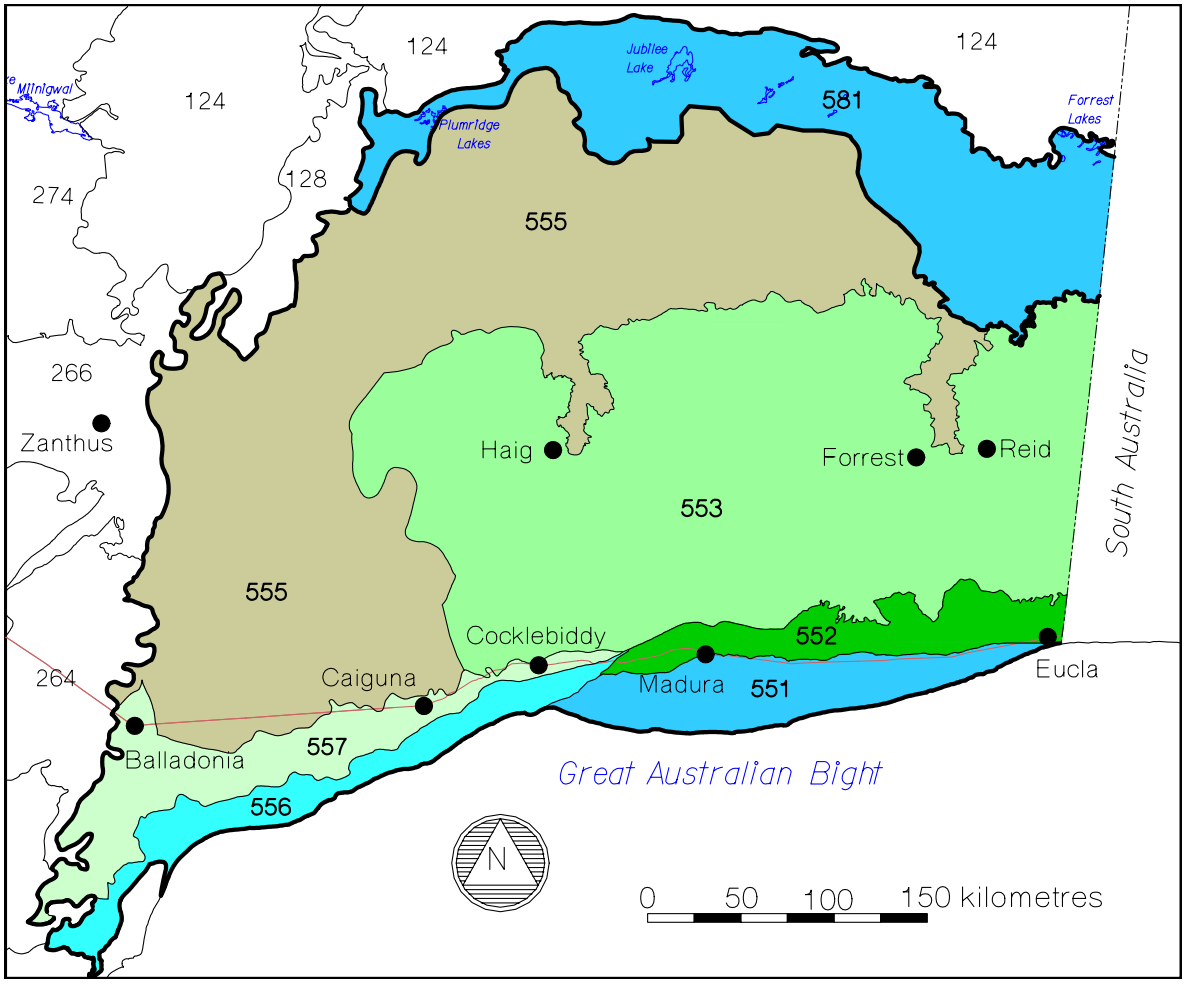

Figure 4.8a: Soil-landscape zones of the Nullarbor and Tarcoola-Quondong Provinces

The featureless Nullarbor Plain supporting chenopod shrublands (PJ Waddell)

58 Tarcoola-Quondong Province

Location and boundaries: Within WA, the Tarcoola-Quondong Province occupies about 22,350 km^2 (0.9% of the State). It forms a narrow strip south of the Gunbarrel Province and north of the Nullarbor Province. It follows a chain of salt lakes, beginning at the Plumridge Lakes in the west and including Lakes Gidgi and Jubilee, the Carlisle and Shell Lakes as well as the Forrest Lakes near the South Australian border.

Tarcoola-Quondong Province corresponds to the Carlisle Section of Jennings and Mabbutt (1977), the Tarcoola-Quondong Province described by Northcote (1983) and the Muckera environmental association mapped in South Australia by Laut *et al.* (1977a).

Geology: The province is situated on the Oligocene marine limestone of the Sherrif Shelf on the northern edge of the Eucla Basin. There are also small outliers of sedimentary rocks from the Gunbarrel and Officer Basin. Overlying the rocks of the Eucla Basin is a covering of late Cainozoic calcrete. Teritiary deposits are associated with the salt lakes.

Landforms: This province is dominated by very gently undulating to uneven, limestone and calcrete plains. These mostly sit at an elevation of 200-240 m AHD. Broad flats and low broad rises are a feature in some areas. The presence of sand-sheets and dunefields that overlie the calcrete and limestone in places reflects the close proximity to the Great Victoria Desert. Saline plains with salt pans, lakes and some fringing dunes are a prominent feature, especially in the west.

Soils: Calcareous loamy earths and Calcareous shallow loams are found on the limestone plains, along with Red deep sands, Red sandy earths and some Red shallow sands and Bare rock. Red sandy earths and Red deep sands dominate the sandplains and dunes, while Salt lake soils, Saline wet soils and Calcareous loamy earths are associated with the saline plains.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is mostly around 150 mm with no seasonal tendency.

Vegetation: Succulent steppe with a open low woodland of mulga (*Acacia aneura*), sheoak (*Casuarina pauper*) and myall (*A. papyrocarpa*) over bluebush (*Maireana sedifolia*) dominate. On the sandplains there are spinifex grasslands (*Triodia scariosa* and *T. basedowii*) with red mallee (*E. oleosa*), other mallees (e.g. *E. youngiana*) and marble gum (*E. gongylocarpa*). Samphire (*Halosarcia* spp.) flats are associated with the saline plains.

Component zones: Only one soil-landscape zone has been recognised (Figure 4.8a):

581 – Carlisle Plain Zone (22,350 km^2)	Limestone plains (with some salt lakes and sandplains) on Oligocene marine limestone of the Eucla Basin. Calcareous loamy earths, Red deep sands and Calcareous shallow loams with Red sandy earths (and some Red shallow sands and Bare rock). Bluebush shrublands with mulga-acacia-sheoak-eucalypt woodlands (and some mallee, spinifex and samphire). Located in the south-east of Western Australia between the Nullarbor Plain and Great Victoria Desert.

6 Central Australian Ranges Region

Sandplains and dunes (with hills and ranges surrounded by wash plains) on the granitic and volcanic rocks of the Musgrave Complex and the sedimentary rocks of the Amadeus Basin. Red sandy earths, Red deep sands and Red loamy earths (with some Stony soils). Mulga shrublands and spinifex grasslands (with some other acacias, eucalypts and desert oak). Located in the central-eastern Arid Interior from Warburton to the South Australian border and Lake McDonald.

Location and boundaries: Central Australian Ranges Region is situated mostly in the Northern Territory, covering much of the south (including Alice Springs, the Macdonnell Ranges, Yuendumu, Yulara and Hermannsburg). It also extends into South Australia covering the Musgrave Ranges and follows the Stuart Highway as far south as Granite Downs. Within WA, it occupies about 57,800 km^2 (2.3% of the State), lying to the east and north of the Sandy Desert Region and south of the Lander-Barkly Plains Region.

The Central Australian Ranges Region sits to the east and south of the Gibson Desert and to the north of the Great Victoria Desert. It includes the Warburton, Brown, Townsend, Barrow, Tomkinson, Jamieson, Finlay, Rawlinson, Walter James, Roberts, Ellis and Sir Frederick Ranges. There are few settlements of any size in Western Australia. Roadhouses are located at Warburton and Warakurna, while there is a Meteorological Station at Giles. Other small settlements shown on the map include Karrku, Yirrirra, Lapaku and Papulankutja.

The Central Australian Ranges Region is based on the Central Australian Ranges Province of Jennings and Mabbutt (1977)[58], also including their McDonald Sandplain Section. It comprises part of the Sandy Desert Region described by Northcote and Wright (1983), falling within their Stuart-Burt, MacDonnell and Ayres-Canning Provinces.

The boundary is based on the combined boundaries of the Amadeus Basin and Musgrave Complex tectonic units of Tyler and Hocking (2001). The northern boundary with the Lander-Barkly Region is based on the southern boundary of the Arunta Orogen tectonic unit of Tyler and Hocking (2001) and the northern boundary of the Macdonald Section of Jennings and Mabbutt (1977). Within WA, the boundary runs west from the Buck Hills (between Lakes Mackay and McDonald on the NT border), along the Gary Junction Road, to the Pollock Hills. From here it heads south briefly before doubling back towards Dover Hill and then swinging south to Mt Forrest on the western edge of the Rawlinson Range. From here it indents south-eastwards along the foot of the Rawlinson Ranges, passing to the south of Giles Meteorological Station before heading north-west to Conglomerate Point near the Old Gunbarrel Highway. It then swings south to Warburton before heading east to Skirmish Hill and south-east to the South Australian border near Baggaley Hill.

Geology: In Western Australia the Central Australian Ranges Region mainly overlies the rocks of the Amadeus Basin and Musgrave Complex. In the north are the Neoproterozoic sandstone and other sedimentary rocks of the Amadeus Basin. In the south, the Mesoproterozoic rocks of the Musgrave Complex include porphyritic granite, highly deformed gneiss and migmatite, granulite, schist, quartzite, basalt, acidic volcanic rocks, conglomerate, sandstone and shale.

Landforms: Although most of this region in WA comprises sandplains (at 450-550 m AHD), the ranges are the most prominent feature. These rise almost to 800 m in places.

The extensive sandplains have numerous dunes, which are often short and of irregular shape and orientation. There are also significant areas of dune fields with longitudinal and ring dunes. Amongst the sandplains are inclusions of residual hills with rock outcrop, occasional low stony residuals, some small claypans, and calcrete platforms.

[58] The boundaries have been altered in places to match the edge of the Paterson Orogen. Along the South Australian border, the boundary may have been extended too far to the south.

Steep hills and ranges have formed on sedimentary, metamorphic, volcanic and granitic rocks. Bare rock outcrop is common in these hills and there are some gorges. Flanking these ranges are extensive out-wash plains and dissected fan and terrace formations. Associated with these plains are some lateritic conglomerates and some calcrete platforms. There are also some sandy plains flanking the granitic ranges.

Plains studded with salt pans, seasonal lakes, calcrete platforms and fringing dunes are a relatively minor feature of the landscape.

Soils[59]***:*** Red sandy earths with Red deep sands are associated with the sandplains. Some Red loamy earths occur in inter-dune areas. Red loamy earths, Red sandy earths and Red-brown hardpan shallow loams are found on the out-wash plains. Stony soils and Red loamy earths are associated with the ranges, along with some Bare rock, Shallow sands and Shallow loams.

Climate: The bioclimate is described by Beard (1990) as Eremaean. This is a desert climate, commonly with 12 dry months a year. Mean annual rainfall is in the 200-250 mm range, with an even chance of summer or winter falls in the south and a tendency towards summer falls in the north.

Vegetation: Hummock grasslands of hard spinifex (*Triodia basedowii*) and feathertop spinifex (*T. schinzii*) dominate the sandplains and dunes. Emerging from these grasslands are bloodwoods (*Corymbia* spp.), marble gum (*Eucalyptus gongylocarpa*), mallees (e.g. *E. youngiana*), two vein wattle (*Acacia bivenosa*) and desert oak (*Allocasuarina decaisneana*). The wash plains support mulga (*Acacia aneura*) low woodlands and shrublands while the hills and ranges have mulga shrublands and hard spinifex grasslands.

Component provinces: The Central Australian Ranges Region is yet to be subdivided into soil-landscape provinces within WA[60]. As in interim measure, the whole region within WA has been placed into Western Desert Ranges Province:

[59] Soil descriptions are derived from allocations of Soil Groups of Western Australia (Schoknecht 2002). These in turn are based on interpretations of the descriptions and Factual Key (Northcote 1979) classifications published in the *Atlas of Australian Soils*. Since much of this region has not actually been surveyed, soil descriptions for this region and its component province and zones should be viewed as educated estimates at best.

[60] It is likely that more than one province exists within this region within Western Australia. This will not be identified until level 2 mapping of the ASRIS hierarchy is complete for the Northern Territory.

61 Western Desert Ranges Province

Sandplains and dunes (with hills and ranges surrounded by wash plains) on the granitic and volcanic rocks of the Musgrave Complex and the sedimentary rocks of the Amadeus Basin. Red sandy earths, Red deep sands and Red loamy earths (with some Stony soils). Mulga shrublands and spinifex grasslands (with some other acacias, eucalypts and desert oak). Located in the central-eastern Arid Interior from Warburton to the South Australian border and Lake McDonald.

As the Western Desert Ranges Province currently comprises the entire Central Australian Ranges Region within WA, the detailed description for that region also applies.

Component zones: The province has been divided into four soil-landscape zones (Figure 4.9)[61]:

- Crompton Dunefield and Hills Zone is based on that portion of the Great Sandy Desert Dunefield Section of Jennings and Mabbutt (1977) overlying the Amadeus Basin tectonic unit of Tyler and Hocking (2001);
- Paterson Sandplain Zone is based on those portions of the Great Sandy and Great Victoria Desert Dunefield Sections of Jennings and Mabbutt (1977) overlying the eastern occurrence of the Paterson Orogen tectonic unit of Tyler and Hocking (2001);
- Amadeus Lowlands Zone is based on the Amadeus Lowlands and McDonald Sandplains Section of Jennings and Mabbutt (1977);
- Rawlinson-Peterman Range Zone is based on the Rawlinson-Peterman Ranges Section of Jennings and Mabbutt (1977);
- Musgrave Range Zone is based on the Musgrave Ranges Section of Jennings and Mabbutt (1977) and corresponds to the Mt Davies and Walatajaranja environmental associations of Laut *et al.* (1977b); and
- Warburton Range Zone is based on the Warburton Ranges Section of Jennings and Mabbutt (1977).

[61] The boundaries of this province and its component zones are poorly defined and should be reviewed with a greater emphasis on geomorphic surface expressions.

612 - Crompton Dunefield and Hills Zone (8,750 km^2)	Sandplains and dunes (with hills and ranges surrounded by wash plains) on sedimentary rocks of the Amadeus Basin. Red deep sands and Red sandy earths with some Red loamy earths, Shallow gravels and Deep sandy gravels. Spinifex grasslands with eucalypts, shrubs and desert oak. Located in the central-eastern Arid Interior between Lake Mackay and the western end of the Rawlinson Range.
613 – Paterson Sandplain Zone (15,725 km^2)	Sandplains and dunes with some wash plains on granitic and volcanic rocks of the Musgrave Complex. Red sandy earths and Red loamy earths with Red deep sands. Spinifex grasslands with mulga (and other acacia) woodlands. Located in the central-eastern Arid Interior between Giles Meteorological Station and the Blackstone and Warburton Ranges (and between Tomkinson Range and Baggaley Hill in the south).
615 – Amadeus Lowlands Zone (11,875 km^2)	Sandplain and dunes with salt lakes, undulating uplands and some hills and ranges on sedimentary rocks of the Amadeus Basin. Red sandy earths with Red deep sands and some Red loamy earths, Shallow gravels and Salt lake soils. Spinifex grasslands with eucalypts, shrubs and desert oak and some mulga scrub. Located in the central-eastern Arid Interior between the Pollock and Buck Hills and Walter James Range (to the south of Lake Hopkins).
616 - Rawlinson-Peterman Range Zone (5,700 km^2)	Hills and ranges surrounded by hardpan wash plains, sandplains and dunes on sedimentary rocks of the Amadeus Basin and granitic and volcanic rocks of the Musgrave Complex. Red sandy earths and Red loamy earths with Red deep sands, Stony soils and some Bare rock, Red shallow sands and Red-brown shallow hardpan loams. Spinifex grasslands and mulga woodlands with eucalypts, shrubs and desert oak. Located in the central-eastern Arid Interior between Giles Weather Station, Lake Christopher and the Walter James Range.
618 – Musgrave Range Zone (8,825 km^2)	Sandplain and dunes with hills, ranges, plains and some wash plains on Musgrave Complex granite and gneiss (with some volcanic and sedimentary rocks). Red sandy earths with Red deep sands, Red loamy earths and some Stony soils and Self-mulching cracking clays. Mulga (and other acacia) woodlands and spinifex grasslands. Located in the central-eastern Arid Interior between the Barrow Range and the South Australian Border.
619 – Warburton Range Zone (6,900 km^2)	Wash plains with associated hill and ranges on Musgrave Complex volcanic rocks, granite and gneiss. Red loamy earths and Red sandy earths with some Red-brown hardpan shallow loams, Calcareous shallow loams and Stony soils. Mulga woodlands with some spinifex grasslands. Located in the central-eastern Arid Interior between Warburton and the Jamieson Range.

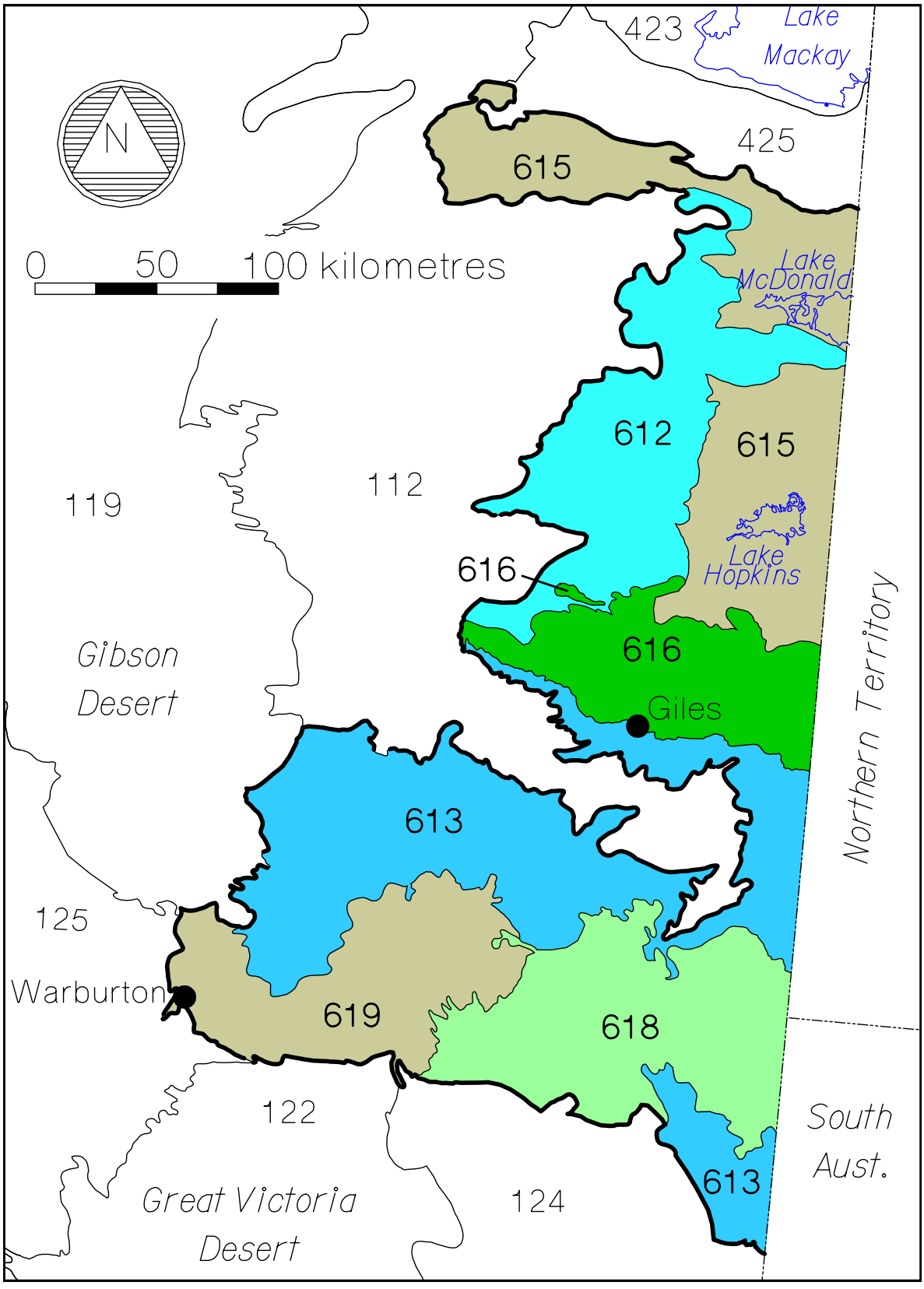

Figure 4.9: Soil-landscape zones of the Western Desert Ranges Province

7 Northern Australian Plateaux Region

Hills and undulating plains (with some sandplains, alluvial plains, coastal mudflats, ranges and plateaux) on the sedimentary and volcanic rocks of the Ord and Bonaparte Basins. Stony soils with Red and Yellow deep sands (and some Cracking clays, Calcareous loamy earths, Tidal soils and Yellow loamy earths). Eucalypt woodlands with tussock, spinifex and tall grasses (and open tussock grasslands, mangroves and tidal flats). Located in the east Kimberley between Cambridge Gulf and Flora Valley (Duncan Road).

Location and boundaries: The Northern Australian Plateaux Region is situated mostly in the Northern Territory where it covers much of the 'Top End' (including Darwin, Katherine, Wave Hill, Arnhem Land, Gove and Roper River). Within WA, it occupies about 23,050 km^2 (0.9% of the State). It lies to the east of the Kimberley Region and north of the Lander-Barkly Plains Region. Two discrete areas are in WA, one to the north of Lake Argyle, and the other to the south. The towns of Wyndham and Kununurra lie within this region.

The Northern Australian Plateaux Region is based on the Northern Australian Plateaux Province of Jennings and Mabbutt (1977). It forms the central portion of the Kimberley-Arnhem-Cape York Region described by Isbell (1983).

The boundary is based on the boundary of the Cambridge Gulf Lowlands and Ord River Basin geomorphic sub-regions of Paterson (1970). It extends from Vancouver Point (on the Cambridge Gulf) south to Home Valley Station (on the Pentecost River) before turning east along the foot of the Cockburn Range to Ivanhoe Station. From here it heads south taking, in the flats of the Dunham River as far as Sugarloaf Hill before doubling back along the foot of the Carr Boyd Range, and swinging west to cross the NT border near the Victoria Highway. It only extends a short distance into the Territory before returning to WA and cutting down the middle of Lake Argyle before heading south to Texas Downs station. From here it turns east before doubling back around Mt Deception and heading south-west along Osmond Creek to Bungle Bungle Outcamp. It then swings south, crossing Duncan Road near Fox River before heading north-east along the edge of the Great Antrim Plateau, passing to the north of Flora Valley and Nicholson Stations before reaching the NT border.

Geology: Within WA, the Northern Australian Plateaux have developed on Devonian to Permian sedimentary rocks of the Southern and Northern Bonaparte Basins to the north. Also present are Proterozoic sandstone, siltstone and mudstone of the Bastion Basin, and Palaeoproterozoic sandstone, siltstone and shale of the Kimberley Basin. Much is overlain by Quaternary alluvial, marine shoreline and aeolian deposits. In the south are the Cambrian basalt, conglomerate, tuff, sandstone, limestone, siltstone and mudstone (with some Devonian sandstone and conglomerate) of the Ord Basin.

Landforms: To the north of Lake Argyle, this region is dominated by alluvial plains, coastal mudflats and areas of sandplains, developed on alluvial, marine shoreline and aeolian deposits. These lowlands lie mostly at an elevation of 5-80 m AHD.

Rising from these lowlands (to elevations above 200 m AHD) are hills and plateaux formed on sedimentary rocks. In the south there is hilly terrain (that includes mesas, buttes, cuestas and plateaux) formed on basalt, sandstone, shale and limestone. These hills reach elevations of up to 400 m AHD (and occasionally higher). Gently undulating plains on shale, limestone and basalt are also common and there are some sandplains on undulating sandstone terrain.

Soils: Stony soils, and some Loamy earths and Calcareous shallow loams, have formed on hilly terrain while the undulating plains have Calcareous loamy earths, Calcareous shallow loams and Hard cracking clays. Red deep sands and Yellow deep sands dominate the sandplains. Tidal soils occur on the coastal flats, along with some Sandy duplexes and Calcareous loamy earths. The alluvial plains have Yellow deep sands, Yellow loamy earths and Self-mulching cracking clays.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Mean annual rainfall is mostly 450-800 mm, but increases up to 900 mm in the north and drops to 400 mm in the south where the bioclimate tends towards Sub-Eremaean (a tropical semi-desert with 9-11 dry months).

Vegetation: Grassy savanna woodlands dominate the hills and undulating plains. These include sparse bloodwoods (*Corymbia* spp.) and Mt House box (*Eucalyptus argillacea*) woodlands with upland tall grasses (e.g. *Sorghum stipoideum*) and arid short grasses (*Enneapogon* and *Aristida* spp.), snappy gum (*Eucalyptus brevifolia*) and silver leafed box (*E. pruinosa*) woodlands with hard spinifex (*Triodia wiseana* and *T. intermedia*), and stringybark (*E. tetrodonta*) and bloodwood (*C. dichromophloia*) woodland with upland tall grasses.

The sandplains support upland tall grasses and curly spinifex (*T. bitextura*) with bloodwood (*C. dichromophloia*), stringybark and woollybutt (*E. miniata*). On the coast are bare mudflats fringed by mangroves, with some samphire (*Halosarcia* spp.) and saline grasses. The clay floodplains and basalt plains support tussock grasslands of blue grass (*Dichanthium* spp.) and Mitchell grass (*Astrebla* spp.). Tippera tall grasses (*Themeda australis*, *Sehima nervosum* and *Chrysopogon fallax*) with northern box (*E. tectifica*) and bloodwood (*Corymbia foelscheana*) woodlands are found on sandy and loamy alluvial plains.

Component provinces: Northern Australian Plateaux Region has been subdivided into two soil-landscape provinces within WA (each comprising only one soil-landscape zone):

- Bonaparte-Diemen Lowlands Province is based on the Bonaparte-Diemen Lowlands Section of Jennings and Mabbutt (1977) and correlates to the Cambridge Gulf Lowlands geomorphic sub-region of Paterson (1970)[62]; and
- Ord-Victoria Plateaux Province is based on the Ord-Victoria Plateaux Section of Jennings and Mabbutt (1977) and correlates to the Ord River Basin geomorphic sub-region of Paterson (1970)[63].

Tidal flats on the edge of the Bonaparte-Diemen Lowlands Province (N Schoknecht)

[62] Bonaparte-Diemen Lowlands Province corresponds to the western portion of the Littoral Province described by Isbell (1983), but also extends into his Kimberley-Arnhem-McArthur Province.

[63] Ord-Victoria Plateaux Province includes the Victoria River Province described by Isbell (1983), but also extends into his Kimberley-Arnhem-McArthur and Ord-Fitzroy Provinces.

71 Bonaparte-Diemen Lowlands Province

Location and boundaries: Within WA, the Bonaparte-Diemen Lowlands Province occupies about 10,275 km^2 (0.4% of the State). It is in the north-east of the Kimberley, extending east from Cambridge Gulf along the coast of the Northern Territory to Ramingining in Arnhem Land. The towns of Wyndham and Kununurra lie within this province.

The boundary is based on the boundary of the Cambridge Gulf Lowlands geomorphic sub-region of Paterson (1970). It extends from Vancouver Point (on the Cambridge Gulf) south to Home Valley Station (on the Pentecost River) before turning east along the foot of the Cockburn Range to Ivanhoe Station. From here it head south, taking in the flats of the Dunham River as far as Sugarloaf Hill, before doubling back along the foot of the Carr Boyd Range and swinging west to cross the Northern Territory border near the Victoria Highway.

Geology: Within WA, the Bonaparte-Diemen Lowlands Province mostly overlies the Southern and Northern Bonaparte Basin tectonic units of Tyler and Hocking (2001). In the north-east are the Carboniferous-Permian sedimentary rocks of the Northern Bonaparte Basin. Across the middle of the province are the Carboniferous and Devonian sandstone, conglomerate and limestone (as well as some Cambrian basalt and conglomerate) of the Southern Bonaparte Basin. In the south-west are the Mesoproterozoic sandstone, siltstone and mudstone of the Bastion Basin, and some Palaeoproterozoic sandstone, siltstone and shale of the Kimberley Basin. Also present are outliers of the Mesoproterozoic sandstone, siltstone and mudstone of the Carr Boyd Basin. Overlying much of this province are Quaternary alluvial, marine shoreline and aeolian deposits.

Landforms: Around the Joseph-Bonaparte and Cambridge Gulfs there are coastal mudflats and estuarine deltaic plains on marine deposits. Along the rivers gently sloping alluvial plains and floodplains have formed. Gently undulating sandplains are found on sandstone and calcareous sandstone. There are also some gently undulating plains on dolomite and shale. These lowlands lie mostly at elevation of 5-80 m AHD.

Rising from these lowlands (to elevations above 200 m AHD) there are ridges, hogbacks, cuestas and structural plateaux. These have formed on sandstone and other sedimentary rocks. There is also some undulating to low hilly country on basalt.

Soils: Yellow deep sands and Red deep sands occur on the sandplains. Yellow deep sands are found in association with Yellow loamy earths on the alluvial plains. Self-mulching cracking clays occur on floodplains, while the coastal flats that fringe the Cambridge and Joseph Bonaparte Gulfs have Tidal soils. Sandy duplexes and Calcareous loamy earths are also associated with the coastal flats. Stony soils dominate the hills and plateaux.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Mean annual rainfall is 700-900 mm.

Vegetation: Grassy savanna woodlands dominate this province. On the sandplains, upland tall grasses (e.g. *Sorghum stipoideum*) and curly spinifex (*Triodia bitextura*) are found in association with bloodwoods (*Corymbia* spp.), stringybark (*Eucalyptus tetrodonta*) and woollybutt (*E. miniata*). Tussock grasslands of mixed blue grass (*Dichanthium* spp.), Mitchell grass (*Astrebla* spp.) and tall grass communities are found on the cracking clays of the floodplains with emergent *Bauhinia cunninghamii*, coolibah (*E. microtheca*) and ghost gum (*Eucalyptus* spp.). On the Yellow deep sands and Loamy earths of the alluvial plains, Tippera tall grasses (*Themeda australis*, *Sehima nervosum* and *Chrysopogon fallax*) are found in association with northern box (*E. tectifica*) and bloodwood (*Corymbia foelscheana*) woodlands. On the coast there are bare mudflats fringed by mangroves, with some samphire (*Halosarcia* spp.) and salt-tolerant grasses. The hills and plateaux support stringybark and bloodwood woodlands over upland tall grasses.

Component zones: In Western Australia, only one soil-landscape zone has been recognised within the Bonaparte-Diemen Lowlands Province (Figure 4.10):

711 - Cambridge Gulf Lowlands Zone (10,275 km^2)	Alluvial plains, coastal mudflats and sandplains (with hills, ranges and plateaux) on alluvial, marine shoreline and aeolian deposits and sedimentary rocks of the Bonaparte Basin. Yellow and Red deep sands, Tidal soils, Stony soils and Self-mulching cracking clays with some Yellow loamy earths and Sandy duplexes. Tall and tussock grasslands with eucalypt woodlands, bare tidal flats and mangroves. Located in the north-east Kimberley between Wyndham, Kununurra and the Cambridge Gulf.

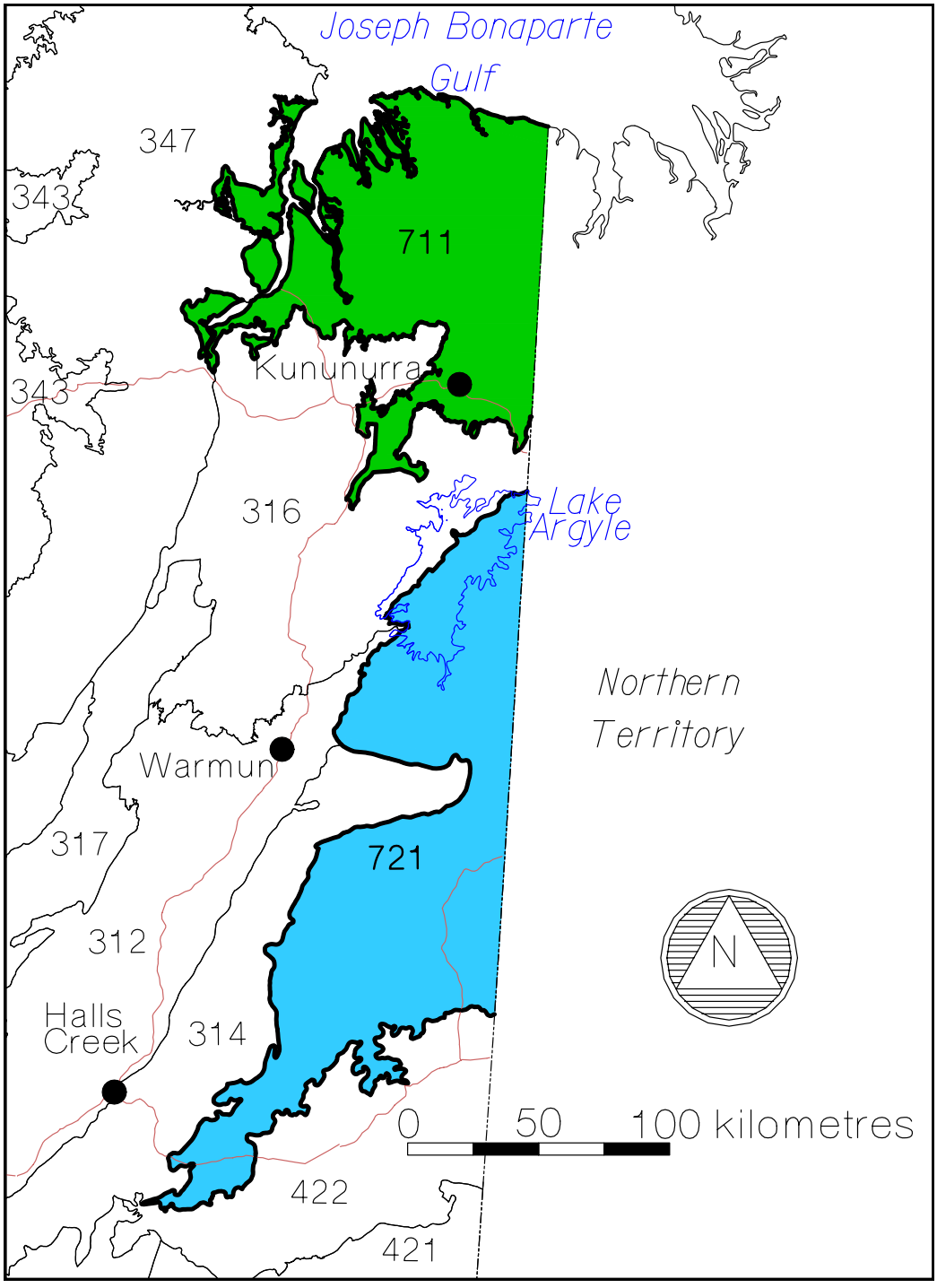

Figure 4.10: Soil-landscape zones of the Northern Australian Plateaux Region

72 Ord-Victoria Plateaux Province

Location and boundaries: Within WA, the Ord-Victoria Plateaux Province occupies about 12,775 km^2 (0.5% of the State). It is in the eastern Kimberley and includes the Bungle Bungle, Dixon and Hardman Ranges. To the east, this province extends to Wave Hill and Willeroo in the Northern Territory.

The boundary is based on that of the Ord River Basin geomorphic sub-region of Paterson (1970) and also mostly follows the boundary of the Ord Basin tectonic unit of Tyler and Hocking (2001). From the Northern Territory border, it cuts down the middle of Lake Argyle before heading south to Texas Downs station. From here it turns east before doubling back around Mt Deception and heading south-west along Osmond Creek to Bungle Bungle Outcamp. It then swings south, crossing Duncan Road near Fox River before heading north-east along the edge of the Great Antrim Plateau (passing to the north of Flora Valley and Nicholson Stations) before reaching the Northern Territory border.

Geology: In WA, the Ord-Victoria Plateaux Province mainly overlies the Ord Basin which comprises part of the Hardman Fold Belt. In the north there is a mix of Cambrian basalt, conglomerate, tuff, sandstone, limestone, siltstone and mudstone. The south is dominated by Cambrian sandstone, limestone, siltstone and mudstone with some Devonian sandstone and conglomerate. Along southern margins, Cambrian basalt and conglomerate again become prominent. In the far south-west, this province extends onto the Neoproterozoic siltstone, mudstone, sandstone, dolomite and conglomerate of the Wolfe Creek Basin and Halls Creek Orogen.

Landforms: Much of this province comprises mesas, buttes, structural benches and rounded hills on basalt or dolerite. There are also structural plateaux and cuestas of sandstone and shale, as well as dissected limestone cuestas. Gently undulating plains on shale, limestone and basalt are also common. Sandplains have formed on undulating sandstone terrain. The elevation ranges from 100 m AHD on the lowlands to 500 m on the crests of the ranges.

Soils: Stony soils (and some Loamy earths) are found on hilly terrain, with Calcareous shallow loams on limestone cuestas. Calcareous loamy earths and Calcareous shallow loams occur on shale and limestone plains, while Hard cracking clays are associated with stony basalt plains. Red deep sands dominate the sandplains.

Climate: The bioclimate is described by Beard (1990) as Thermochimenic. This is a dry hot tropical climate with 7-8 dry months in winter. Mean annual rainfall is mostly in the 450-700 mm range, but drops to 400 mm in the south where the bioclimate tends towards Sub-Eremaean (a tropical semi-desert with 9-11 dry months).

Vegetation: The hilly terrain supports grassy savanna. Sparse bloodwoods (*Corymbia* spp.) and Mt House box (*Eucalyptus argillacea*) woodlands with upland tall grasses (e.g. *Sorghum stipoideum*) and arid short grass (*Enneapogon* and *Aristida* spp.) are common. Snappy gum (*Eucalyptus brevifolia*) and silver leaf box (*E. pruinosa*) woodlands with hard spinifex (*Triodia wiseana* and *T. intermedia*) are also present.

Tussock grasslands of Mitchell grass (*Astrebla* spp.) and blue grass (*Dichanthium* spp.) are found on cracking clays on basalt, while the sandplains support sparse silver-leafed box woodland with *Aristida* spp. and ribbon grass (*Chrysopogon fallax*).

Component zones: With Western Australia, only one soil-landscape zone has been recognised within the Ord-Victoria Plateaux Province (Figure 4.10):

721 - Ord River Basin Zone (12,775 km^2)	Hills and mesas (with undulating plains and some sandplains and stony plains) on volcanic and sedimentary rocks of the Ord Basin (Hardman Fold Belt). Stony soils with Calcareous loamy earths and Calcareous shallow loams and some Hard cracking clays, Loamy earths and Red deep sands. Eucalypt woodlands and tussock grasses and spinifex and open tussock grasslands. Located in the east Kimberley between Lake Argyle, The Bungle Bungles and Flora Valley (Duncan Road).

Grassy eucalypt savanna on sandstone hills (N Schoknecht)

5. RECOMENDED FUTURE DEVELOPMENTS

The work presented in this report should not be seen as representing an endpoint for mapping of the Rangelands and Arid Interior. Rather, it should be viewed as a base upon which future work can be built. Tasks that still need to be undertaken include:

- Reviewing regions, zones, provinces and systems along the State border to edge-match them with the mapping of South Australia and Northern Territory when it becomes available.
- Interpretation of air photos or relevant digital data sets to improve the edge-matching of map unit boundaries between the Rangeland surveys, the *Atlas of Australian Soils* and mapping from the Agricultural Area.
- Reviewing the hierarchy level assignment to many of the rangeland land systems. Some of are probably more appropriate as soil-landscape subsystems and new soil-landscape systems may need to be created by combining existing rangeland systems.
- Determining where in the hierarchy the map units taken from the *Atlas of Australian Soils* units fit and assigning proper link labels.
- The summary and detailed landform, geology, soils and vegetation fields for the soil-landscape systems in the Map Unit Database need to be further populated. This could be achieved using information contained in the map unit descriptions in the published rangeland survey reports, as well as data derived by matching the new soil-landscape system mapping with the digital maps of geology and vegetation associations.
- The allocation of the land units in the 'Components by Percent' field for soil-landscape systems in the Map Unit Database requires review. Where possible, soil group qualifiers and landscape positions should be specified along with the Soil Group of Western Australia. The allocations should be based on the land units shown for the parent system in the descriptions published in the rangeland survey reports. They could also incorporate information about the systems derived from digital terrain data.
- Where there are differences between soil-landscape systems now occurring in different zones but originally derived of the same rangeland land system (e.g. Rocklea land system as discussed in Section 3.3.1 above), separate map unit descriptions and Soil Groups of Western Australia allocations should be entered into the Map Unit Database to highlight these differences.

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Nullarbor sunset – Kybo Station (PJ Waddell)

8. APPENDICES

Appendix 1. Example of land system description

From the Pilbara Survey (Van Vreeswyk *et al.* 2004)

BOOLALOO LAND SYSTEM (1,502 km², 0.8% of the survey area)

(modified from Payne *et al.* 1988)

Granite hills, domes and tor fields and sandy plains with shrubby spinifex grasslands.

Land type: 1

Geology: Archaean granite and gneiss, minor Quaternary sand.

Geomorphology: Erosional surfaces; granite hills with boulder strewn slopes, tor heaps and bare domes surrounded by restricted stony and sandy plains; widely spaced tributary drainage patterns of narrow drainage floors and channels. Relief mostly <50 m, occasionally up to 100 m.

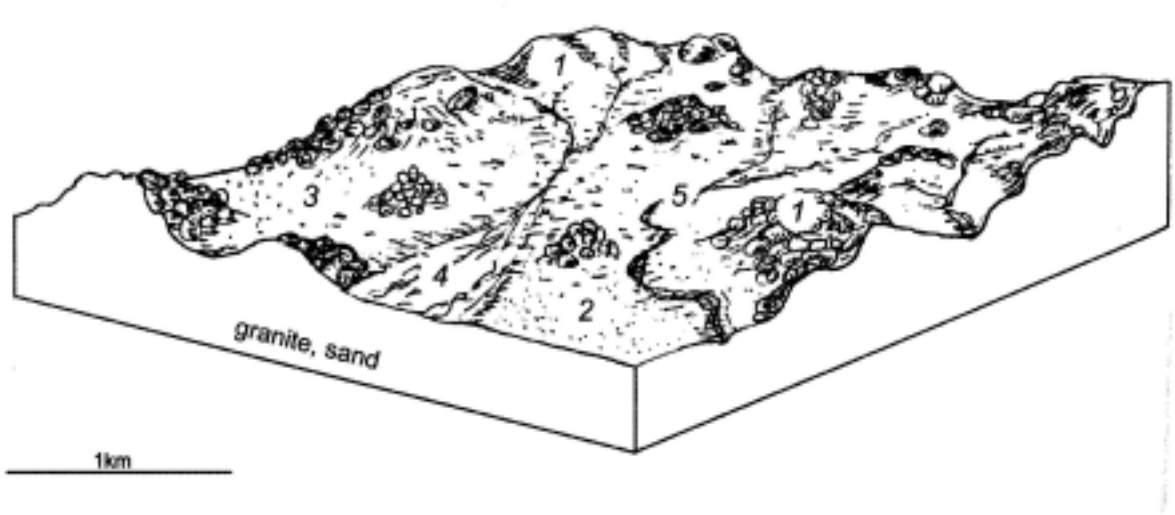
Land management: Hills and tor heaps are poorly accessible to livestock, elsewhere on the system the spinifex vegetation is not usually prone to grazing induced degradation but is subject to fairly frequent burning.

Traverse condition summary: (71 assessments)

Vegetation - very good 100%.

Soil erosion - nil 100%.

Area mapped as sde: Nil.



No.	Unit name	Traverse recordings	Inventory sites
1.	Hill, tor heap and hill slope	8	6
2.	Sandy plain	17	-
3.	Stony plain	39	3
4.	Run-on tract	-	-
5.	Narrow drainage floor and channel	7	-
	Total	71	9

Boolaloo land system

Unit	Area	Landform	Soil	Vegetation
1.	70%	**Hills, tor heaps and hill slopes** - rounded hill crests with gently inclined to steep stone and boulder strewn slopes, bare domes and tor heaps. Relief mostly <50 m, occasionally higher.	Bare rock, stony soils (203) and red shallow sands (423).	Scattered hummocks of *Triodia pungens* (soft spinifex) with isolated *Acacia* spp. and other shrubs, occasional *Terminalia canescens* trees (HSPG).
2.	10%	**Sandy plains** - Level to very gently inclined sandy plains between hills and tor heaps.	Red deep sands (445).	Hummock grasslands of *Triodia* sp. (hard spinifex) with very scattered to scattered *Acacia* spp. and other shrubs (PHSG). Occasionally *T. pungens* (soft spinifex) (PSSG).
3.	13%	**Stony plains** - level to undulating plains with gritty surfaces and mantles of variable density granitic or quartz pebbles and cobbles, occasional granite outcrops.	Red shallow sands (423).	Hummock grasslands of *T. wiseana, T. brizoides* (hard spinifex) or *T. pungens* (soft spinifex) with very scattered shrubs such as *Acacia orthocarpa, A. maitlandii* (PHSG, PSSG).
4.	5%	**Tracts receiving run-on** - level tracts receiving run-on, usually unchannelled but may have a few rills and gutters.	Red shallow sands (423).	Hummock grasslands of *T. pungens* with scattered *Acacia* spp. and other shrubs (ASSG).
5.	2%	**Narrow drainage floors and channels** - level drainage floors up to 200 m wide, channels up to 50 m wide and 3 m deep.	Red sandy earths (463). Channels with river bed soils (705).	Scattered shrublands or hummock grasslands with *Acacia* spp. and *Triodia* spp. (soft and hard spinifex) (DAHW, AHSG). Larger channels have fringing woodlands of eucalypts and melaleucas (GMEW).

Appendix 2. Physiographic Divisions of Jennings and Mabbutt (1977)

Below are the descriptions of the physiographic sections identified within Western Australia by Jennings and Mabbutt (1977). These are shown in Figure 3.1 on page 18.

North Australian Plateaux Province		
123	Bonaparte-Diemen Lowlands	Alluvial plain, mainly clay
129	Ord-Victoria Plateaux	Dissected plateaux, mainly basaltic but partly of sandstone and with local laterite cappings
Kimberley Province		
131	Kimberley Plateau	Sandstone plateaux with tabular high summits; ria coast and islands to NW
132	Drysdale Lowlands	Undulating to hilly lowlands, mainly on basalt
133	Couchman Uplands	Undulating to hilly lower plateaux, mainly on basalt
134	Leopold-Durack Ranges	Prominent ranges of dipping quartzites rimming the main plateau
135	Yampi Peninsula	Parallel ridges of quartzite and sandstone and narrow valleys of basalt; extending as a ria coast and islands`
136	Richenda Foothills	Rounded hills and ridge and lowlands on a belt of granite and folded metamorphic rocks with minor basalt
137	Fitzroy Plains	Floodplains and broad estuarine plains
138	Napier Limestone Ranges	Limestone tableland and intricately dissected beveled ridges; rocky karst surfaces with box valleys
139	Springvale Foothills	Granite hills and minor undulating plains
140	Halls Creek Ridges	Ranges and rounded hills on granite and metamorphic rocks
141	Fitzroy Ranges	Scattered sandstone tablelands and ranges; extensive sandplain and E-W longitudinal dunes
Lander Barkly Plains Province		
147	Wiso Sandplain	Sandplain with minor dunes in south; floodplains and floodouts on margins; stony rises in north
155	Birrundudu Plain	Low basaltic plain with clay soils; intermediate drainage with large claypans
156	Tanami Sandplain and Ranges	Sandplain with scattered low ranges and tablelands and occasional granitic hills
157	Sturt Creek Floodout	Floodout with distributary channels and claypans

Central Australian Ranges Province		
165	Amadeus Lowland	Dunefields and sandplains with scattered sandstone ranges; salt lakes and calcrete plains along lowland axis
166	Rawlinson-Petermann Ranges	Dissected sandstone ranges with prominent escarpments
167	Kulgera Hills	Sandy granitic plains with prominent hills
168	Musgrave Ranges	Granitic ranges and rounded high hills
169	Warburton Ranges	Ranges and hills of basic volcanic rocks and granite
Sandland Province		
170	Dampier Tablelands	Low sandstone tablelands, partially lateritized and with extensive sandplain cover
171	Eighty Mile Plain	Coastal dunes and estuarine plain
172	Anketell Hills	Low mesas, buttes and stony rises of lateritized sandstone and shale among E-W longitudinal dunes and sandy plains
173	Great Sandy Desert Dunefield	E-W longitudinal dunes and minor salt lakes
174	Stansmore Dunefield and Ranges	E-W longitudinal dunes locally broken by narrow sandstone ranges
175	Gibson Desert Plains	Sandy or stony lateritic plains
176	Redvers Dunefield	E-W longitudinal dunes
177	Macdonald Sandplain	Mainly sandplain with dune-fringed salt lakes
178	Stanley Hills and Dunes	Isolated sandstone ridges among W-E longitudinal dunes and sandplain
179	Carnegie Hills	Sandstone tablelands, stony limestone plains, salt lakes and adjacent dunes
180	Leemans Sandplain	Sandplain with small salt lakes
181a	Great Victoria Desert - main dunefield	W-E Longitudinal dunes
181b	Great Victoria Desert - north-west dunes and hills	W-E Longitudinal dunes broken by low tablelands and ridges

Pilbara Province		
182	DeGrey Lowlands	Floodplains and deltaic plains; granitic and limestone lowlands; scattered ranges of metamorphic rocks in north
183	Nullagine Hills	Dissected flat-topped hills of granites and metamorphic rocks with partial lateritic cappings; narrow estuarine plain and islands
184	Rudall Tablelands	Dissected low sandstone tablelands
185	Hamersley Plateaux	Dissected bold plateaux and ranges of flat-lying or moderately folded sandstone and quartzite
186	Chichester Range	Narrow range of dipping quartzite and sandstone
187	Fortescue Valley	Mainly alluvial lowland, possibly a graben
188	Augustus Ranges	Parallel ranges and dissected plateaux with intervening sandy lowlands
Western Coastlands Province		
189	Onslow Plain	Alluvial, deltaic and littoral plains; minor islands
190	Carnarvon Dunefield	S-N longitudinal dunes
191	North West Cape Ridges	Low ridges and peninsula formed by folded sedimentary rocks and limestone dunes
192	Kennedy Range	Dissected sandstone plateau with partial laterite cappings, covered by longitudinal dunes
193	Carnarvon Plain	Alluvial plain
194	Shark Bay Peninsulas	Pensinsulas and islands formed by indurated limestone dunes
195	Yaringa Sandplain	Sandplain with minor dunes
196	Greenough Hills	Dissected plateaux and hills of sandstone and shale, with extensive sand cover in lower parts
197	Dandaragan Tablelands	Dissected plateaux and hills of chalk and greensand, with minor laterite cappings and dry valleys; extensive sand cover in lower parts.
198	Swan Plain	Dune ridges, mainly of limestone, and inner alluvial plain
199	Donnybrook Lowland	Lowland on down-faulted weak sedimentary rocks
200	Leeuwin Peninsula	Narrow granitic horst ridge with extensive cover of calcareous dune sands

Yilgarn Plateau Province		
201	Murchison Plateau	Mainly granitic plains with out-going drainage, broken by ridges of metamorphic rocks
202	Glengarry Hills	Sandstone plateau sloping north to low hills of basic volcanic rocks
203	Salinaland Plateau	Sandplains and laterite breakaways; granitic and alluvial plains; ridges of metamorphic rocks and granitic hills and rises; calcretes, large salt lakes and dunes along valleys
204	Woodrarrung Hills	Low rounded ridges of folded metamorphics
205	Northam Plateau	Flat-floored valleys of moderately incised ocean-ward drainage; older laterite remnants with breakaways on divides in east; shallow younger laterites on valley sides in west
206	Narrogin-Ongerup Plateau	Sandplains and laterite cappings with breakaways on divides; stripped granitic plains on valley sides; small salt lakes and bordering dunes along shallow valley floors
207	Coonana-Ragged Plateau	Sandplain and stripped gneissic plains with low hills of granite and metamorphic rocks; calcretes and scattered small salt lakes along shallow valleys
208	Darling Range	High plateau rim with steep western fall; remnant laterite cappings and deeply incised valleys of oceanward drainage
209	Collie-Kalgan Slopes	Gently sloping dissected edge of plateau on granite and gneiss with laterite cappings
210	Albany Headlands and Inlets	Granitic headlands and inlets with lagoons
211	Stirling and Barren Hills	Hills and low ranges of granite and metamorphic rocks with intervening plains and moderately incised southerly valleys
212	Esperance Hills	Low granite hills and plains extending as headlands and inlets
Nullarbor Plain Province		
213	Carlisle Plain	Sandstone plain with shallow closed depressions
214	Bunda Plateau	Covered karst plain of flat-lying limestone with closed depressions and caves; continuous cliff margin in south
215	Roe Plain	Coastal plain with extensive dunes
216	Israelite Plain	Narrow coastal plain with extensive dunes

Appendix 3. The 47 rangeland land types

Land Type	Description	Landform component	Vegetation component
1	Hills and ranges with acacia shrublands	Hills and ranges	Acacia shrublands
2	Hills and ranges with spinifex grasslands	Hills and ranges	Spinifex grasslands
3	Hills, ranges and plateaux with eucalypt woodlands and tall grasses	Hills, ranges and plateaux	Eucalypt woodlands and tall grasses
4	Hills, ranges and plateaux with eucalypt woodlands and spinifex	Hills, ranges and plateaux	Eucalypt woodlands and spinifex
5	Mesas, breakaways and stony plains with acacia or eucalypt woodlands and halophytic shrublands	Mesas, breakaways and stony plains	Acacia or eucalypt woodlands and halophytic shrublands
6	Mesas, breakaways and stony plains with spinifex grasslands	Mesas, breakaways and stony plains	Spinifex grasslands
7	Hills and lowlands with eucalypt woodlands and spinifex	Hills and lowlands	Eucalypt woodlands and spinifex
8	Hills and lowlands with eucalypt woodlands and tussock grasses	Hills and lowlands	Eucalypt woodlands and tussock grasses
9	Low hills with eucalypt or acacia woodlands with halophytic undershrubs	Low hills	Eucalypt or acacia woodlands with halophytic undershrubs
10	Low hills and stony plains with acacia shrublands	Low hills and stony plains	Acacia shrublands
11	Undulating plains and uplands with eucalypt woodlands and spinifex	Undulating plains and uplands	Eucalypt woodlands and spinifex
12	Undulating plains with eucalypt woodlands and mixed grasses	Undulating plains	Eucalypt woodlands and mixed grasses
13	Undulating plains with tussock grasslands	Undulating plains	Tussock grasslands
14	Undulating stony plains with cracking clay soils and tussock grasslands	Undulating stony plains with cracking clay soils	Tussock grasslands
15	Gritty-surfaced plains and granite tors and domes with acacia shrublands	Gritty-surfaced plains and granite tors and domes	Acacia shrublands
16	Stony plains with acacia shrublands	Stony plains	Acacia shrublands
17	Stony plains with acacia shrublands and halophytic shrublands	Stony plains	Acacia shrublands and halophytic shrublands
18	Stony plains with spinifex grasslands	Stony plains	Spinifex grasslands

Land Type	Description	Landform component	Vegetation component
19	Limestone plains with woodlands and bluebush shrublands	Limestone plains	Woodlands and bluebush shrublands
20	Limestone plains with open saltbush and bluebush shrublands and grasslands	Limestone plains	Open saltbush and bluebush shrublands and grasslands
21	Plains with low woodlands and spinifex/tussock grasslands	Plains	Low woodlands and spinifex/tussock grasslands
22	Sandplains and dunes with acacia shrublands and spinifex	Sandplains and dunes	Acacia shrublands and spinifex
23	Sandplains with eucalypt woodlands and spinifex/tussock grasses	Sandplains	Eucalypt woodlands and spinifex/tussock grasses
24	Sandplains and dunes with pindan woodlands and spinifex/tussock grasslands	Sandplains and dunes	Pindan woodlands and spinifex/tussock grasslands
25	Sandplains and occasional dunes with grassy acacia shrublands	Sandplains and occasional dunes	Grassy acacia shrublands
26	Sandplains with acacia, mallees and heath	Sandplains	Acacia, mallees and heath
27	Sandplains and drainage floors with acacia and halophytic shrublands	Sandplains and drainage floors	Acacia and halophytic shrublands
28	Sandplains and occasional dunes with spinifex grasslands	Sandplains and occasional dunes	Spinifex grasslands
29	Sandy plains with acacia shrublands and wanderrie grasses	Sandy plains	Acacia shrublands and wanderrie grasses
30	Plains with eucalypt woodlands with non-halophytic undershrubs	Plains	Eucalypt woodlands with non-halophytic undershrubs
31	Wash plains on hardpan with mulga shrublands	Wash plains on hardpan	Mulga shrublands
32	Wash plains and sandy banks on hardpan, with mulga shrublands and wanderrie grasses or spinifex	Wash plains and sandy banks on hardpan	Mulga shrublands and wanderrie grasses or spinifex
33	Alluvial plains with mixed woodlands/shrublands and mixed grasses	Alluvial plains	Mixed woodlands/shrublands and mixed grasses
34	Alluvial plains with acacia shrublands	Alluvial plains	Acacia shrublands
35	Alluvial plains with eucalypt woodlands and halophytic undershrubs	Alluvial plains	Eucalypt woodlands and halophytic undershrubs
36	Alluvial plains with halophytic shrublands	Alluvial plains	Halophytic shrublands
37	Alluvial plains with currant bush shrublands	Alluvial plains	Currant bush shrublands

Land Type	Description	Landform component	Vegetation component
38	Alluvial and sandy plains with soft spinifex grasslands	Alluvial and sandy plains	Soft spinifex grasslands
39	Alluvial plains with tussock grasslands	Alluvial plains	Tussock grasslands
40	Calcrete plains with acacia shrublands	Calcrete plains	Acacia shrublands
41	Calcrete plains with spinifex grasslands	Calcrete plains	Spinifex grasslands
42	River plains with grassy woodlands and tussock grasslands	River plains	Grassy woodlands and tussock grasslands
43	Salt lakes and fringing alluvial plains with halophytic shrublands	Salt lakes and fringing alluvial plains	Halophytic shrublands
44	Coastal plains, cliffs, dunes, mudflats and beaches; various vegetation	Coastal plains, cliffs, dunes, mudflats and beaches	Various coastal vegetation
45	Swamps	Swamps	Swamps
46	Disturbed land (mines)	Disturbed land (mines)	Disturbed land (mines)
47	Lake, river channel, bare lake bed or claypan	Lake, river channel, bare lake bed or claypan	No vegetation (lake or river)

Eucalypt woodland and spinifex grasses (PJ Waddell)

Appendix 4. Proposed additional rangeland land types

Land	Description	Landform component	Vegetation component
48	Hills and ranges with eucalypt woodlands and shrub understorey	Hills and ranges	Eucalypt woodlands and shrub understorey
49	Hills and ranges with eucalypt woodlands and halophytic shrubs	Hills and ranges	Eucalypt woodlands and halophytic shrubs
50	Mesas, breakaways and stony plains with acacia or eucalypt woodlands (non-halophytic)	Mesas, breakaways and stony plains	Acacia or eucalypt woodlands (non-halophytic)
51	Low hills with acacia or eucalypt woodlands (non-halophytic)	Low hills	Acacia or eucalypt woodlands (non-halophytic)
52	Sandplains and dunes with eucalypt woodlands and spinifex/tussock grasses	Sandplains and dunes	Eucalypt woodlands and spinifex/tussock grasses
53	Low hills with mixed shrubs and scrub	Low hills	Mixed shrubs and scrub
54	Undulating plains with mixed shrubs and scrub	Undulating plains	Mixed shrubs and scrub
55	Low hills with eucalypt or acacia woodlands and shrublands (non-halophytic undershrubs)	Low hills	Eucalypt or acacia woodlands and shrublands (non-halophytic undershrubs)
56	Undulating plains with acacia shrublands	Undulating plains	Acacia shrublands
57	Undulating plains with eucalypt woodlands	Undulating plains	Eucalypt woodlands
58	Undulating plains and uplands with spinifex grasslands	Undulating plains and uplands	Spinifex grasslands
59	Undulating plains and uplands with mulga shrublands	Undulating plains and uplands	Mulga shrublands
60	Calcrete plains with mallee shrubland	Calcrete plains	Mallee shrubland
61	Sandplains with acacia shrublands and spinifex grasslands	Sandplains	Acacia shrublands and spinifex grasslands
62	Gritty-surfaced plains and granite tors and domes with eucalypt woodlands	Gritty-surfaced plains and granite tors and domes	Eucalypt woodlands
63	Sandplains and dunes with spinifex grasslands and eucalypts	Sandplains and dunes	Spinifex grasslands and eucalypts
64	Alluvial plains with spinifex grasslands	Alluvial plains	Spinifex grasslands